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Edited by

Kevin Moore

Susan White

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Cover photo : Keir Vaughan-Taylor on Lake 2, Koonalda Cave, Nullarbor Plain. (Photo by Kevin Moore)

Back Cover : The Khan and Beagum in Kubla Khan Cave Tasmania (Photo by Garry K. Smith)

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Preface

Welcome to the 17th International Congress of Speleology and we hope you enjoy the Congress and appreciate the papers presented here in the Proceedings. These Proceedings are issued by the 17th International Congress of Speleology (Speleo2107) on July 22-28, 2017 in Sydney, NSW, Australia.

The large number of papers and posters presented here represents a huge amount of work by the authors, the reviewers and the editorial team. There are about 250 oral paper presentations and 61 posters. This represents a huge number of received e-mails and a similar number of responses during the last 6 months, with a similar load of electronic files and over 800 printed pages of text. This is a large amount of interesting material concentrating on Cave and Karst matters.

The author's guidelines stipulated that the particular contributions should not exceed 6 pages of text and we were delighted to find that most authors prepared contributions close to this upper limit. This illustrates a clear willingness of the cavers and karst scientists to share their discoveries and research conclusions.

The presented contributions (abstracts/papers) stand for both oral and poster presentations as indicated in the headings. Contributions in each session are arranged alphabetically by the last name of the first author. All contributions were reviewed by invited reviewers. Assistance was given to improve the English expression for those whom English is not their primary language. This has improved the clarity and readability of the contributions. Unfortunately due matters out of our control this reviewing process took much longer than expected and the problems of lost emails and the vagaries of the internet added to the unfortunate delays.

Twenty two thematically different sessions three plenary lectures were scheduled to cover the whole range of subjects to be discussed within the wide scope of the 17th ICS. Low numbers of contributions for some sessions necessitated their grouping with others in the program but we have attempted to keep them separate here. The contributions are grouped into two separate volumes.

The volumes are published digitally and will be available on the Karst Information Portal. http://digital.lib.usf.edu/karst. There are very few copies printed in hard copy. This is partly due to issues of people travelling to Australia and needing to either carry bulky books or expensively post home. The printed copies are only in black and white whereas the digital are print quality full colour. In many cases it will be more cost effective for people to print from the data stick at home, and certainly much easier to transport.

We apologize for the all mistakes that might have crept into various submissions, from various versions of the manuscripts and other related files and emails which passed through our computers. We hope that everybody finds interesting reading here and we wish that the whole publication (Volumes 1 & 2) is a valuable record of the 17th meeting of enthusiasts addicted to the fascination of the underground world.

Finally we thank all the authors for their contributions and the reviewers for their work in improving the text. Thank you everyone for their patience.

Enjoy!

Kevin Moore and Susan White

Editors Speleo2017 Proceedings

The contribution of cave sites to the understanding of Quaternary Australian megafauna records.

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Abstract

Since the first discoveries of megafauna fossils in the Wellington Valley of New South Wales in the 1830s, caves have featured prominently in the study of Quaternary Australia. Today, most of the well-dated, stratified Quaternary megafauna sites are known from caves. This reflects the relatively stable preservation environment within Australian caves, where skeletal remains may lay undisturbed for hundreds of thousands of years. Sir Richard Owen described several of the most iconic megafauna species from the Wellington Caves, including the giant marsupial Diprotodon and the so-called marsupial lion Thylacoleo carnifex. Over the past 180 years, a vast array of megafauna species has been discovered in Australia and cave sites have now yielded most of the known Pleistocene species.

Figure 1. Sediment cones, Naracoorte

Discoveries of megafauna fossil sites and their research has been greatly enhanced over the past six decades with the systematic survey and exploration activities of caving groups. The most spectacular discoveries of Australian megafauna have been made by cavers, the most remarkable on the Nullarbor Plain in Western Australia and within the caves of Naracoorte in South Australia. In 2002, following years of systematic exploration, significant discoveries were made in the aptly named 'Thylacoleo Caves'. These caves have yielded articulated skeletons of several megafauna species including Thylacoleo carnifex and also the remains of new species of tree kangaroo and giant birds. The caves of the Nullarbor provide a critical insight into evolution of this vast area of Australia and the megafauna species that inhabited it during the Pleistocene.

Arguably, the jewel in the crown of Pleistocene megafauna fossil localities is the World Heritage listed Naracoorte Caves. Dozens of sites within these caves preserve an extended record of biodiversity and environment over at least the last 500,000 years. Articulated skeletons and exquisitely preserved fossils of over 20 megafauna species have greatly increased our understanding of the biology of these unique animals. Significantly, the remains of well over 100 species of mammals, birds, reptiles and amphibians are preserved alongside the megafauna, providing insight into the vertebrate community structure over a long time scale. In addition, the deposits preserve extensive palaeoenvironmental proxies within speleothems, fossil plant material, microfossils and sediments.

The cause and timing of megafauna extinctions in Australia remains a topic of debate. Caves continue to play a critical role in this discussion, with many of the key sites spanning the time of extinction (~40 to 45 ka) occurring in caves. Recent research at Warratyi rock shelter in the Flinders Ranges of South Australia has revealed a reliably dated stratigraphic association of megafauna bones and human artefacts at ≥49 to 46 ka. There is no direct evidence from the site to suggest human hunting of megafauna as in Northern Hemisphere sites; however, it does show humans and some megafauna were contemporaneous in the arid interior during the late Pleistocene.

Figure 2. Upper Ossuary, Naracoorte

Palaeontological investigation of the Quaternary fossil record has moved beyond studies of bones to broader, multi-disciplinary studies of past environments and patterns of change over time. Caves provide a unique opportunity to provide a climate and environmental context for megafauna remains with the preservation of vegetation records, climate proxies and deep sedimentary records. New technologies are also enhancing our knowledge of the evolutionary relationships of these extinct giants. The cool temperatures and high altitude of caves of Tasmania have preserved DNA in megafauna bones, with ancient DNA sequences for the extinct kangaroos Simosthenurus occidentalis and Protemnodon anak recently retrieved from Mt. Cripps.

As cavers and palaeontologists continue to explore and research Australian cave sites, there will undoubtedly be many more spectacular discoveries that will increase our understanding of Australia's lost giants.

Cave Diving in Australasia

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[2]*CEGSA – Cave Exploration Group of South Australia*

Abstract

Australia and New Zealand offer a range of interesting and challenging cave diving experiences. Mt Gambier in South Australia is a popular destination for the weekend cave diver. The vast Nullarbor Plain, spanning the border of Western Australia and South Australia, has some fascinating cave diving for those keen on longer expeditions. In addition to these caving areas there are many sites hidden in various corners of the country which offer significant potential for those cave divers prepared to face the varied challenges of cave diving in remote areas. New Zealand also contains numerous cold-water sites currently undergoing exploration, especially on the spectacular South Island.

This presentation gives an overview of the better-known caves. Caves in remote areas are also described and the current state of exploration is presented. Each remote site has its own challenges in terms of access, heat, cold water and depth. The ways in which these challenges are met is described, and the diverse beauty of the caves is presented.

Keywords: Cave Diving, Australia, New Zealand

1. Australian Karst Regions

The southern edge of the Australian continent has three vast karst areas of interest to cavers and divers – the Mount Gambier region, the Nullarbor Plain and the Roe Plain. These differ from most of the world's karst because they are flat-layered sheets and the limestones have not been significantly compressed. Therefore they are highly fossiliferous and are referred to as 'soft limestone' platforms. They were deposited in the Tertiary period ~15–30 million years ago and the platforms have been steadily uplifted at varying rates from the sea floor since that time. Each contain vast regional-scale groundwater aquifers which have dissolved caves in small and large horizontal passage systems along layer and fracture weaknesses in the limestone sheets.

In the Mount Gambier region this results in dozens of deep sinkholes ('cenotes') and cave systems almost filled with clear freshwater which are an international attraction for cave divers. The two deepest sites are Piccaninnie Ponds (110 mfw) and The Shaft (120 mfw), which occur along deep fault zones.

The Nullarbor Plain is the mightiest of these karst sheets and is the largest continuous sheet of limestone in the world. Some of its horizontal caves are gigantic! Cocklebiddy Cave is approximately 6.5 km long in almost a straight line and follows a 100 km fault zone. Other caves are decorated with gypsum and salt speleothems as they are in a desert environment. The groundwater provides spectacular cave diving as visibility is near-perfect with the water being filtered slowly through the porous limestone.

A part of the Nullarbor, known as the Roe Plains, is very close to sea level. The caves in this area are shallow and water-filled but with very extensive lateral passage systems and excellent cave diving. Their mode of formation is the same as the shallow systems of Mount Gambier and more systems are being discovered in this remote area.

The groundwater of all three karst sheets drains slowly to the coastline, which allows the cave systems to develop. By contrast, a fourth large karst sheet, the Murray Basin, has only a few small caves because the karst is virtually landlocked ('impounded') without a major groundwater outflow so that water movement and solution processes are severely restricted, unfortunately for cave divers!

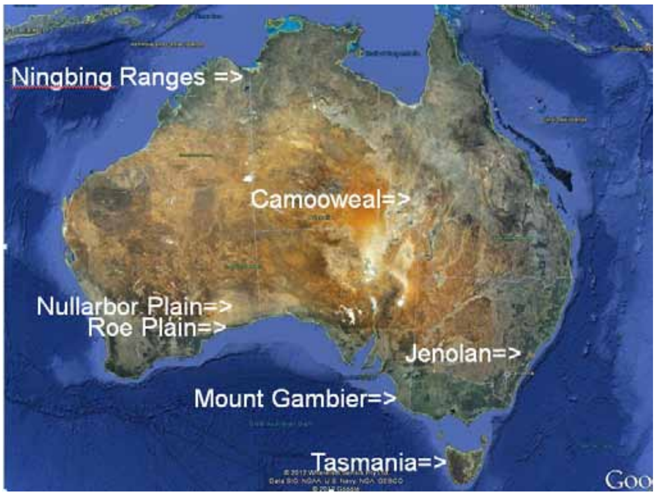

Figure 1. Major cave diving areas in Australia

These Australian karst sheets have been preserved unaltered because they are on the southern 'trailing edge' of the continent, which is moving northward. The limestone sheets at the 'front end' of the Australian Plate have been crunched up into the New Guinea highlands as the Australian Plate rams into the Pacific Plate. No such forces occur along the southern continental margin. The only other limestone sheets, sinkholes and cenotes similar to those in the Mount Gambier region exist in the Caribbean for the same reason – the North American Plate is moving westward so the limestone sheets of Florida, the Bahamas and the Yucatan have been preserved and have developed similar cave systems.

In eastern Australia and Tasmania underwater caves are found in much older Limestone. In northern Australia the Devonian reef limestone has huge exploration potential both for dry caving and cave diving.

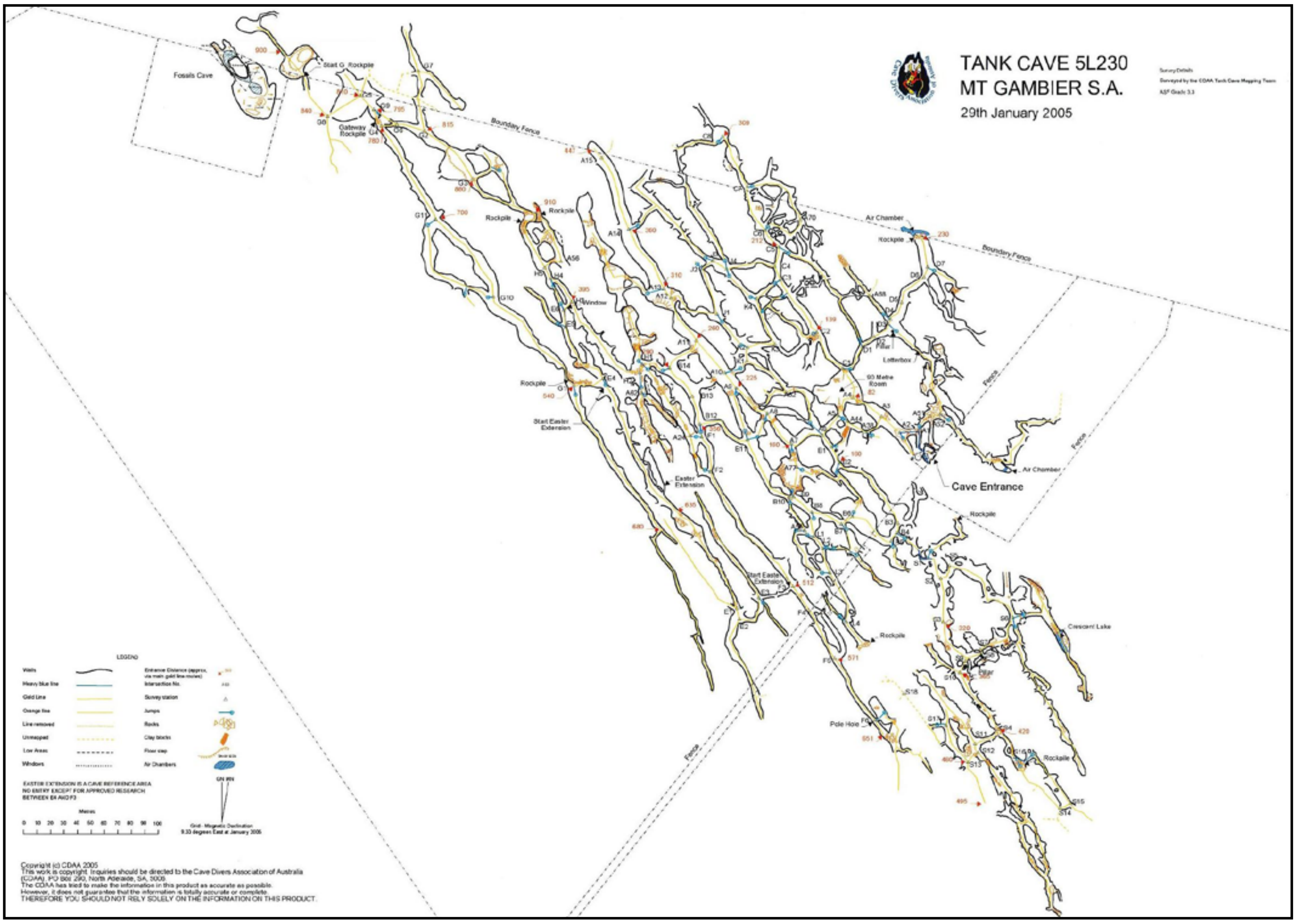

Figure 2. The Maze Passages of Tank Cave

2. Cave Diving at Mount Gambier

Mount Gambier is located in the south east of South Australia. The numerous sinkholes filled with clear fresh water were inviting to scuba divers used to diving in the sea. In the 1960s, as diving became more popular, increasing numbers of divers came to Mount Gambier to experience diving in deep, clear water. In the early 1970s a series of deaths in the caves attracted media attention and there was pressure to close the "killer sinkholes" to diving. The Cave Divers Association of Australia (CDAA) was formed in September 1973 in response to the possibility that cave diving would be prohibited at Mount Gambier. By offering training and certification of divers the safety of the sport was improved and closure of the caves was avoided.

In 1982 Peter Horne and Mark Nielsen dived into an uninviting cave on a farming property between Mount Gambier and the town of Millicent. They negotiated a tight silty entrance and found cave passage beyond. A later dive in 1983 found some more passage, but the difficult entry deterred any further exploration until the early 1990s. The cave began to reveal its secrets and within the space of a few years many kilometres of underwater passages were discovered. The cave was named Tank Cave after the old metal tank that used to cover the entrance. With a maze of around 10 km of surveyed passage (Fig. 2), it is now one of Australia's best cave diving sites.

Mapping an underwater cave the size of a Tank tested the limits of traditional underwater cave surveying. Cumulative errors became more significant as distance from the single entrance increased and there was no way of closing the surveys to a reference point on the surface. In 2000 a submersible radiolocation system, nicknamed the "Pinger", was developed. Divers placed transmitters (Pingers) underwater in the cave and these could be located with an above ground receiver. The position was determined by differential GPS and used to make an accurate survey. Since then the Pinger system has been extensively used at Tank Cave and other sites.

3. The Nullarbor Plain

Cave diving on the Nullarbor Plain began in the early 1970s. The very remote location and the difficult access to the water were a challenge to divers used to the comforts of Mount Gambier. Dive gear had to be lowered and carried to the water table 90 metres below the plain. The saline water was not drinkable and water had to be transported to site.

Once in the water cave divers were rewarded by huge underwater passages and spectacular clear water. Cocklebiddy Cave in particular had a huge passage heading north which never seemed to end. In 1982 a 240 m long air chamber named Toad Hall, was discovered. The cave continued underwater and in 1983 a French cave diving team claimed to have reached the end of the cave. Later that year, Australian Hugh Morrison added 200 m to the end of the French line in tight and difficult passage. Since then several expeditions have added a few hundred metres of line. But no more large passage has been discovered.

4. The Roe Plains

The Roe Plains extend 300 km from Twilight Cove, near Cocklebiddy, in the west to Eucla in the east and are bounded by the Nullarbor escarpment in the north and the southern ocean in the south. Dry caving expeditions had found caves that quickly met the water table only 7 to 10 metres below ground surface. Several cave diving expeditions led by Paul Hosie in the early to mid 2000s led to the rapid discovery of several kilometres of shallow underwater passages. The most significant caves were Olwolgin cave with a multilevel maze of 2.4 km of passage extending north east from the entrance; and Burnabbie cave with its narrow crawl way entrance, and 2 km of passage. By the late 2000s discovery of new passage had slowed.

On October 6th 2011 Paul Hosie dived in a small lake in Olwolgin cave that had previously been assessed as having no passage. Hosie negotiated a tight letter-box entrance and broke through into a passage that increased in size. After laying 100 m of line he returned through the entrance restriction in zero visibility to announce that a new cave had been found. Over the next 3 days 1.6 km of passage was discovered. By 2016 the cave was Australia's longest underwater cave system with over 12.5 km of surveyed passage & a maximum penetration of 3 km. Exploration is still continuing.

5. Other Areas in Australia

- North of Kununurra in Western Australia lies the fascinating spiky karst of the Ningbing Ranges (Fig. 2). Many well decorated dry caves exist in these ranges as well as underwater caves which drain large volumes of water during the wet season. South of Kununurra near the Bungle Bungles is Kija Blue sinkhole which fills up during the wet season and slowly drains into a nearby creek system in the dry season. It has been dived to a depth of 111 metres and is the second deepest cave dive in Australia.
- At Camooweal, in Queensland, the caves drain large volumes of water during "the wet". There is potential for more exploration here, limited only by increasing depth and distance.
- The famous show caves at Jenolan also have underwater sections where some of the first cave diving in Australia was done in the 1950s.
- Junee Resurgence in Tasmania is a treat for cave divers. A dive of 200 metres leads to several hundred metres of well decorated cave passage named "For your eyes only". Sinkholes in the nearby rain forest have also led to cave passage with potential for more exploration.

6. New Zealand

The Pearse Resurgence (Fig. 3 and 4) marks the origin of the Pearse Stream located on the eastern side of the Arthur Range, New Zealand. It is a Vauclusian spring with an average discharge of approximately 2 cubic metres per second. Dye tracing has proved a connection as far away as the Ellis Basin; a distance of approximately 6 km. The nearby Nettlebed cave system has also been shown to provide water to the resurgence. The cold (6-7 °C) waters of the resurgence were first dived in 1975 but the remote nature of the cave and harsh conditions have precluded extensive exploration over the years.

Figure 3. The Pearse Resurgence in New Zealand

The original limestone was laid down around 450 million years ago. It was buried under further deposition around 400 million years before present (BP). Re-crystallisation of the rock (due to heat and pressure) and deformation of the layers caused the formation of marble around 300–350 BP.

Further deposition and erosion occurred 50 to 100 million years BP. Tectonic uplift and faulting of the rock to form a pattern of cracks and weaknesses and intrusion by volcanics took place 10 million years BP to the present. Mount Arthur emerged as erosion of overlying layers of non-calcareous rock took place 10 million years BP to 1–2 million years BP.

Cave development began 1–2 million years BP. Water penetrated into the cracks and weaknesses in the marble, developing flow paths down and through the rock mass. Passage enlargement occurred wherever solution or abrasion was greatest.

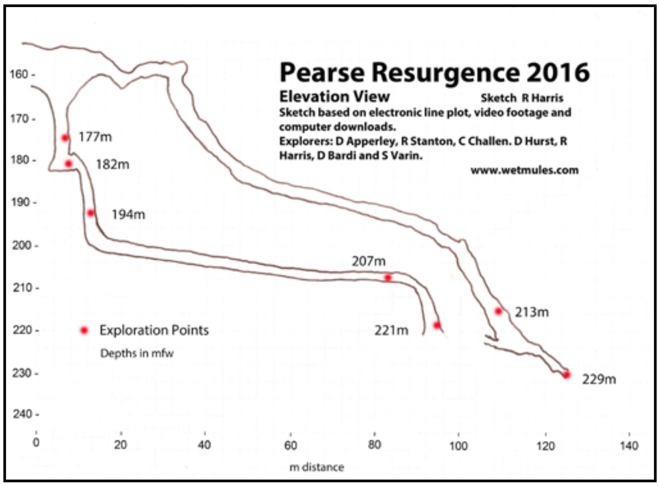

Figure 4. The Deep Section of the Pearse Resurgence

Several divers have played a major role in the exploration of the Pearse since the earliest dives. Keith Dekkers from NZ was pivotal in the early days, visiting the cave on several occasions and pushing down the start of the main shaft. 1995 saw an ill-fated expedition led by NZ caver Kieran McKay during which one of the divers (Dave Weaver) perished during an attempt at a depth record whilst breathing air. From 1997, expeditions by Sydney-based diver David Apperley made the most significant advances in the cave's exploration with the first use of a decompression habitat (2000) and culminating in the exploration of the cave by Apperley and Rick Stanton (UK – Cave Divers Group) to 177 m in 2007. From 2008 to the current date, a team of Australian cave divers including the authors have systematically pushed the cave further, relying increasingly on more sophisticated technology to survive prolonged decompression in the frigid waters. The most recent dive to 229 mfw in 2016 lasted 13 hours and utilised four separate decompression habitats at 40, 28, 16 and 7mfw respectively. The divers breathed helium-based gases from innovative twin rebreather systems until they reached the first habitat at 40 mfw. Thereafter, homemade micro rebreathers were breathed in the habitats for the subsequent 10 hour ascent to the surface. In the largest habitat at 16 m, the divers essentially turned the entire underwater chamber into a rebreather by scrubbing the exhaled CO_2 from the atmosphere and carefully adding oxygen. Surface-supplied 12 V power to heat electrical undergarments and a two way communication buzzer all contributed to a safe outcome for the team.

When diving to the great depths in the Pearse the divers do not have time to perform any mapping tasks. The divers focus is entirely on completing the dive safely. For this reason, even the direction of cave passage had not been determined with certainty. This led to discussion about an automatic method of mapping the cave. John Volanthen in the UK had developed a device called the "Lazy Boy" sump mapper. When mounted on a diver propulsion vehicle (scooter) it recorded depth, bearing and distance travelled through the water. This allowed a three-dimensional line track through the cave to be constructed. With information provided by John Volanthen a similar device, named the "C-Logger" was constructed for use in the Pearse Resurgence (Fig. 5). First used in January 2014 it has proved invaluable in mapping the cave as exploration took place.

Figure 5. The C-Logger mounted on a Scooter

7. Conclusion

In recent years there have been many interesting discoveries in underwater caves in Australia and New Zealand. The greatest challenge for the future appears to be the further exploration of the Pearse Resurgence. The cave, at 229 m deep, is large and continuing deeper. Of note, the cave passage is currently heading in precisely the opposite direction to the known water source! The opportunity for further exploration is clearly there for those who have the equipment and skills to safely dive in this fascinating cave system.

Acknowledgements

The authors would like to thank the landowners, both government and private who have allowed access to the caves on their land for many years.

Special thanks are also due to the Nelson Speleological Group which has provided great help with all of the many trips to the Pearse Resurgence.

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Australian Karst – Caves in an Ancient Land Rejuvenated

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Keywords:

1. Introduction

Australia has yielded the oldest known mineral grains on Earth (zircon crystals 4.4 billion years old extracted from ~3 billion year old conglomerates at Jack Hills in Western Australia; Valley *et al.* 2014). The continent also contains some very old landscapes; a low relief erosion surface that covers a large part of southeastern Australia probably formed largely during the Triassic and Jurassic (Webb 2017). Today Australia is surrounded by passive margins and is traditionally regarded as a tectonically stable continent.

However, in the last 10 million years parts of Australia have seen extensive volcanic and tectonic activity, that belie the continent's reputation as dull, stale and tired. In the Late Miocene a major transgression covered coastal and inland areas in southeastern Australia (Paine *et al.* 2004; McLaren *et al.* 2011), and between ~6 million years and 6 thousand years ago there were widespread basaltic eruptions across this region; nearly 200 scoria cones, ~200 lava volcanoes and ~40 maars erupted 15,000 km^2 of lava flows and ash deposits (Joyce *et al.* 2003). Between around 8 and 4 million years ago a major phase of tectonic activity, the Kosciuszko Uplift, changed the southeastern Australian landscape completely. Extensive faulting created the Southern Highlands of Victoria (now up to 600 m high), and probably doubled the elevation of the Southeastern Highlands to the current maximum elevation of over 2000 m (Webb *et al.* 2011). Earthquake activity has been ongoing, albeit at a lower rate, to the present, with significant faulting in the last 30,000 years (Quigley *et al.* 2006).

Along with this tectonic and volcanic activity, Australia has seen widespread climate change. In the Paleogene, the climate was warm and relatively wet, so that even inland Australia was covered with open forest and rainforest grew along watercourses (Alley *et al.*, 1999). From the Miocene onwards, the climate became progressively hotter and drier, apart from an abrupt warm, wet episode from about 5 to 3.45 million years ago (Sniderman *et al.*, 2016), but the climate did not reach its present level of aridity until about 1 million years ago (Fujioka and Chappell, 2010).

This long and diverse geological and climatic history has impacted karst development in Australia. It has been superimposed on the great variation in age and lithological characteristics of carbonate outcrops, from strongly cemented Neoproterozoic and Palaeozoic limestones and dolomites with very low primary porosity and well-developed jointing ('hard' rock karst), to Tertiary and Quaternary limestones with varying degrees of intergranular porosity and often poorly developed jointing ('soft' rock karst; Webb *et al.* 2003). Unlike the Northern Hemisphere, Mesozoic limestones are virtually absent in Australia.

As a result, although the Australian continent is not well-endowed with caves on a world scale, Australian karst is

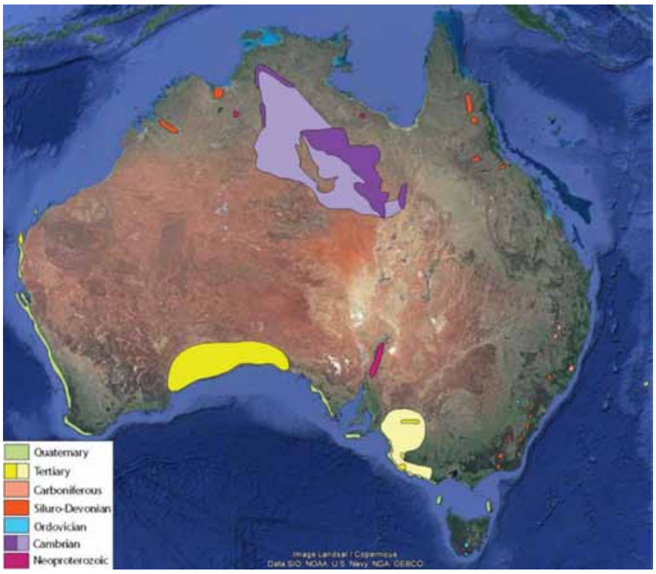

Figure 1. Carbonate distribution in Australia, by age of deposition; covered areas of Tertiary and Cambrian carbonates have lighter shading. Note that the areas of all small outcrops are exaggerated at this scale. Barkly karst area from Grimes (2009).

notable for its diversity. From the razor-sharp towers of north Queensland to the cold, deep shafts of southwest Tasmania, from the carbonate dunes of southwest Western Australia to the clear cenote lakes of southeastern South Australia and the ancient reefs of northwest Western Australia, Australian karst has something for everyone.

2. 'Hard' rock karst developed in Neoproterozoic and Palaeozoic carbonates

Australian Neoproterozoic and Cambrian carbonates are dominantly dolomitic, whereas the younger Ordovician – Carboniferous carbonates are almost all limestones. These carbonates are all strongly lithified with high mechanical strength, frequently resulting in the development of impressive cliffs and canyons. In eastern Australia the carbonates have been extensively faulted and folded and outcrop over relatively small areas. Across northern Australia the carbonate outcrops are generally almost flat-lying and may be very extensive (Barkly Tableland).

The Australian hard rock karst areas can be divided into broad groups based on their lithology, outcrop patterns and climate regime (past and present).

2.1. Glaciated karst

Proterozoic dolomites on Mt Anne in western Tasmania represent the only karst area in Australia that has undergone glaciation. The largest cave, Anne-A-Kananda, reaches 340 m in depth; it has an impressive doline entrance at an altitude of almost 1000 m, and is characterised by highly unstable areas of loose rock, probably related to the glaciation 18–20,000 years ago, when glaciers covered substantial areas of Tasmania, including Mt Anne (Webb *et al.* 2003).

2.2. Limestone karst of Tasmania

In Tasmania, high annual rainfall (>1500 mm) and extensive outcrops of Ordovician limestone have combined to produce relatively densely cavernous karst areas (e.g. >200 caves in 200 km^2 of limestone at Mole Creek; Kiernan 1989), some of them covered in dense rainforest. They contain some of Australia's deepest and longest caves (respectively, Growling Swallet system ~350 m deep, Exit Cave with >40 km of large passages and deep shafts), as well as the best decorated Australian cave (Kubla Khan). The caves are frequently challenging: cold and wet, with numerous vertical drops and difficult climbs and squeezes.

2.3. Limestone karst of temperate humid southern and eastern Australia

The highlands of southeastern Australia contain a substantial number of small karst areas, which are developed on Ordovician to Carboniferous (mostly Siluro-Devonian) limestones. Because they mostly receive the bulk of their surface water as runoff from catchments in surrounding non-limestone rocks, dry valleys and springs are common. Surface karst features include Bungonia Gorge, with its 285 m high sheer cliffs, and the extensive doline field at Buchan. Several of the caves, particularly at Bungonia, contain high levels of carbon dioxide, released by decay of organic material washed into the cave. Speleothems are often abundant, composed of calcite (mostly), aragonite, hydromagnesite and gypsum.

The largest outcrop is at Buchan, where cave development can be closely related to the surface landscape (Fabel *et al.* 1996; Webb *et al.* 1992, 1991). The higher level caves are phreatic mazes that formed beneath the broad valley of the ancestral Buchan River, that may be part of the Mesozoic low relief erosion surface occurring across southeastern Australia. The lower level caves are characterised by well-developed flat roofs that can be correlated with river terraces along the Buchan River nearby. Dating of speleothems and sediments within the caves indicates that even the lowest cave level, only a few meters above the Buchan River, formed more than 750,000 years ago (Musgrave and Webb 2003).

At Jenolan the walls in some of the caves intersect ancient, sediment-filled passages (Osborne 1999); these could date back to the Late Palaeozoic, when mid-Devonian to Early Carboniferous orogenies first exposed the limestones of the southeastern Australian highlands at the surface, allowing cave formation. Even more intriguing, clay minerals from sediments in one Jenolan cave have been dated as Carboniferous (Osborne *et al.* 2006); if these clays are authigenic and have not been transported into the cave, it indicates that this cave has existed as an open cavity since the Palaeozoic.

Many of the caves in southern and eastern Australia have high, domed, circular chambers (cupolas), such as the Temple of Baal at Jenolan Caves, and spongework, wall pockets and bedrock projections. Osborne (2010) has interpreted these features to indicate hypogene formation of much of the karst; this is disputed, although it depends on the definition of hypogene, which differs greatly between different karst researchers, and hypogene karst may be more common in Australia than previously acknowledged.

2.4. Limestone and dolomite karst of monsoonal tropical northern Australia

The monsoonal climate of northern Australia means that almost the entire annual rainfall is concentrated in ~3 months (the wet season). The high intensity rainfall and tropical temperatures have resulted in spectacular surface karst developed in Silurian and Devonian limestones at Chillagoe and Mitchell-Palmer: limestone towers up to 50 m tall, covered in razor-sharp rillenkarren up to 2 m high, and surrounded by low gradient pediments (Grimes 2009). Outcrops of Late Jurassic sediments occur near the highest parts of some towers, indicating that the karst landscape at Chillagoe was well developed by the Late Jurassic (Webb 1996). The limestone towers are densely cavernous; the caves are mostly mazes of interconnected phreatic chambers and the lower levels generally flood in the wet season. Passages frequently connect upwards with grikes, so daylight chambers are common, and the caves are very well-ventilated. As a result, evaporation plays a major role in calcite precipitation, and speleothems, particularly cave coral, generally have a chalky appearance. The cave walls often display beautifully preserved Siluro-Devonian stromatoporoids and corals. In daylight areas sharp prominences cover the walls, all pointing towards the light, due to etching by algae/cyanobacteria.

In the northwestern Australia are ranges of Devonian limestone, containing wonderfully preserved fossil reefs more or less in their original positions (Playford 2002). Caves are generally hosted by the massive reef and fore-reef limestones; large joint-controlled maze systems occur beneath giant grikelands. Some caves contain permanent pools and lakes, and there are extensive tufa deposits associated with springs along the flanks of the ranges. A low relief land surface has been eroded across the limestone ranges and may date to the Permian, suggesting that initial karst development dates to this time (Playford 2009). Dissection of this old land surface has formed spectacular gorges, which expose cross-sections through the reefs in their walls.

There are two small north Australian karst areas developed in thin, flat-lying Proterozoic dolomite: Pungalina and Bullita. Bullita is Australia's longest cave (123.5 km), a complex close-spaced maze system beneath a surface grikefield (Martini and Grimes 2012). At Pungalina the dolomites contain abundant stromatolite fossils often picked out by solution on the rock surface (White *et al.* in press).

The flat-lying Cambrian dolomites and limestones of north Queensland and the Northern Territory are very extensive, but covered by thin Mesozoic and Cainozoic sediments except for the northwestern margin near Katherine and the eastern edge at Camooweal and Lawn Hill (Webb *et al.* 2003; Grimes 2009). There are warm springs in places and the caves are typically warm and humid; caving in this region generally involves large amounts of sweat. In the Camooweal area many of the caves descend to water-table lakes 70-80 m below the surface; meandering canyons and gravels in the lower passages reflect the strong wet season floods. Near Lawn Hill, a stream has cut through the limestone, to form a beautiful, tree-lined gorge fed by large, permanent springs, and dammed by extensive tufa deposits. Grikefields are well developed over parts of the limestone, and have associated maze caves (Gale *et al.* 1997).

2.5. Limestone and dolomite karst of arid southern Australia

In the Flinders Rangers thin, folded Neoproterozoic limestone and dolomite formations contain scattered caves: linear systems where the bedding is more steeply dipping and mazes in more gently dipping beds. Wooltana Cave was once a major roosting site for the Ghost Bat, and contains large amounts of bat guano (mined in the past for fertilizer) and mummified bats preserved by the dry climate.

Further south, on Yorke Peninsula, a small outcrop of flat-lying Cambrian limestone contains over 13 km of multi-level maze passage that covers an area only 450 m x 250 m.

3. 'Soft' rock karst developed in Tertiary and Quaternary limestones

In the Paleogene, Neogene and Quaternary, temperate limestones accumulated around the southern and western edges of the Australian continent, and continue to do so today; they are composed mostly of sand-sized fragments of bryozoans, forams, echinoids and calcareous red algae. These limestones differ from tropical limestones of the same age because they are composed predominantly of calcite rather than the more soluble aragonite, so there is less cement precipitation in the pore spaces, and temperate limestones frequently have high intergranular porosity. As a result these limestones generally have dual porosity/permeability, i.e. both primary porosity and secondary karstic conduits; the latter are an integral part of groundwater flow through the limestone aquifers.

Caves formed in these limestones are more subject to collapse than those in 'hard' rock karst, because of the relatively low strength of the surrounding rock, and the cave floors are often covered in sandy sediment derived from breakdown of the limestone.

There are three separate 'soft' rock Paleogene-Neogene karst areas in Australia (Nullarbor and Gambier karsts in flat-lying Eocene-Miocene limestones, and the Cape Range karst in gently folded Oligocene-Miocene limestones), as well as the widespread Quaternary coastal dune limestone.

3.1. Nullarbor karst

The Nullarbor Plain, which covers an area of ~200,000 km^2, is very flat (mostly <10 m relief) and rainfall (400–150 mm) is much less than potential evaporation (2000–3000 mm). Small trees grow along the coast but the vast majority of the Nullarbor Plain is treeless. The surface of the plain slopes gently seawards to terminate abruptly at a 40–90 m high cliff-line that is unbroken for some hundreds of kilometres and mostly falls sheer into the sea. The exposed surface of the limestone plain is covered by calcrete with poorly developed karren (Lowry and Jennings, 1974), and exhibits undulating bedrock ridges and swales up to a kilometre wide and a few meters high, that change orientation from north-south in the western part of the plain to south southeast-north northwest in the east. The ridges and swales appear to be the etched footprints of an extensive linear sand dune system that formerly covered the plain (Burnett *et al* in review).

Substantial karst features (~150 steep-sided collapse dolines and ~100 caves with significant passage lengths) are mostly within 60 km of the coast. The deeper caves extend 50–150 m below the surface of the plain, and are characterised by extensive collapse and few speleothems; some contain water table lakes of clear, salty water that lead into flooded passages (Webb & James 2006). There are also a number of shallow caves (< 40 m deep) in the coastal belt; these are generally low collapse chambers with abundant speleothems of halite, gypsum and very dark brown calcite; the latter have been dated to mid-Pliocene (~3.45–5 Ma; Sniderman *et al.*, 2016).

The deep caves probably formed during the warm, seasonally wet conditions of the Oligocene; they drained and collapsed once the Nullarbor karst was uplifted in the late Miocene (Webb & James 2006). In the late Miocene – early Pliocene, the climate in the Nullarbor region was semiarid, followed by a warm, wet episode in the mid-Pliocene, when shallow caves containing calcite speleothems developed and pocket valleys were eroded into the cliffs (Lipar and Ferk, 2015). As the climate reached its present level of aridity ~1 million years ago, evaporite (salt and gypsum) speleothems precipitated within the caves.

The Nullarbor Plain also contains ~20,000 blowholes, smooth-walled vertical tubes up to 2 m in diameter and a few meters deep; strong air drafts blow in and out of them, because they connect to extensive shallow cave systems of small passages, which are relict phreatic features (Doerr *et al.*, 2012). The blowholes are concentrated in a 25–30 km-wide band ~75 km inland, located along the Late Miocene (~6 Ma) shoreline across the Nullarbor, and formed in the zone of enhanced dissolution at the seaward margin of the freshwater lens (Burnett *et al.*, 2013), so they can be regarded as flank margin caves on a low gradient limestone platform.

Extensive surface and underground karst features have not developed on the Nullarbor due to the flatness of the plain, the high primary porosity, the limited jointing and the lack of inception horizons in the limestone (Webb and James, 2006; Burnett *et al.*, 2013). The characteristics of the lithology restricted the karst development of the Nullarbor Plain under past wetter climates; the present arid climate has preserved the caves and dolines, but is not responsible for the overall lack of karstification (Webb & White 2013).

Speleothems from the Nullarbor caves have been instrumental in two recent significant technical advances in speleothem palaeoclimate studies: U/Pb dating of calcite back to at least 10 million years (Woodhead *et al.* 2006) and extraction of spores and pollen from speleothem calcite for reconstruction of paleovegetation (Sniderman *et al.*, 2016).

3.2. Gambier karst

The Gambier karst represents the exposed portion of limestone units present within both the Otway and Murray Basins; over most of these basins the limestone is covered by younger sediments and basalt. Caves in the limestone are concentrated in three main areas: Mt Gambier, Naracoorte and along the Glenelg River (Grimes 1994).

Around Mt Gambier shallow, horizontal, joint-controlled caves are scattered across the limestone plain; the longest has over 7 km of mostly underwater phreatic tubes, and extends to a maximum depth of ~30 m (Webb *et al.* 2010). There are numerous small springs and two major ones with discharges of 1–2 m^3/sec.

The most spectacular features of the Mt Gambier karst landscape are the cenotes, circular cliffed collapse dolines up to 60 m in diameter surrounded by walls up to 30 m high. The cenotes contain lakes up to ~125 m deep with stromatolites growing in the walls and rubble cones on the floors. Most cenotes are concentrated in two small areas located along trends sub-parallel to the main joint direction in the limestone. The cenotes formed by collapse into large chambers (up to >1 million m^3) that extended 125 m or more below the land surface. Initial dissolution was most likely due to acidified groundwater containing large amounts of volcanogenic CO_2 related to the Pleistocene-Holocene volcanic eruptions of nearby Mt Gambier and Mt Schank. Deep reservoirs of volcanogenic CO_2 occur nearby (Webb *et al.* 2010). Collapse to form the cenotes probably occurred during the low sea levels of the Last Glacial Maximum ~20,000 years ago. The cenotes then flooded ~8000 years ago as sea level rose, and stromatolites began to grow on the walls.

At Naracoorte the caves are overwhelmingly horizontal, consisting of large solutional domes connected by smaller passages; orientation is strongly controlled by NW/SE joints parallel to the Kanawinka Fault escarpment (White & Webb, 2015). The coastline lay along this escarpment at ~0.9–1.1 Ma, when the caves formed within the zone of enhanced dissolution at the seaward margin of the freshwater lens. They have the typical flank margin cave morphology, except that joint development adjacent to the fault caused the strong linear orientation parallel to the coastline. Sea level had dropped sufficiently to completely drain the caves at 780–880 ka, and continuing gradual uplift through the Pleistocene means that the caves are now >100 km inland, obscuring the essentially coastal nature of the Naracoorte karst.

In the limestone cliffs along Glenelg River are entrances to vertical fissure caves that probably owe their origin to local steepening of the water table as the river incised its gorge. The longest cave in this area, Drik Drik stream cave, runs beneath a basalt cover through both Tertiary and Pleistocene limestone before discharging into Glenelg River.

3.3. Cape Range karst

Cape Range is a north-south oriented limestone peninsula with a broad gentle anticline running down its centre. The fossils in the limestones include the normal temperate ocean fauna (forams, molluscs, echinoids, red algae, bryozoans) as well as corals, reflecting the northerly latitude of Cape Range; there is a coral reef growing offshore at present.

Of the several hundred caves on Cape Range, the majority are vertical solution pipes, often modified by collapse; a few have extensive, low, horizontal, joint-controlled passages (Humphreys 1993). The thickness of the limestone (<100 m) has limited the depth of the karstification (Webb & White 2013). The intense tropical cyclones that characterize this area have incised deep canyons on the surface and deposited coarse, well-rounded gravels within the caves. Most of the caves are believed to have a flank-margin origin, with different levels due to periodic tectonic uplift (Mylroie *et al.* 2017), which also caused incision of four wave-cut terraces on the seaward side of the range.

4. Karst in Quaternary limestones

Quaternary limestones are widespread as beach dunes across southern Australia and on Lord Howe Island, and are similar to the Tertiary limestones, but are even more porous and contain well-developed steeply dipping cross-bedding, reflecting their aeolian origin. They form ridges parallel to and just inland from the coast, rising up to 100 m high in Western Australia (Webb *et al.* 2003). Each dune represents a former high sea level, and the ages of the dunes are correlated with interglacial highstands. In areas of slow tectonic uplift the dunes are separated by swampy swales; elsewhere they are stacked on top of each other, separated by soil horizons, in deposits up to 160 m thick.

The most common surface karst features are solution pipes, which are vertical tubes typically 0.1–1 m wide and 1–5 m deep, with rounded terminations and cemented rims up to 10 cm thick. They are overlain by palaeosols and filled mostly with palaeosol material, and have formed by focused dissolution, most likely beneath trees as a result of focussed infiltration due to stemflow (Lipar *et al.* 2015). The expansion of solution pipes in dune limestones in Western Australia has left remnant conical or cylindrical karst pillars (the Nambung Pinnacles; Lipar and Webb, 2015).

In dune limestones the process of limestone cementation immediately precedes cave dissolution (syngenetic karst; White, 2000), so the caves have formed rapidly over a few hundred thousand to perhaps a few thousand years. Collapse is virtually ubiquitous due to the poor consolidation of the limestone, and the resulting broadly dome-shaped chambers may be almost filled with rubble. The limestone often lacks jointing, so cave development is determined largely by the dip direction of the water table. At Bats Ridge in western Victoria, caves only developed directly adjacent to swamps on the inland side of one dune ridge, down the hydraulic gradient towards the coast (White, 1994). The level of cave development in the dune limestones may also be related to sea level highstands (Mylroie & Mylroie, 2009).

Caves in dune limestones often contain abundant speleothems; because of the high porosity of the limestone, water percolation can occur over the entire ceiling, which can be covered with thousands of straws up to 7 m long; this is particularly true of W.A. caves like the Jewel-Easter Cave system, a network maze with over 8 km of passage.

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Archaeology and Palaeontology in Caves

(Abstract) Timing Of Fossil Emplacement At Toca Da Boa Vista Cave System In Northeastern Brazil

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Abstract

Toca da Boa Vista and Toca da Barriguda are two hypogene caves that together comprise approximately 140 km of maze passages. These ancient cave systems have experienced a long evolutionary history that gradually, due to denudation and uplift, placed cave passages in the vadose zone and relatively close to the surface. Multiple episodes of entrance opening and closure (due to sediment infilling or collapse) occurred at different areas of the caves. These caves contain remarkably well preserved fossil assemblages, generally represented by complete articulated skeletons, including new species of the South America's megafauna. By coupling radiocarbon ages in guano and U-series ages in calcite overlying bones we were able to outline entrance opening/closure episodes, patterns of fossil distribution and the approximate chronology of fossil-rich areas.

Dating Paleolithic cave art in Shulgan-Tash cave, Ural, Russia

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Abstract

Shulgan-Tash (also known as Kapova) cave is located on the western slope of the Ural Mountains, Russia. The cave is famous for its colorful paintings, made with red ochre and minor addition of charcoal. It is the easternmost European cave art monument of late Paleolithic age. In many ways, the paintings are similar to cave art in the Franco-Cantabrian region of Western Europe. Based on the style of the paintings they were assigned to the late Solutrean to middle Magdalenian of the late Paleolithic. This initial attribution was supported by seven radiocarbon dates on charcoal retrieved from cultural layers in the cave (16,300 to 19,600 cal. yrs BP).

In order to better constrain the age of cave art in Shulgan-Tash (Kapova) cave, we performed uranium-thorium (U-Th) dating on thin flowstone (calcite) layers underlying and overgrowing the drawings at 21 sites in three chambers of the cave. Altogether, 58 U-Th dates were obtained. The youngest age for the underlying flowstone (i.e., the maximum age of cave art) was 36,400 ±115 yrs BP. The overlying flowstone (constraining the minimum age of cave art) started growing during Termination I (14,500 ±40 yrs BP). The "time window" during which the paintings in Shulgan-Tash cave were made thus constitutes 21,900 ±155 yrs and encompasses the Last Glacial Maximum.

Keywords: cave art, Paleolithic, U-Th dating, flowstone

1. Introduction

In the last ten years the method of U-Th dating has been successfully used for dating Paleolithic cave art in Europe (Pettitt and Pike 2007; Pike *et al.* 2012) and Indonesia (Aubert *et al.* 2014). In this paper we report results of U-Th dating of cave art in Shulgan-Tash (Kapova) cave, the easternmost European cave art monument of the late Paleolithic age.

For successful application of the U-Th method, cave art must either be painted on a "canvas" flowstone (dating of which yields the maximum age of cave art; *terminus post quem*), or be overgrown by flowstone (dating provides the minimum age; *terminus ante quem*). The shorter the hiatus between the deposition of the "canvas" and the overgrowth flowstone, the more accurately the age of the cave art can be constrained.

2. Shulgan-Tash (Kapova) cave

Shulgan-Tash (Kapova) cave is located on the western slope of the Ural Mountains (53°02'40" N; 57°03'50" E) some 4,000 km to the east of the Franco-Cantabrian region of Western Europe, the home to classic examples of Paleolithic cave art. The cave is carved in folded Devonian and Carboniferous limestones forming the right bank of Belaya River.

The cave has a total length of 3323 m. The lowermost part of the cave is phreatic, with explored underwater galleries reaching a depth of -80 m. This part hosts the underground river Shulgan, which emerges as a deep lake-spring near the natural entrance of the cave. The subaerial part of the cave can be subdivided into two levels. The lower level is accessed through an imposing, 20 m high and 40 m wide, portal of the main entrance, followed by the 150 m long Main Gallery. The level extends ca. 350 m northward, then north-eastward and eastward; it is nearly horizontal (in its most remote part the floor is only 25–30 m higher than the entrance). The three large chambers (Domed Hall, Hall of Signs, and Hall of

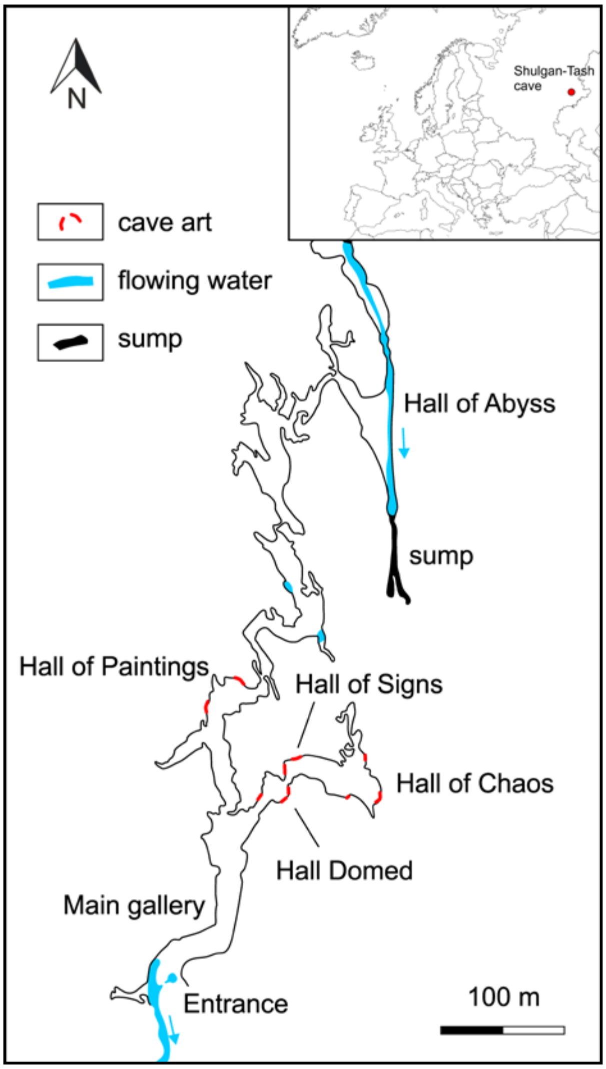

Figure 1. Location and schematic map of Shulgan-Tash (Kapova)

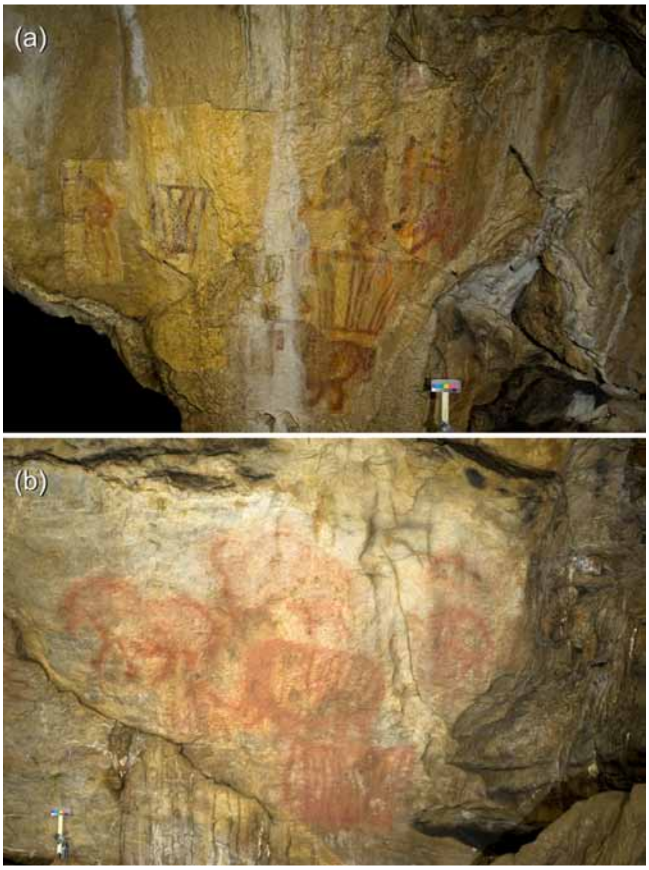

Figure 2. Examples of late Paleolithic paintings in Shulgan-Tash cave: (a) The composition Horses and Signs in the Hall of Chaos was painted on old flowstone and was later overgrown by younger flowstone; several flowstone layers (visible on the photo) were removed by restorers to reveal the paintings. (b) Composition Herd in the Hall of Paintings (mammoths, rhinoceros, horses). Photo: Y. Lyahnitsky.

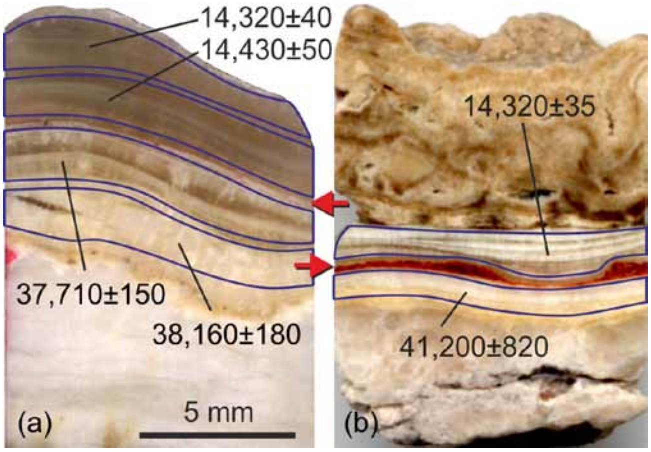

Figure 3. Examples of dating of cores that intersected the paint layer. Red arrows indicate the position of the pigment layer, numbers indicate U-Th ages in yrs BP: (a) Core ShT10bis ("Lower Slingshot"; [#22-12]); a layer of pre-paint flowstone and a layer of post-paint flowstone were dated; the overlying thick deposit of tuffaceous calcite was not sampled. (b) Core ShT6 near the "New Antropomorph" [#20-6] of the composition Horses of the Chamber of Chaos; two sub-layers of pre-paint flowstone and two sub-layers of post-paint flowstone were dated.

Chaos; Fig. 1) in which the samples were taken are separated from the Main Gallery by a constriction. The latter plays an important role in restricting air circulation in the cave and creating a microclimate in the chambers hosting cave art (temperature 2.4 to 7.6 °C, which is markedly warmer that the mean annual temperature in the area, +1.2 °C; relative humidity ~100%; Chervyatsova *et al*. 2015). The upper level is located 30 to 40 m above the lower. The levels are connected by a steep shaft, from the upper part of which some 700 m of galleries and large chambers extend to the northwest. At the upper level Paleolithic art was found in the Hall of Paintings; unfortunately, the latter hosts no flowstone, and U-Th dating therefore was not possible. At the end of the upper level the gallery steeply descends to the cave base level where the underground river Shulgan emerges from a sump and flows for 250 m to sink again underground.

Paintings in the Shulgan-Tash (Kapova) cave are in many ways similar to the late Paleolithic cave art of the Franco-Cantabrian region. Paintings are mostly made by red, red-brown and purple-brown ochre, sometimes with minor additions of charcoal. The paintings depict animals (mammoth, rhinoceros, horse) and seemingly anthropomorphic figures.

Also abundant are various geometric symbols and diffuse red spots. The latter likely represent the remains of figurative paintings destroyed by humidity and temperature fluctuations. Generally, the cave's microclimate is not favorable for preservation of paintings due to seasonal temperature fluctuations, high humidity and commonly present water films on the walls (water can be aggressive but more commonly it is supersaturated, depositing calcite; Chervyatsova *et al.* 2015). The most colorful paintings are those that were coated with a layer of flowstone, subsequently removed by archaeologists/restorers in the 1960s (see Fig. 2a). The restorers left a *ca*. 1 mm-thin layer of translucent calcite to protect the paintings.

Based on the style of the paintings (silhouettes of animals with colored contours, silhouettes without contours, rough contours, and geometrical marks) they were considered equivalents of the late Paleolithic late Solutrean to middle Magdalenian cultures of Western Europe (Bader 1965).

3. Sampling

In order to better constrain the age of the Paleolithic art in Shulgan-Tash (Kapova) cave, samples were collected in Domed Hall (two sampling locations), Hall of Signs (seven locations) and Hall of Chaos (fourteen locations). Most of the samples were taken as small-diameter (10 mm) cores, intersecting the overgrowth flowstone, the pigment layer, and the underlying flowstone (Fig. 3). This sampling method was approved by national conservation authorities of the Republic Bashkortostan. To minimize the visual impact of coring, the holes were subsequently patched with lime putty mixed with puzzolana and then camouflaged using natural local pigments (clays). Sampling locations in this paper are identified by numbers in square brackets according to the catalogue of Liakhnitsky *et al.* (2013).

The collected cores were cut longitudinally using a precision diamond saw (blade thickness 0.3 mm). The flat surfaces were polished. In some cases, the outer cylindrical core surfaces were also polished in order to reveal the curvilinear growth surfaces of flowstone and to guide accurate sampling for U-Th dating. Samples for dating were taken using a hand-held milling device in an Air Clean 600 hood.

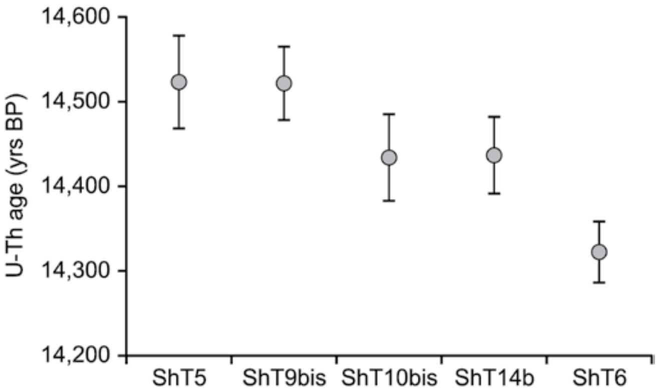

Figure 4. The terminus post quem ages obtained on the flowstone overgrowing the paintings. Uncertainties are shown at the 2σ-level.

Most of the sampling locations in the cave were characterized by several U-Th dates on both the "canvas" flowstone (where present) and the overlying flowstone. The dating was performed in the Trace Metal Isotope Geochemistry Laboratory at the University of Minnesota (Minneapolis, USA) using procedures and protocols described in Edwards *et al.* (1987), Shen *et al.* (2012), and Cheng *et al.* (2013) on a multi-collector inductively coupled plasma mass spectrometer Neptune (MC-ICP-MS; Thermo Finnigan). Altogether, 58 dates were obtained.

4. Results and discussion

The youngest age of "canvas" flowstone (*terminus post quem*) is 36,400±115 yrs BP (sample ShT14b, painting "Tower" in the Chamber of Chaos; [#22-13]). The closest approximation of the "true" age of the cave art is provided by the overgrowth flowstone. The *terminus ante quem* age was measured at 14,520±40 yrs BP (sample ShT5, composition "Horses of the Chamber of Chaos" [#20-1] and sample ShT9bis, painting "Upper Slingshot"; [#22-7] in the Chamber of Chaos). Similar ages were obtained for other paintings in the Chamber of Chaos (Fig. 4). The "time window" during which the paintings were made in Shulgan-Tash cave is therefore 21,900±155 yrs. This result is consistent with the radiocarbon ages obtained on charcoal samples from the cultural layer of the cave that spans 16,300 to 19,600 cal. yrs BP (Dublyansky, Zhitenev, 2017, in press).

This time window does not reflect human activity in this cave, but is rather determined by the paleoclimatic and paleohydrological factors, controlling formation of flowstone. Some 14,500 yrs ago, after almost 20,000 yrs of no-flow conditions, small amounts of supersaturated water started to infiltrate into the Chamber of Chaos. This might have been related to the thawing of permafrost in response to climate warming at the end of the last glaciation (more precisely, at the onset of the Bølling Interstadial; Hoek 2009). According to our unpublished data from Shulgan-Tash and Victoria caves, permafrost was present (possibly intermittently) in the area during Marine Isotope Stage 3 (MIS 3), between 53,000 and 33,000 yrs BP. Some 33,400 yrs ago, ice was present in the upper galleries of Shulgan-Tash cave. Permafrost conditions were present even during a relatively warm period of MIS 3, after which, *ca*. 26 thousand years ago, the massive cooling of the Last Glacial Maximum began. Permafrost expanded greatly in Eurasia during that time and reached as far south as the Southern Ural. Infiltration of water and subsequent slow growth of speleothems was impossible at that time, which is confirmed by the lack of stalagmites of this age from caves in the Southern Ural (Shulgan-Tash, Grioz, Kulyurtamak, Victoria, Grandioznaya, Khlebodarovskaya; see Dublyansky *et al.* 2017, this volume).

5. Conclusions

U-Th dating of flowstone in Shulgan-Tash (Kapova) cave provides robust age constraints on late Paleolithic paintings of this easternmost European cave art site. The paintings were made between 36,400±115 and 14,500±40 yrs BP. The oldest ^{14}C ages reported from cultural layers in the cave fall within this "time window" (16,300 to 19,600 cal. yrs BP).

Acknowledgements

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(Abstract) Copper Age ceramics from the Cerişor Cave (Southern Carpathians, Romania)

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Abstract

Ceramic sherds found in caves bear information about the social, economic, technological and cultural level of ancient people. At the Great Cave of Cerişor, a 125 m-long cave developed in the Paleozoic carbonate rocks of the Getic Domain (Southern Carpathians, Romania) the archaeological excavations unveiled hundreds of pottery sherds, which were assigned to a Copper Age ("Coțofeni") population. In this study, 237 Coțofeni ceramic fragments have been analyzed using polarized light optical microscopy (OM), X-ray diffraction (XRD) and electron microprobe analysis (EMPA) with the aim of describing the raw materials and the firing conditions. In order to infer the technological conditions involved in producing the pottery and to find the provenance of the raw materials, the silty loam from the cave as well as Miocene mudstones from the neighbouring area were analyzed by XRD. The OM, XRD and EMPA study shows a Fe-rich, illitic ceramic matrix which embeds various mineral clasts (temper), mostly quartz, muscovite, feldspar and metamorphic rocks, igneous and sedimentary rock fragments. The ceramic body includes also older crushed ceramic fragments, added as temper. The thermal transformation of the sherds components indicates a firing temperature ranging from ~800 °C to ~900 °C. The mineralogical composition of the cave silty loam did not fit to the composition of the ceramics, but the Miocene mudstones seem to be a potential source of the raw material.

(Abstract) Differential preservation of vertebrates in Southeast Asian caves

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Abstract

Caves have been an important source of vertebrate fossils for much of Southeast Asia, particularly for the Quaternary. Despite this importance, the mechanisms by which caves accumulate and preserve vertebrate remains in Southeast Asia has never been systematically reviewed or examined. Here, we present the results of three years of cave surveys in Indonesia and Timor-Leste, describing cave systems and their attendant vertebrate accumulations in diverse geological, biogeographical, and environmental settings. While each cave system is unique, we find that the accumulation and preservation of vertebrate remains are highly dependent on local geology and environment. Nevertheless, the dominant factor responsible for faunal deposition remains the presence or absence of biological accumulating agents, a factor directly controlled by biogeographical history. In small, isolated, volcanic islands, the only significant accumulation occurs in archaeological settings, thereby limiting our understanding of the palaeontology of those islands prior to human arrival. In karstic landscapes on both oceanic and continental islands, our understanding of the long-term preservation of vertebrates is still in its infancy. The formation processes of vertebrate-bearing breccias, their taphonomic histories, and the criteria used to determine whether these represent syngenetic or multiple deposits remain critically understudied. The latter in particular has important implications for arguments on how breccia deposits from the region should be examined and interpreted when reconstructing palaeoenvironments.

Forensic Speleology – Exploration of caves containing WW2 human remains in Slovenia

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Abstract

The paper gives a brief account of the use of caves as mass graves by the Communist regime and, in particular, of the role of speleologists in forensic research. The caves were used during the Second World War (1942–1945) and afterwards. The exhumation of victims, the exploration of caves and even discussion of the topic was prohibited in Slovenia until the political changes that took place in the late 1980s. We estimate that around 100 caves were used as mass graves and that around 12,000 people were thrown into them. After the killings, several cave entrances were dynamited, concealed or used as rubbish dumps in order to hide the bodies. Since 1999 cavers have been helping various official bodies in the identification of caves used as mass graves. They inspect caves and also carry out exhumation of victims. To date around 80 caves have been investigated and all human remains have been removed from 15 caves and buried. In another 40 caves human remains have been collected from the surface only and exhumation will take place in the future. Working in such caves is not very pleasant and the subject is still the source of difficulties and misunderstanding.

Keywords: massacre, communist, cave graveyard, exhumation, human remains.

1. Introduction

To understand the phenomenon we must briefly introduce events in the territory of present-day Slovenia during and after the Second World War. The area was part of Yugoslavia and was occupied by German and Italian forces. During the occupation a Communist-led resistance movement began. Its characteristics included the liquidation of civilian opponents and prisoners, culminating in massacres which continued for several months after May 1945 and the end of the war in Europe. It is estimated that around 100,000 people were killed in Slovenia in this period.

For the first two years after the war, the western part of Slovenia, including the Karst plateau above Trieste, was under the Allied Military Government. Here, in response to pressure from the relatives of those killed, exhumations were already carried out in the 1945–48 period, with the participation of cavers from Trieste (today in Italy). The process of excavation was conducted by the police. (De Giorgi, 1948).

In Yugoslavia, meanwhile, the exhumation of victims of mass executions, exploration of caves and even discussion of the topic remained impossible until the break-up of the country, since any such activity would have completely discredited the legitimacy of the Communist regime. The authorities therefore concealed the locations of the killings and prevented access to them. Anyone who attempted to probe the issue could find themselves facing prosecution or prevented in some other way. On 1 November, when people traditionally light candles at the graves of their relatives, known sites of mass killings were guarded by the police. Even in as late as 1982, a family was arrested near Postojna for lighting a candle outside a cave called *Pasja jama*.

2. Exploration of caves used as mass graves

In 1991 Slovenia broke away from Yugoslavia and established itself as a parliamentary democracy. This opened the way for the public discussion of the civil war and revolution, where the most important question remained the killings during and after the war. Immediately following Slovenian independence, the Parliament of the Republic of Slovenia created a commission to address the issue of mass killings (Jančar 2010). Owing to political disagreements, the work of the newly created commission presented considerable difficulties, and a good deal of time was needed before the first exhumations of smaller mass graves and burials of victims could begin.

Figure 1. Brezno pod Kotarjevo ogrado *contained 18 people before exhumation.*

Later at Slovenian government The Commission on Concealed Mass Graves was established. It is an expert commission whose task is to coordinate the search for and documentation of mass graves. The members of the commission include a historian, an archaeologist and, owing to the large number of caves, a speleologist. The commission has established a methodology of investiagtion and exhumation in accordance with legislation defining sites of mass killings as crime scenes. Regulations prescribe the forensic, archaeological and anthropological procedures to be followed during excavation, and also the documentation and handling of items that are found. For caves where all the remains are badly damaged and mingled together, making it difficult to distinguish individual victims, these criteria are somewhat modified (Jamnik, 2015).

Figure 2. Jama v Bukovju. *Photograph was taken in front of the cave entrance during the exumation of 20 people.*

Figure 3. Entrance to Brezno pri Konfinu I. *Behind the person there is a wall of rocks and organic material behind that was lifted from the cave during exumation.*

The commission prescribes the conditions, but the work itself is carried out via public contracts, which include the participation of cavers. The purpose of this article is to show how cavers have taken part in the process of discovery, but probing and the extraction of victims from caves.

On the Karst plateau, mass killings and individual executions were usually carried out by throwing people into shafts or chasms. There are few flat graves, usually on the floors of valleys. The killings began during the war, 1942 (Bajt, 1999) and intensified following the capitulation of Italy and the disintegration of the Italian occupying forces. They culminated after the end of the Second World War. During the war itself, the victims were mainly members of the local population. After the war they were for the most part people attempting to flee to western Europe ahead of the approaching Red Army. They come from the territory of the present states of Albania, Serbia, Bosnia-Herzegovina, Montenegro, Croatia and Ukraine (Ferenc, 2012) and include people returned to Yugoslavia by the British Army a month after the end of the war (Papo 1999, Tolstoy 1986).

We estimate that around 100 caves were used in the killings and that around 10,000 people (Mihevc 2001) were thrown into them.

3. Collecting information

Cavers began finding bodies in caves even during their first visits to caves after the war. The first record of the discovery of a corpse in the Caves Register of the Caving Association of Slovenia dates from January 1946. The person who made the entry in the register reports that there was a fresh corpse in a cave, that he reported this to the militia, but that when they examined the case together the corpse was no longer there (Pretner 1946).

Later mentions of such discoveries are few and far between, in view of the prohibition by the authorities of discussing such matters. Entries continued to be made despite the fear of prosecution, but in most cases these were merely brief mentions. On the other hand an oral tradition developed regarding caves containing bones and events connected with them. This included information provided to cavers by local people about who the people thrown into caves were, and also about whether caves were under police surveillance. This was possible in rural areas where local cavers enjoyed the confidence of the local population. Cavers also removed items that they found on the victims. Since the motivation for this was mainly souvenir collecting, many of these items have been lost (Mihevc 1995a).

Figure 4. Exhumations at Brezno pri Konfinu I*, into which 198 persons, mostly patients from a hospital in Ljubljana were thrown.*

The secret police supervised the activities of caving groups and also had their own informants or confidants in caving clubs and societies. Apart from a few visits by the police and the occasional interrogation, however, cavers did not experience major problems. A kind of modus vivendi established itself where cavers did not talk too loudly about such matters and in exchange were left in peace. This may also explain the fact that specialist literature contains no mentions of caves into which people were thrown. This, on the other hand, is a main topic of the commemorative literature published by Slovene people that after the war emigrated to other countries. Typically, such literature deals with the topic in a correct manner but contains many mistakes in the names of the caves and with regard to their locations. This is understandable, in that it was only thanks to data from the Caves Register and oral reports that we were able to compile (in as early as 1991) a fairly complete list of 86 caves containing human remains (Mihevc 1995).

The data from the Caves Register were very good. There were almost no cases of human bones being mistaken for animal

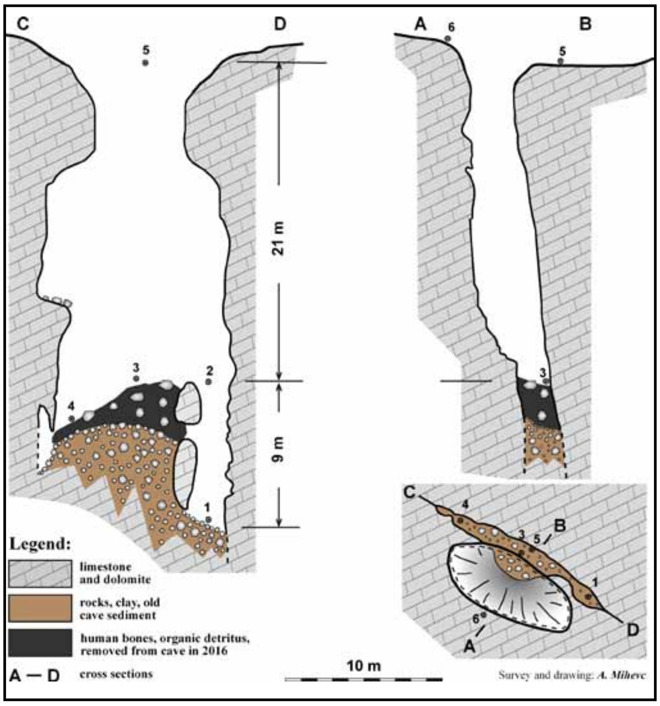

Figure 5. Plan of Krimska jama before and after being emptied. A total of 38 m³ of rock, organic detritus and 3 m³ of wood was removed from the cave in 2016.

bones. Only in a few cases did the bones turn out to be older. It did, however, transpire that there were considerably more caves used as mass graves than there were entries in the Caves Register. Cavers either overlooked bones or these were concealed by rubble and waste deliberately thrown into the cave. In some cases the entrances to caves were dynamited.

4. Participation in exhumations and recording

Formally or informally, cavers have worked on numerous projects connected with concealed graves ever since Slovenia became independent. They have inspected caves in numerous municipalities and reported on this to municipal commissions. The Caves Register of the Slovenian Caving Association has also supplied information to the criminal police. The systematic inspection of caves began in 2007 and 2008, when 40 shafts were inspected. Speleologists were only authorised to make records of bones lying on the surface and to probe areas where more recent material had covered human remains. Using rope techniques, cavers inspected the entrance shafts to caves and carried out measurements, after which they added a plan to the report on the mass grave (Mihevc, 2011).

The recording process continued in 2013 and following documentation of mass graves, bones lying on the surface were removed from caves. Visits to caves and the removal of bones were carried out using standard caving techniques. All bones removed were re-examined and photographed on the surface outside the cave. Recording and, above all, subsequent removal involved the cooperation of a police officer, an archaeologist and the professional speleologist. Later, the remains were also examined in a laboratory by an anthropologist.

To date 70 caves have been examined in this manner. The remains of at least 252 people have been removed from them.

Figure 6. Exhumations at Krimska jama. *Digging by hands in a limited space at the bottom of cave. A system of moving pullies above the entrance pit and a forestry winch was used to raise debris and human remains from the cave.*

The deepest cave to have been inspected was 140 m deep. The majority of caves were between 20 and 40 m deep.

To date, complete exhumation has only taken place in a few selected caves. *Brezno pri Konfinu* and a neighbouring shaft 30 m away contain the remains of 198 people, for the most part wounded people who were brought there in May 1945 from a hospital in Ljubljana and thrown into the cave. In order to conceal the bodies, the edges of both shafts were dynamited (Šturm 2000). This meant that in order to proceed with the exhumation it was first necessary to remove the resulting rubble. An electric winch was used to remove 20 m³ of rock from *Brezno pri Konfinu* and 30 m³ of rock from the neighbouring shaft, in order to be able to remove bones from the caves. Both shafts were important because by chance the hospital records of the victims had survived, making DNA identification possible (Zupanič Pajnič 2011).

A similar process was used for the shaft of *Krimska jama*. This shaft was used by partisans for executions in as early as 1942. After the war the entrance was dynamited a number of times. A total of 31 people were thrown into the shaft, which is 30 m deep. The corpses were covered by rock from the dynamited edges of the shaft. The technical part of the exhumation process was conducted by cavers from the local Borovnica caving club, aided by local residents and cavers from clubs in nearby areas. Work took place on Saturdays and Sundays, in people's free time. A winch mounted on a forestry tractor was used to remove wooden beams from the cave, followed by 38 cubic metres of ruble covering the corpses.

Between 1945 and 1947, 199 bodies were exhumed from caves on the Karst plateau (De Giorgi, 1948). The record of these exhumations gives the exact number of victims and also states other circumstances. In July 1947, 156 corpses were removed from the *Jelenca* cave. On inspecting this cave in 2013, we found the remains of the skeletons of at least 13 people on the bottom of the cave, which means that they were thrown into the cave after July 1947. A similar conclusion may be reached in the case of *Volčigrajska globonica*, a cave near Volčji Grad, from which 15 people were exhumed. A comparison of the pre-war and post-war plans shows that a large quantity of rock was subsequently thrown into the cave. The only reason for this could have been to conceal corpses thrown into the cave following the exhumation in 1947 (Mihevc 2011).

5. Conclusion

To date, the majority of caves in Slovenia have been inspected and the remains of around 650 people removed from them, but complete exhumation has only taken place in 15 caves and the caves that are expected to contain several thousands of victims each have not been excavated yet.

These are the caves in the area around the town of Kočevje in SE Slovenia. In the case of *Brezno pod Macesnovo gorico*, the edge of the shaft was blown up, causing between 600 and 1,000 m^3 of rock to fall into the cave, completely burying the entrance pit. It is estimated that the debris is up to 5 m thick, but in winter warm air rises past it and along the wall, allowing us to predict that there is a part of the cave not filled with rock beneath the entrance shaft. A similar situation exists at *Brezno pod Krenom*. It is probable that several people managed to escape from these two caves: those who avoided a bullet in the back of the neck and survived the fall into the pit. They claim to have survived in the cave for several days and that several thousand people were killed in each cave (Ižanc 1970). Other accounts talk about the existence of a third cave, *Ušiva jama*, which we are still looking for. It is said that the entrance shaft at the top of the cave was concreted over and then covered with earth. Other similar caves also exist, and searching for these is a very important part of the job of the cavers working with the commission.

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Bone-Hunters: exploration, analysis and interpretation of sub-fossil remains from Jenolan Caves, Australia

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Abstract

Sub-fossil vertebrate bones in cave systems are an enormously important resource, providing vital information on faunas that lived in or near these caves in times past. Cave environments, with constant temperature and humidity and little disturbance, have produced some of the most spectacular sub-fossil finds known. Preservation can be exceptional, and complete individuals are often found in the caves where they died. Floods and cave collapses are other sources for bones entering caves, processes that have occurred for millennia. Australian cave systems have yielded some of our most well-known Pleistocene species such as the 'Marsupial Lion' (*Thylacoleo carnifex*), the Mainland Long-beaked Echidna (*Zaglossus* species) and even some of the larger diprotodontoid species (such as *Zygomaturus trilobus*). This presentation will discuss the numerous extinct species now identified from Jenolan Caves, along with the methodology involved in exploration, analysis and identification of these sub-fossil remains. Pleistocene to Recent species include *Zygomaturus*, the Tasmanian Thylacine *Thylacinus cynocephalus*, the Tasmanian Devil *Sarcophilus harrissii*, and short-faced kangaroos in the genus *Simosthenurus*. Study sites include an in-progress excavation of owl pellet remains in the Nettle Cave and numerous unexcavated sites where species have been identified and locations mapped. Appropriate dating methods and preparation techniques will be discussed, along with potential applications for other cave systems.

Keywords: sub-fossils, vertebrates, Jenolan Caves, Pleistocene, megafauna, owl pellets

1. Introduction

Animals enter caves for many reasons - shelter, pursuit/caching of prey, escape from predators, or seeking water in times of drought. Carcasses may wash in during floods, or animals may accidentally fall through surface openings. Preservation of bones in caves can be exemplary due to the undisturbed conditions and relatively constant temperature and humidity. Most vertebrate remains found in caves are Quaternary in age (about 1.8 million years ago to the present), although bones may be many millions of years old, especially in geologically stable regions.

Australia, because of its biogeographical history, has megafaunal marsupial species as well as megafaunal birds and reptiles. World Heritage status was conferred on Naracoorte Caves in South Australia for its vast fossil vertebrate assemblages. New South Wales has numerous caves with rich fossil deposits, including Wombeyan Caves (discovery site for the Mountain Pygmy-possum, a living species first found as sub-fossils) and Wellington Caves (Australia's first megafaunal site) (Hope 1982). Here I introduce Jenolan Caves in New South Wales as an important palaeontological site, part the Greater Blue Mountains World Heritage Area, or GBMWHA. Jenolan Caves, reportedly one of the world's oldest cave systems, has not previously been recognised as a major fossil site.

Figure 1. Anne in Nettle Cave

2. Materials and Methods

A small number of bones collected over the past 150 years have been deposited at the Australian Museum in Sydney, forming a 'starter collection'. Work is now underway to 1) survey show caves and wild caves for vertebrate remains; 2) excavate sites (including the Nettle Cave owl pellet excavation, now in progress); and 3) identify, collect and analyse these sub-fossil remains. As resident palaeontologist supported by Jenolan Caves Reserve Trust and the Office of Environment and Heritage, and as a Research Associate of the Australian Museum, I work under the necessary permits (essential for any palaeontological or archaeological work of this kind). Cavers are a key part of this effort: my team includes a small group of experienced cavers, and caving clubs also tell me of their finds. Bones are identified, described, photographed, and left *in situ* (as required by both federal and state regulations) until further plans are made for the material. The in-progress owl pellet excavation utilises palaeontological and archaeological methodology and tools, and material is processed by

Figure 2. Thylacine bones in Jersey Cave

sifting sediments prior to sorting, identification and analysis of bones. Specialist tasks such as dating of remains and pollen analysis are done in collaboration with experts in these fields.

3. Results

Several extinct marsupial species are now known from Jenolan. Many of these often occur together in other south-eastern Australian fossil vertebrate assemblages, such as that of Wombeyan Caves (i.e., a suite of species suited to temperate, mesic environments) (e.g., Hope 1982). These include the marsupial 'rhino' *Zygomaturus trilobus*, the Tasmanian Thylacine *Thylacinus cynocephalus*, Tasmanian Devil *Sarcophilus harrisii*, and short-faced kangaroos in the genus *Simosthenurus*. Smaller mammals discovered include bettongs, possums (including the Mountain Pygmy Possum), several native rodent species and later arrivals like the Dingo *Canis dingo*. Additional bones collected during these studies await identification.

4. Summary and Conclusions

Most caves will produce prehistoric cave faunas, including Ice Age megafauna. Universities and museums can provide

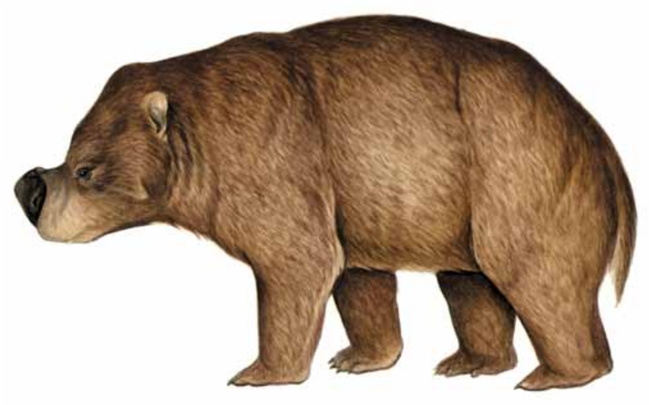

Figure 3. Zygmomaturus

critically important expertise, working collaboratively with cave managers and government bodies or institutions. Understanding the past history of cave systems not only advances science but adds depth, context and interest to interpretation for visitors and other stakeholders.

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Palaeontology Of Northeastern Australian Caves

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Abstract

Numerous Australian caves have produced fossil records that have been critical in piecing together the story of the evolution of the continent's ecosystems through time. Among the most important are those of the Riversleigh World Heritage Area of northeastern Australia. Although the majority of caves in the region have since been destroyed as a result of natural collapses and erosive activities, now-exposed breccias are remarkably abundant in fossils. The fossil faunas include the distant ancestors of the majority of modern Australian vertebrates, as well as extinct lineages such as those of the marsupial 'lions' (Thylacoleonidae) and the diprotodontoids, a group of oversized wombat-like marsupials. Recent radiometric dating in the region, coupled with biochronology, demonstrates that the majority of Riversleigh's fossil assemblages are Miocene in age (ca. 10-18 million years old). Notably, the younger end of the fossil record is poorly represented at Riversleigh, but other cave systems across northeastern Australia provide the necessary temporal extension that can document the emergence of the modern faunas and ecosystems. Karst-dominated regions such as Chillagoe have produced Quaternary-aged (<2.6 million years) fossils, including species found nowhere else on the continent such as *Propelopus chillagoensis* ('Chillagoe's carnivorous kangaroo'). Chillagoe is also home to the enigmatic extinct land-dwelling crocodile, *Quinkana fortirostrum*. Recent work in the region has also extended slightly southward to the Broken River karst system. The fossil assemblages in the Broken River caves mostly represent owl-roost accumulations, although deposits thought to be collected by ghost bats and natural pit-fall traps have also been recognised. The oldest radiometrically dated fossil deposits are around 350 ka (thousand years old) and include a combination of both extinct and extant faunas. Quaternary geographic range extensions have been recognised for several species including pig-footed bandicoots (*Chaeropus* spp.), as well as the now-extinct giant short-faced kangaroos (sthenurines), a group previously thought to only occur in southern Australia during the Quaternary. Further to the south, the Mt Etna region provides evidence of significant faunal and ecosystem change through the late Quaternary. Rainforest-adapted vertebrates occur in abundance in cave deposits >280 thousand years old, but give way to more open-adapted faunas by around 200 thousand years ago.

Keywords: Caves, owls, pitfall traps, vertebrates, megafauna, extinction

1. Introduction

Caves play a seemingly unlikely, but remarkable role in documenting the evolution of terrestrial ecosystems through time (Lundelius, 2006). Unwary land animals typically fall into caves, and unable to make their way back out, die underground, with their tough and durable skeletons readily becoming incorporated into the fossil record. Such caves are commonly called 'natural pitfall traps'. Airborne predators such as owls also play a key role in accumulating terrestrial vertebrates in cave settings. Owls will commonly hunt at night targeting a wide range of food resources including small-bodied vertebrates. After securing a kill, they will tear their victim apart with their beak and talons, usually swallowing the entire carcass in 'bite-sized' pieces. Upon returning to the roosting cave, they will regurgitate any undigested remains (e.g., feathers, fur, teeth and bones) in the form of pellets that fall to the floor of the cave. Subsequent breakdown and burial of those remains may then make their way into the fossil record.

Numerous fossil-yielding caves have been reported from the extensive limestone deposits that fringe the modern margin of the Australian continent (Hocknull *et al.*, 2007; Price *et al.*, 2009a, b; Reed and Bourne, 2009; Prideaux *et al.*, 2010). These caves have been critical in piecing together the story of the evolution of Australia's terrestrial vertebrates. Among the most important caves are those of northeastern Australia, a region that contains not only the oldest record of fossil-bearing caves, but also those that span the longest temporal sequence for any one place on the continent. The aim of this paper is to provide an overview of the vertebrate fossil record of northeast Australia's caves.

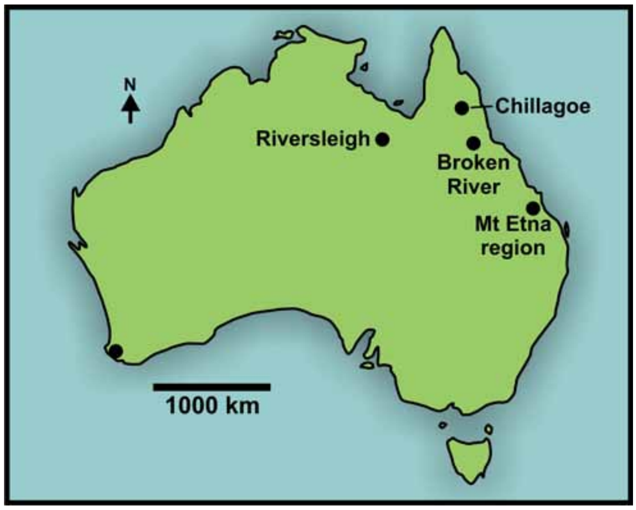


Figure 1. Map of Australia showing key sites of interest

2. Riversleigh

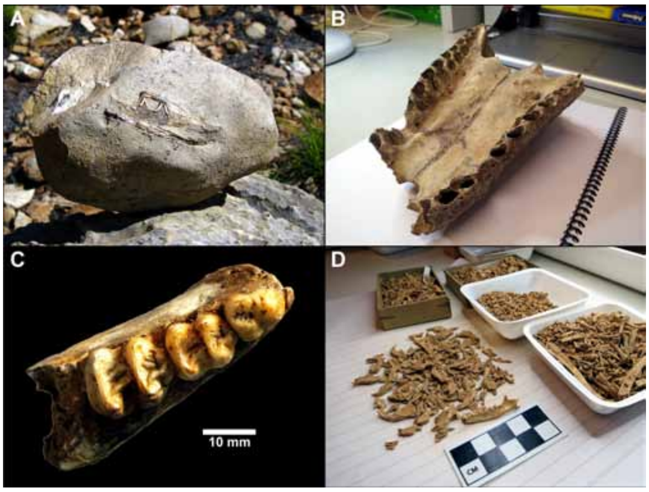
The oldest and longest record of fossil-bearing caves in Australia are those from Riversleigh of northwest Queensland (Figure 1). Fossils were first reported from the region in the 1960s, with over 200 fossil sites now known (Archer *et al.*, 2006). So important are the fossil deposits of Riversleigh that the region was declared a World Heritage Area in 1994, an honour shared with the Pleistocene-aged Naracoorte Caves of southeastern South Australia.

The basement rocks at Riversleigh are Cambrian in age. During the late Oligocene (*ca*. 24 million years ago), numerous freshwater limestones developed, some of which are rich in fossil vertebrates. Following karstification, an extensive series of caves formed within the limestone that later functioned as natural pitfalls, effectively trapping a wide variety of terrestrial vertebrates (Arena *et al.*, 2014). Other vertebrate-bearing cave deposits are thought to have accumulated at least in part by predators, such as ghost bats. The majority of Riversleigh's cave deposits are Miocene, the oldest dating to *ca*. 18 million years in age (Woodhead *et al.*, 2016).

Although the majority of Riversleigh's caves have since been destroyed as a result of natural geological processes, they are still discernible on the modern landscape and have been the focus of targeted excavations since the mid-1970s. The brecciated deposits are remarkable for the variety of vertebrates that they contain, with the palaeo-diversity comparable to that of a modern rainforest in Borneo (Woodhead *et al.*, 2016). Similarly, the vast majority of Riversleigh's fossil vertebrates are considered to have been rainforest specialists, especially those from the early and middle Miocene. Amongst the extinct bestiary are the earliest ancestors of all the modern major groups of marsupials, such as Notoryctomorphia (marsupial 'moles'), Peramelemorphia (bandicoots and bilbies), Dasyuromorphia (Tasmanian devils, Tasmanian 'tigers', and dunnarts among others), Vombatomorphia (wombats), Phascolarctomorphia (koalas), Phalangeroidea (possums) and Macropodoidea (kangaroos and allies) (Archer *et al.*, 2006; Louys *et al.*, 2007; Black *et al.*, 2014; Butler *et al.*, 2016).

Many of Riversleigh's fossil vertebrates share a similar body plan to modern Australian vertebrates, but with some bizarre exceptions and groups of organisms that are now extinct. For example, the yalkiparidons, informally known as 'thingodonts', were a group of small-bodied marsupials that possessed a bony 'beak' and may have been ecologically convergent with woodpeckers (Beck, 2009). Riversleigh also bore witness to the earliest members of the now-extinct Thylacoleonidae (marsupial 'lions') and Diprotodontoidea (marsupial 'tapirs' and 'rhinos'; Figure 2A), two groups that eventually came to dominate the top mammalian predator and herbivore niches, respectively, of mid-late Cenozoic Australia (Wroe *et al.*, 1999; Price and Piper, 2009).

Riversleigh shows remarkable transitions of ecosystems through time, with the open forests of the late Oligocene overtaken by extensive rainforests for much of the Miocene. During the late Miocene, a trend towards drier conditions saw many of Australia's terrestrial ecosystems become patchier and more open. A Pliocene (2.6–5.3 million years ago) fossil record is absent from Riversleigh, with the youngest cave deposits in the region dating to the early Pleistocene (*ca*. 2 million years ago) (Woodhead *et al.*, 2016). The story of the evolution of northeastern Australia's terrestrial vertebrates then takes up with cave deposits that date from the middle-late Pleistocene to Holocene (*ca*. last 500 thousand years).



A) Lower jaw of a diprotodontoid (wombat-like marsupial) encased in rock from Riversleigh; B) Holotype of land-dwelling crocodile, Quinkana fortirostrum, from Chillagoe (Australian Museum Fossil 57844). C) Occlusal view of lower jaw of a sthenurine (giant short-faced) kangaroo from Robert Broom Cave, Broken River; D) Fossils of 'microfauna' from Colosseum Chamber, an owl roost deposit from the Capricorn Caves, Mt Etna region.

3. Chillagoe

Extensive tower karst occurs in the Chillagoe area of northeastern Australia (Figure 1). The limestone here is late Silurian – early Devonian (*ca*. 400 million years old) and contains numerous fossil molluscs, brachiopods and corals (De Keyser and Wolff, 1964). Bone breccias are common in the caves, many of which are topographically higher than the modern land surface in the region.

Unlike Riversleigh, the majority of caves in the region are still intact, but have not been explored by palaeontologists anywhere near as extensively. The majority of fossil vertebrates from Chillagoe are small-bodied and include bilbies (*Macrotis*) and pig-footed bandicoots (*Chaeropus*), species that are found in the historic period only in Australia's central arid core (Muirhead and Godthelp, 1995). Their occurrence at Chillagoe suggests a more open habitat and drier climate in the area in the past.

Several species of 'megafauna' have also been recorded from around Chillagoe including a species of land crocodile (*Quinkana fortirostrum*; Figure 2B), giant carnivorous kangaroo (*Propleopus chillagoensis*), and marsupial 'tapir' (*Palorchestes azael*). Chillagoe is also the type locality for the former two species (Archer *et al.*, 1978; Molnar, 1981). Radiometric dating of the marsupial 'tapir' suggests that it occurred locally during the penultimate glacial cycle (*ca*. 137–200 thousand years ago) (Price *et al.*, 2013).

4. Broken River

The Broken River karst is situated approximately 60 km south of the small township of Greenvale in northeastern Queensland (Figure 1). Numerous caves occur within the Silurian-Devonian limestones, the majority of which also contain vertebrate fossils (Withnall and Lang, 1993).

Work in the region is preliminary but ongoing. The majority of vertebrate remains appear to have accumulated in the caves from the feeding activities of owls. Most species recovered and identified to-date are thus unsurprisingly from small-bodied species, but include extremely diverse assemblages of marsupials and rodents, species of which suggest an open-type savannah and thus similar to the palaeoenvironmental signal from Chillagoe.

One of the most exciting deposits is that from Robert Broom Cave (a system named by the Chillagoe Caving Club in honour of the palaeoanthropologist famous for discovering the early hominid, 'Mrs Ples', the most complete skull of *Australopithecus africanus*). Here the taphonomic signature differs to that of other caves at Broken River, with the contained fossil species being those of large-sized taxa and includes the largest-ever marsupial 'lion', *Thylacoleo carnifex*, as well as the largest-ever marsupial overall, the enormous wombat-like *Diprotodon*. It is clear that this system acted as a pitfall trap. The cave also contains abundant fossils of macropods, the majority of which are those of the modern dominant kangaroo, *Macropus*, although fossils of sthenurines (giant short-faced kangaroos) have also recently been collected (Figure 2C). Previously, Pleistocene species of sthenurines were known only from southern Australia, thus, their occurrence at Broken River marks a *ca*. 1200 km geographic range extension for the time period. This finding highlights just how poorly explored the fossil record of northern Australia is in comparison to the south.

An extensive, but mostly hitherto unpublished radiometric dating program of Broken River fossil deposits demonstrates that the majority are younger than *ca*. 350 thousand years old. The palaeoecological signature from fossil vertebrates suggests largely an open habitat through time, a finding that is in contrast with the record from the Mt Etna region, approximately 700 km to the south.

5. Mt Etna region

The Mt Etna region includes both Mt Etna itself and the adjacent Limestone Ridge, thus encompassing both National Park and private land (Figure 1). The marine limestones here are Devonian and preserve abundant fossils of corals, brachiopods and molluscs (Sprent, 1970). Numerous caves occur within the limestone karst.

Mt Etna was subjected to extensive quarrying activities from the 1970s to the 2000s. Serendipitously, while the quarrying destroyed numerous caves and roosting sites for local bats, many fossil deposits were exposed and made accessible for palaeontological assessment. The fossil faunas collected here, and on the adjacent Limestone Ridge, are particularly diverse and include a range of both small- and large-bodied taxa including molluscs, frogs, lizards, snakes, marsupials and rodents (Hocknull, 2005).

The story of the Mt Etna region is somewhat similar to that of Riversleigh. The oldest fossil faunas recovered include many species that appear to have been rainforest specialists, some of which share close evolutionary links to those found today in lowland rainforests of New Guinea today. Radiometric dating demonstrates that such deposits are >280 thousand years old, implying more humid conditions locally at that time. However, by *ca*. 200 thousand years ago, few rainforest-adapted taxa are known, the majority of which appear to have been ecologically replaced by open, arid-adapted forms including species such as bilbies (Hocknull *et al*., 2007). This purely climatically driven extinction event occurred at least 150 thousand years before the arrival of humans on the continent.

Several megafaunal species are recorded in the region, the geologically youngest of which is a variety of giant goanna (species uncertain, but likely referable to either Megalania, *Varanus priscus*, or Komodo dragon, *V. komodoensis*). Previously thought to have suffered extinction prior to human arrival (Price *et al*., 2011; Wroe *et al*., 2013), recent dating of a specimen from Colosseum Chamber (Capricorn Caves; Figure 2D) shows that it is slightly younger than 50 thousand years old, placing it within the timeframe of the earliest humans on the continent (Price *et al*., 2015). A local archaeological signature is absent for that time, thus it is unknown whether humans and giant lizards actually ever directly encountered each other.

6. Summary

Caves of northeastern Australia record a drying continent over the last 25 million years, although certain areas appear to have maintained more humid conditions until geologically recent periods. The unique palaeoenvironmental signals from the region's caves are critical in helping us understand faunal change in response to past climatic and environmental perturbations, which of course has important implications for understanding the effects of modern climate change.

Although fossils have been known from northeastern Australian caves for well over a century, the region has been somewhat neglected in the past in terms of palaeontological investigation. Despite many advances, we are still scratching the surface of this most important palaeontological resource. Exploration of new caves, and new caving regions, are almost certainly likely to result in discoveries that will challenge or rewrite existing paradigms in Australian palaeontology. Palaeontologists will continue to rely on the co-operation and assistance of the speleological community for these discoveries.

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Nova spilja (New Cave) from 1882 - in Croatia

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Abstract

This is a documentary film about an international project of archeological excavation in Nove spilja (New Cave) in Croatia.

Croatian speleologists and cavers have followed an article published in the Archeological journal of 1882. In the same article there is also published the oldest known cave map in Croatia. During exploration they found interesting fragments of pottery dated to the Neolithic period. This motivated speleologists from Croatia, Greece and the UK to organize detailed excavations and research during an expedition in 2016.

A Speleo-Archaeology Study Of Kali Banjar Underground River:

Approach On The Research Of Site Formation Procces

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Abstract

Gunung Sewu is a fascinating karst area based on its various secrets of human prehistoric life. Features such as its underground drainage system, caves and rock shelters are contain important data for the study of archeology. Among other things, the Kali Banjar underground river, which is located in Wareng, Punung, Pacitan, is becoming the most interesting site to study further because of the large numbers of stone artifact deposits found in the underground river system. These indicate the relations between the archaeological sites on the surface of karst area such as *Song Terus* and *Gua Tabuhan* with the underground morphology. The idea of research is developed but based on limited numbers of underground river archeological studies. This paper is intended to relate the early results of the on-going research into the Kali Banjar underground river formation process. It tries to use popular cave mapping methods in Indonesia to record the field data, the underground river morphology and the archeological data context. It also uses other methods, such as the velocity method, to record the number of underground river debits. Other data methods are also necessary for the archeological data transformation process. This research use taphonomy analysis to find the factors, which effects the archaeological data transformation in the Underground River and the Kali Banjar site context type. Then, the typology data of the stone artifacts and the locations of the deposits will be related to acquire the information about the characteristic of the deposit location.

Keywords: Kali Banjar underground river system, artifacts remain, transformation, methods

1. Introduction

The Kali Banjar underground river is located in an active cave between Song Terus and Tabuhan Cave. This underground river has deposits of stone artifacts concentrated at several locations along its length. Based on the type of flow, this cave has an intermittent tunnel where water passes through during the rainy season, starting from the mouth of Kali Banjar (A) down to the forks and perennial tunnel, which is covered in water all year long starting from the forks heading upstream and downstream (Fig. 1).

Unlike Song Terus and Tabuhan Cave, which garnered attention from R.P. Soejono and Basoek as early as 1953, research on Kali Banjar was only started by National Archaeological Research Center and MNHN in 1990 in the form of a survey, yielding stone artifacts as a result.nother research was done by Anton Ferdianto in 2015 as part of his research on Functions of Stone Tools in Southeast Asia. This lack of research might beydue to Kali Banjar's lack of morphological parameters supporting prehistoric human activities.

One thing that influences data transformation is natural features (Schiffer, 1986). Finding stone artifacts in Kali Banjar underground river is interesting, as it shows a connection with surface sites such as Song Terus and Tabuhan Cave.

Transformatioin processes are thought to play a role moving stone artifacts and depositing them in the middle of, on the cave floor, walls, and even the roofs of Kali Banjar underground river. This idea was supported by Schiffer, 1987, who writes about the role of natural features, among them the underground river system, in transforming archaeological data.

Taphonomical study is a way to understand the transformation processes that happened as soon asathe material was removed from its original context by observing cause and

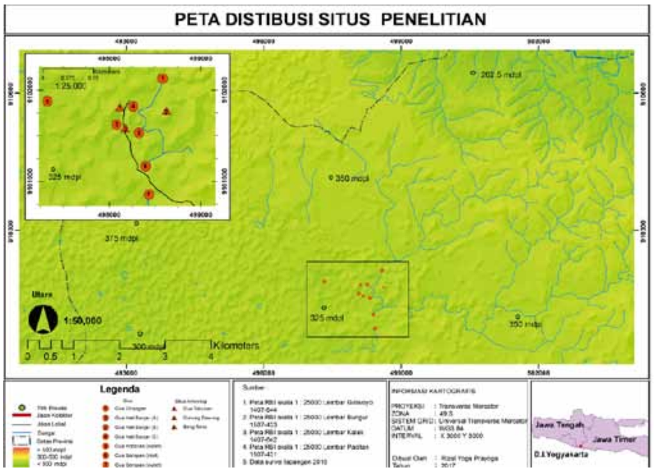

Figure 1. Location of Kali Banjar underground river and surrounding site localities

effect from several contributing factors. The application of taphonomical study by archaeologists on underground river systems in Indonesia ig new. This study requires change in surveyingetechniques, such as the implementation of standard operational procedures for caving, and mapping the cave in correlation with archaeological data sampling.yIt is also important to observe the exokarst or endokarst environment and the activities of surrounding communities as they havs the potential to cause data transformation. All of these adjustments are taken to ensure the research will be successful in fulfilling its goal.

2. Regional Setting

Kali Banjar underground river system is located on the eastern part of Gunung Sewu karst region, a region covering 1265 km2 with geographical boundaries in the form of Opak fault to the west, Wonosari and Baturetno basins and the massive hills of Panggung, to the east is Pacitan bay, and the south is

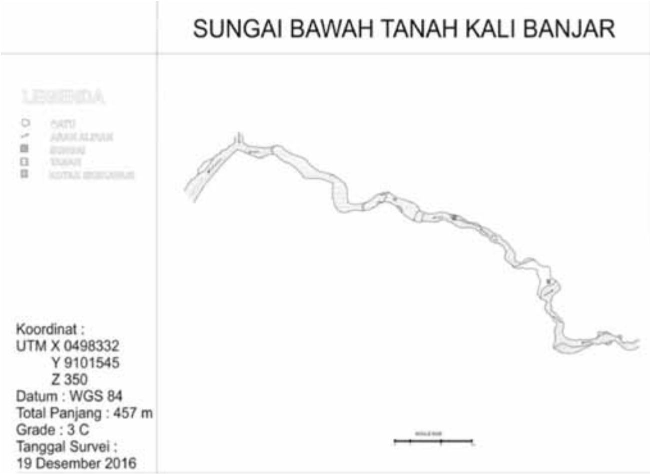

Figure 2. Map of Kali Banjar underground river

the Indian Ocean (Yuwono, 2013:1). This site's administrative location is Wareng Village, Punung District, Pacitan Regency. Kali Banjar Underground river has one downstream entrance with a coordinate of UTM 49S x:498080mT y:9101621mU (B) and two upstream entrances with coordinates of UTM 49S x498263mT y:9101820mU (C) and UTM 49S x498323mT y:9101533mU (A) (Fig.1).

In the general geological context, the research area is located in Wonosari formation, a limestone formation dominated by limestone reefs. There are also layered limestone, marlstone, tuffaceous sandstone, silts, and conglomerate limestone (Purnomo 2005). The formation is estimated to be formed during the mid-Miocene to upper Miocene with a sedimentation environment of a shallow sea in the neritic2 zone. This formation is over 800 meters thick (FIsko, 1996 in Fajri 1998: 15). The research area comprises karst hills characterized by rounded hills and steep slopes (Yuwono, 2005:40) (see picture 2.1). Generally the slopes have teak (*Tectona grandis*) vegetation with variable thickness, interspersed with grasses and wild shrubs (*Graminae*).

According to the Koppen Classification, the Pacitan area, including Gunung Sewu, has a wet/dry tropical climate (Aw) with a rainfall between 2000 – 3000 mm/year, so that the drought of the dry season is balanced by the rain during the wet season. The average monsoon cycle is similar to other parts of Indonesia, that is between October and April. The Average temperature in the area is around 20 – 28 °C.

3. Materials and methods

This research stems from a personal curiosity concerning the transformation process of the stone artifacts in Kali Banjar Underground river,tand may resuld in inconclusivesresults. The Early stages of this research consisted of gathering topographical maps, research reports, books, and journal articles related with this particular research to be reviewed. The following field observations ais to obtain a map of the cave (Fig. 2), stone artifacts, coordinates for sites around Banjar river system, flow rate of Kali Banjar underground river, condition of the research location and other data.

Field observation at Kali Banjar underground river was done thoroughly with an emphasis on safety, therefore the use of exploration gear that meet the safety standards for cave exploration such as mandatory helmets, coveralls, two sources of lights, rubber boots, tackle bag, and floatey. Other than exploration gear, surveying tools used in collecting data are; digital camera, flash, external scale, North pointer, PVC pipes, sample bags, compasses, distometer laser, measuring tape, and worksheet. Sampling processes did not include archaeological excavation as it takes a longer time and was not relevant to be done in a cave with active water flows.

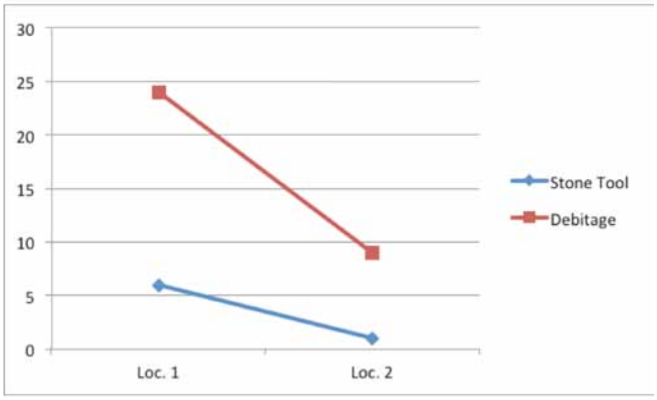

Figure 3. The Percentage of Lithic artifacts

The analysis used during this research is an attribute analysis to know the types of artifacts located in Kali Banjar underground river (i.e. Typology) and taphonomy analysis to understand what processes happened to those archaeological data. Variables for the taphonomical research are archaeological data context, the morphology of Kali Banjar underground river, and flow rate of Kali Banjar underground river.

4. Results and discussion

Archaeological remains gathered from the survey of Kali Banjar consisted of 40 lithic artifacts taken from two sedimentary locations. Both locations also contained sands and gravel. Stone artifacts deposits in Kali Banjar shows the significant role played by hydrological processes of karst area and underground river morphology. The Sedimentary transformation process on the surface of karst area was influenced by moving water, which was responsible for the transportation of stone artifacts, while the morphology of the underground river governs the sedimentation process of the artifacts.

4.1. Deposition of stone artifacts

Kali Banjar underground river has two types of passages differentiated by the water-flow period: intermittent tunnel, from the (A) entrance down to the junctions, which was a vadose inactive tunnel, with a seasonal hydrological system and perennial tunnel beginning from the upstream junction toward (C) entrance and the downstream (B) entrance. This tunnel is a vadose tunnel in a high water sub zone characterized by continuous water flow an, outside seasonal effects (Samudra, 2010:107-108). The formation of these two tunnels was controlled by a fractal plane. This is seen in the patterns of tunnel meanders, which tend to be radical and regular, forming > 90° angles (Fig. 2).

4.2. Deposition Location of stone artifacts

Stone artifacts from the surface were transported by water currents into the underground river. In the Kali Banjar case, these

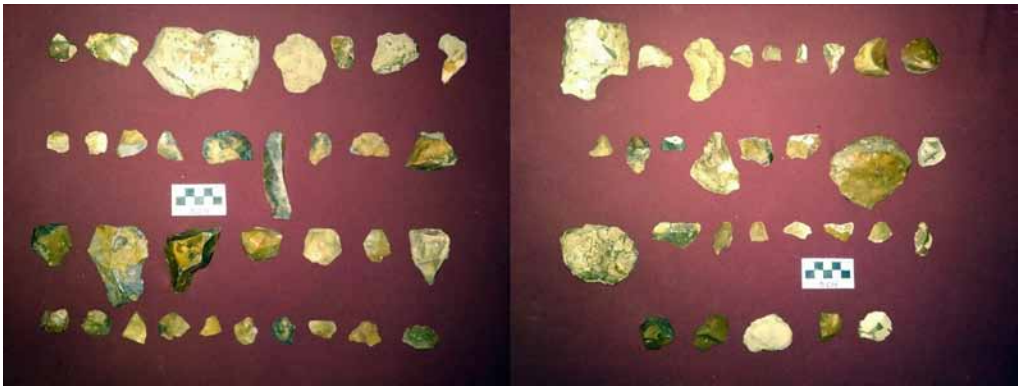

Figure 4. Lithic artifacts from Kali Banjar underground river

stone artifacts were deposited in locations with certain morphological features such assmeanders,and widening and narrowing points of the river channel. The depostional process of archaeological data in Kali Banjar Underground River is fully controlled by the water currents, and is. shown by the location of deposits along the underground river. In the intermittent tunnel with run-off flows, there are two deposition locations, the first was located in a point where the river widens and the second was located on the outer wall of a meander.

4.3. Lithic Artifacts

From the table above, we can see that there are two types of artifacts deposited in Kali Banjar underground river; stone tools and lithic waste or debitage. There were 30 artifacts taken from the first sampling location with 6 confirmed stone tools and 10 artifacts from second location with 1 confirmed stone tool.

5. Conclusion

In a karst region, rain water accumulates in surface depression zone. This waters usually transports materials from higher elevations, such as the karst hills. If there is a cave located in that depression zone, connected to an underground river system, the material transported by water would then continue with the current, entering the underground river system. In this underground river, the materials transported from the surface would have potential to be deposited along the underground river tunnel. In Kali Banjar Underground River, this process of sedimentation was influenced by the flow of the water and the morphology of the passages. Archaeological research studying archaeological data in underground cave systems is rarely undertaken. The result of this research is, at this stage, hypothetical and limited in interpretation and synthesis of the results. However, as a pioneering research in studying underground cave system, we hope that this research might serve as a guideline or reference when researching similar phenomenon in other underground river tunnels, whether they be active river or had already dried up.

Acknowledgements

The author is deeply indebted to Ahmad Surya Ramadan and J.S.E. Yuwono the first to introduce the study of archeology at the underground river. The author would like to thank Pusat Arkeologi Nasional, Bali Pelestarian Cagar Budaya Jawa Timur, Balai Arkeologi Yogyakarta and Archaeology Department UGM for allowing and providing research facilities. The author also gives thanks to the survey team consisting of Adi Fauzi, Anna, Risky, Agil, Dama, Wastu, Upal, Indah, Ester, Tika, Dede, Reinhart, Yayum, Febri, Sabrina and locals of Wareng who have kindly helped author during exhaustive fieldwork, especially to Mr. Suroto and Mr. Edi.

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Australian Caves and Karst

"Fatuk-Kuak Hosi Timor Lorosa'e": Caves Of Timor-Leste

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Abstract

Timor-Leste (formerly East-Timor) is one of the youngest nations in the world. Partly because of its troubled recent history, this small Southeast Asian country nowadays remains one of the least explored as far as speleology is concerned. With a total area of 15,000 km^2, a high percentage of the country's territory is limestone and it hosts one of the largest poljes in the world.

In September, 2016, the "Fatuk-kuak hosi Timor-Lorosa'e" project (Caves of Timor-Leste), created by four Portuguese caving clubs and joined by the only Timorese caving club, made its first expedition to Timor-Leste, briefly visiting some of its karst areas. During the month long expedition – carried out under the auspices of the International Union of Speleology (UIS) and the Portuguese Federation of Speleology (FPE) – more than 50 caves were registered in the districts of Ainaro, Baucau, Lautém and Viqueque.

The major highlights are: i) Bakua cave; this 650 m long, 197 m deep sink near Maubisse is the country's longest and deepest cave to date. The Biribui spring cave, the system's most probable resurgence point, lies roughly 800 m away and 350 m below; ii) The polje of Lake Iralalaro, one of the largest in the world, continuously drains its water through the Irasiquero River, which sumps after 3.5 km at the (yet impenetrable) Mainina sink. The resurgence of this system is unknown and probably lies at the ocean bed, no less than 4 km away; and iii) the first biospeleological survey, providing new species for science and the discovery of a rich biodiversity in these tropical caves.

Access remains an obstacle to visiting some areas of the country, so some of the karst with the most potential for caves is yet to be visited. The "Fatuk-kuak hosi Timor-Lorosa'e" project will return annually, to continue exploration and support the development of Timorese speleology.

Keywords: Timor-Leste, caves, biospeleology

1. Introduction

In 2016, four Portuguese caving clubs, Núcleo de Espeleologia da Universidade de Aveiro (NEUA), Liga para a Protecção da Natureza – Centro de Estudos e Actividades Especiais (LPN-CEAE), Centro de Investigação e Exploração Subterrânea (CIES), and Grupo Protecção Sicó (GPS), organized an expedition to Timor-Leste. The main objectives were to visit some of the major limestone areas and start an inventory of caves and karst springs in the districts of Ainaro, Baucau, Lautém and Viqueque (Fig 1). Topographic surveys of the caves were made whenever possible. Additionally, education sessions were given in some schools, to raise awareness for the protection of caves, springs and other karst landforms. Finally, we strived to nurture Timorese speleology, which is now taking its first steps.

2. Timor-Leste

The Democratic Republic of Timor-Leste is one of the youngest nations in the world, having achieved its independence on May 20th, 2002. It comprises the eastern half of the island of Timor in the Malay Archipelago, having an area of about 15,000 km^2. Also part of the country are the coastal enclave of Oecussi-Ambeno located in West Timor and the islands of Ataúro and Jaco.

Figure 1. Map of the districts of Timor-Leste

The capital city, Dili, is located on the North shore and the official language is Portuguese. However, Tetum is the most spoken language across the country's territory.

Timor-Leste's climate is tropical with two seasons, rainy and dry. Due to the island's mountainous geography the seasons' timings aren't the same everywhere, being September the last dry month common to the entire Timorese territory. This fact weighed heavily in the choice of the timing of the expedition.

The administration and management of Timor-Leste's underground resources (including caves) falls under the scope of the Ministry of Petroleum and Mineral Resources. In the municipality of Lautém, the Nino Konis Santana Natural Park, is managed by the Ministry of Agriculture and Fisheries.

3. Timor-Leste's geology

Thompson (2011) provides an excellent introduction to the geology of Timor-Leste: "The island of Timor sits at the eastern end of and just south of the archipelago of volcanic islands, the Banda Arc, running eastwards from the Indonesian island of Bali. This volcanic arc is the surface expression of lithospheric subduction currently taking place as the Australian crustal plate moves north eastwards towards and underneath the Eurasian plate.

However, for the last 5 million years or so that subduction has become 'locked' in the Timor region thereby causing the island of Timor to be thrust upwards as the only relief mechanism available as the two crustal plates continue to converge. In layman's language, Timor is going up like a 'Geological Cork' at the extreme north eastern edge of continental Australia.

Structurally, the rocks on Timor belong to the Australian plate with basement rocks (Lolotoi Complex) uplifted as the mountainous spine of the island. The results of the continental collision, leading to immensely deformed, sheared and thrusted lithologies are seen along the north of the island in the syn-collisional metamorphic rocks of the Aileu Complex.

Younger, Mesozoic sediments lie in structurally controlled basins on top of these basement lithologies and Plio-Pleistocene to recent reefal limestones continue to be laid down and uplifted in syn/post orogenic basins on and around the periphery of the island." The Baucau Plateau and the easternmost tip of the island, near Tutuala, are examples of these reefal limestones and were visited during this expedition.

Thompson (2011), continues: "The overall geological engine behind the creation of Timor is extreme uplift due to the 'locked' continental collision. This is reflected in the mountainous nature of the island and the chaotic geology with the island broken into an immense number of thrust and uplifted structural units. Softer sediments, shales, sandstones and bedded limestones for example are sheared, crushed and folded into complex and contorted lithologies. The more massive reefal and marine limestones however are strong enough to have maintained their integrity and have been literally pushed up through the geological mélange in huge up-thrust slices as seen at Cablac and Matebian for example and elsewhere throughout the central spine of the island." The Mount Fatubessi limestones near Maubisse, visited during this expedition, are yet another example of these up-thrust slices.

3.1. Previous speleological exploration

Timor-Leste's speleology is still in its infancy. Records are scarce and most published cave references pertain to archeology and paleontology expeditions.

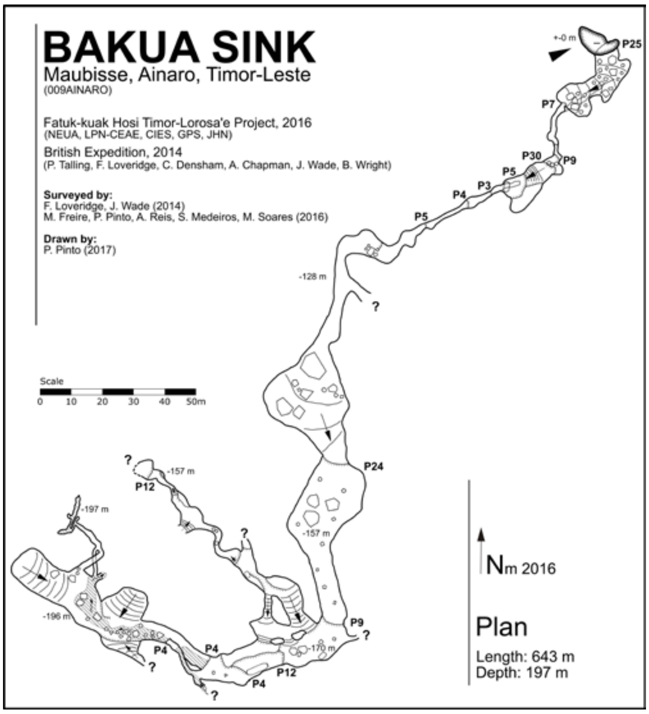

Figure 2. *Map of Bakua cave in Maubisse*

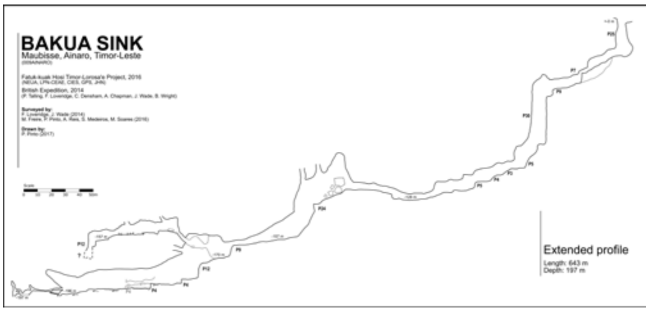

Figure 3. *Extended profile of Bakua cave.*

The only previous specifically speleological incursions in Timor-Leste we're aware of are:

1) Australian expedition in 2005, by S. White, N. White and G. Middleton (White *et al*, 2006);

2) John Brush's (Canberra Speleological Society) work, as a member of the archaeological expedition led by Prof. Sue O'Connor in June, 2009;

3) British expedition in 2014, by P. Talling, F. Loveridge, C. Densham, A. Chapman, J. Wade and B. Wright.

More recently, a nature activities club from Dili named Juventude Hadomi Natureza (JHN) founded a small caving group. When we learned about them, we made contact and they were straightaway welcomed aboard. Having only exchanged a few emails with the JHN folks before our arrival, we spent little time getting acquainted before heading out to the countryside.

4. The 2016 expedition

The expedition took place between September 3rd and October 2nd and was officially supported by the International Union of Speleology (UIS) and the Portuguese Federation of Speleology (FPE). Locally, a partnership with the Univer-

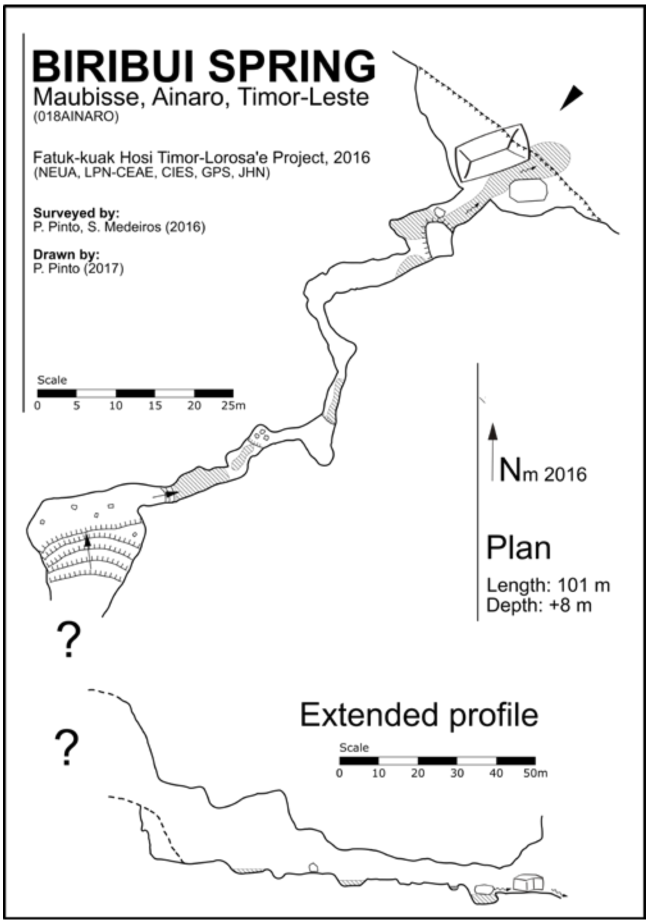

Figure 4. Map of Biribui cave, in Maubisse.

sidade Nacional Timor Lorosa'e (UNTL) was an invaluable asset.

A few days were spent in Dili for official contacts and logistical preparations. Then we visited the four targeted districts in this sequence: Ainaro, Baucau, Lautém and Viqueque.

4.1. Ainaro District

In this district work was limited to the area of Mount Fatubessi, 5 km to the northeast of the town of Maubisse.

The most significant cave so far is a sink at the end of a blind valley with a small stream (dry at the time of the expedition). The cave was discovered and explored by the British expedition of 2014 to a depth of -125 m. Beyond this point the passage gets higher and wider and continues so, down to -197 m. Near that depth, a small stream runs even in this dry season.

The survey now totals 643 m, but many passages are yet to be explored. This sink cave, called Bakua (also known as Petrem, in the 2014 expedition), lies less than 1 km away from the escarpment that limits the limestone to the North.

Even though the cave develops mainly to the southwest, it is expected to turn north towards the base of the escarpment. Locals guided us to the probable resurgence, a spring cave called Biribui, roughly 350 m below. We explored and surveyed a horizontal passage for about 100 m, until we reached a high gallery, but climbing gear was needed to progress further in.

Going back up the escarpment, the guides showed us two horizontal caves located at different altitudes, which were used as refuge by local people during the Indonesian occupation of the country. Despite the galleries being choked after a short while, we were impressed by their width and height, close to decametric dimensions. These were probably ancient base level resurgences, as the limestone block was being pushed up by tectonic uplift forces.

With future exploration in Bakua sink (which is to our knowledge the longest and deepest cave in Timor-Leste) along with Biribui spring and also in other cave shafts that were located but not explored, a good chance exists of revealing a relatively large system with several km of development and up to 500 m total depth, if the highest entrances can connect to the lowest, Biribui.

In total, 20 cave entrances were registered in this area, but not all of them were explored.

4.2. Baucau District

After Maubisse, the expedition moved to the reefal limestones of the plateau of Baucau.

The team visited and mapped several caves: Lilawy Cave, a sink in the vicinity of Kairiri; Wai-lia-bere and Wai-lia-mata, two caves near Darasula that provide access to the plateau's aquifer; Lilawehú, an ancient resurgence cave near Karavela. We also spotted several caves and shelters in the escarpments near Ossowa, and visited the Baninau doline, which has a diameter close to one km. In total, 9 caves and springs were registered.

4.3. Lautém District

In this district, the team divided their time by two areas: the Paitchau range and the coastal karst near Tutuala.

The Paitchau range marks the southern limit of Lake Iralalaro. This lake, with an area that fluctuates seasonally between 10 – 55 km^2, is contained inside a very large polje, which as an area of about 100 km^2, with 406km^2 entirely contained as internal drainage (White *et al,* 2009). The water from Lake Iralalaro drains south via the Irasiquero River and sinks after roughly 3.5 km, at the Mainina sinkhole.

No resurgence is yet known and the shortest distance to the sea (in a straight line) is no less than 4 km to the southeast, over the Paitchau range. At the sinkhole, a huge pile of boulders blocks the way into a possible cave gallery. We managed to progress between the boulders for more than 20 m, but it got too narrow to continue further in.

As far as we know, the Irasiquero never dries, which is not surprising with such a wide area draining to the lake at the center. However, there are no open streams at the surface in the dry season, so all the water that streams into the polje flows underground.

Near the southwestern edge of the polje, two caves were visited: Kuronohonoho sinkhole, which has very high levels of CO_2 blocking any exploration attempt, and the Puropoko cave that carries an active stream in it. This cave was explored upstream until a boulder choke was reached. Downstream, 153 m were mapped, but once again the presence of CO_2

Figure 5. Mainina sinkhole (Photo: A. Reis)

limited the exploration. The stream inside Puropoko flows towards the Iralalaro Lake, even though the cave lies 6.5 km away from the lake's boundary.

Tutuala is probably the Timorese area with the most published cave references, due to the several archeological studies made there. The archeological sites are in general small caves and shelters, but we visited some interesting caves like the ponor Lenetulu, with 170 m of extension, 51 m depth. Its main gallery is impressive, as it is more than 10 m wide.

In both the Paitchau range and the Tutuala coast, 18 caves were registered.

4.4. Viqueque District

Only two days were spent here, in the vicinity of Ossu, which allowed us to register 5 caves. On the first of those days, for lack of a guide, the team made a reconnaissance hike up Mount Mundo Perdido.

On the second day, now accompanied by a local guide, the team went south of Ossu, and were led to an impenetrable sink, a rift cave and an open sink. The rift cave, called Kaisahe, is home to a colony of fruit bats and was explored down to -30 m, at which level the rift widens into a small horizontal passage, about 25 m long, without further continuation. The rift should be explored horizontally at entrance level (traverse line needed), but we couldn't for lack of equipment. The open sink, called Lunaha Mana, starts as an 8 m wide, 18 m deep shaft, and continues down through a series of narrow steps until reaching a larger down-sloping passage at -40 m. Although the way ahead was open, the exploration and survey were cut short due to rainfall: the probability of a flash flood was low but we just wouldn't risk it. After all, it was our first visit to the country and we were warned about how fast dry river beds change into high flow rivers in Timor-Leste.

4.5. Cave biology

During our expedition an ad-hoc sampling using direct prospection of cave invertebrates was performed. Only the cave-adapted fauna of East-Timor was studied and it is hitherto composed of arachnids, crustaceans and insects. Whip spiders (Amblypigydi), shorttailed whipscorpion (Schizomida), amphipods (Amphipoda), centipedes (Chilopoda), decapods (Decapoda), cockroaches (Blattodea) and water beetles (Dytiscidae), contribute to the troglobiont and stygobiont fauna of the country. Ongoing taxonomics study reveals the existence of new species for science. We also registered the presence of the wide dispersed species of millipedes: *Chondromorpha xanthotricha* (Attems, 1898) and *Cylindroiulus hirsutus* (Pocock, 1889) in caves of the province of Baucau and the presence of the coconut crab, *Birgus latro* (Leach, 1816), in caves of the Tutuala region (Figure 6).

Figure 6. Specimens of the coconut crab in caves of Timor-Leste (Photo: M. Soares)

5. Conclusions

In total, 50 caves, sinkholes and springs were registered in the four districts that were visited. The surface has only been scratched, in terms of speleological exploration in Timor-Leste. The data collected in areas like Maubisse, the Paitchau range and Ossu, for example, points to cave systems much larger than seen so far. Other, less accessible, major limestone areas in the country are yet to be visited.

The young speleologists of Timor-Leste will continue to gain experience by taking part in future expeditions, as the "Fatuk-kuak hosi Timor-Lorosa'e" project returns annually.

In areas like the Baucau plateau, where the aquifer lies at a very low depth, pollution is a real problem, especially considering that this aquifer is the sole provider of freshwater to the second largest city in Timor-Leste.

In a country that struggles to provide quality freshwater to its population all year round, the knowledge of caves, their underground waters and springs is indeed valuable information.

Acknowledgements

The team would like to thank the following persons and institutions, without whose help this expedition would not be possible: Portuguese embassy in Timor-Leste, Universidade Nacional Timor Lorosa'e, Universidade de Aveiro, Fundação Oriente, Vodacabo, SA, Câmara Municipal de Pombal, the UIS, the FPE, Geiza Marques d'Oliveira, Graça Viegas, Miguel Ferreira, Henrique Peixoto, Pete Talling, Fleur Loveridge, Greg Lauer, Joe Sydney, Greg Middleton, Tim Anderson, Dr. Nuno Oliveira, Raul Pedro, the people of Timor-Leste and everyone at JHN.

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Pocket valleys on the escarpments of the Nullarbor Plain, southern Australia, and their potential for palaeoenvironmental reconstruction

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Abstract

The Nullarbor Plain, one of the world's largest limestone outcrops, stretches from the Great Victoria Desert in the north towards the Great Australian Bight in the south where it ends abruptly with up to 90 m high cliffs. The two low-lying areas of the Israelite and Roe plains were formed during the cliff retreat as a result of coastal erosion in the Pliocene. The former coastal cliffs were abandoned when the sea withdrew, forming the Wylie and Hampton scarps.

This study documents previously unrecognised pocket valleys on these escarpments and uses their characteristics for palaeoenvironmental reconstruction. Initial GIS analyses were followed up by detailed field work, sampling, mapping and measuring of morphological, geological, and hydrological characteristics of representative pocket valleys on the Wylie and Hampton scarps. Rock and sand samples were examined for mineralogy, texture and grain size, and a U-Pb dating of a speleothem from a cave within a pocket valley enabled the establishment of a time frame of the pocket valleys formation and its palaeoenvironmental implications.

There are two main morphographic characteristics indicating their karst origin. They lack fluvial catchments – instead they transit suddenly into steep walls at their upstream end, and they show evidence of an underground outflow of water within pockets, demonstrated by solutional voids and caves. Three stages of their formation are proposed: (1) the early-mid Pliocene characterised by the formation of joint-controlled solutional channels predating the pocket valleys, (2) the late Pliocene characterised by commenced retreat of the pocket valleys, (3) the Quaternary characterised by reshaping of the pocket valleys due to variable gravitational and hydrological processes.

The main period of intensive karstification is placed into the wetter climates of the Pliocene epoch, as confirmed also by a U-Pb age of the flowstone. The locations of the caves indicate the palaeohydrological conditions at that time, and their relation to shallow caves on the Nullarbor Plain allow estimating hydraulic gradients and the distance of the palaeo-cliffs and related springs to the coastline. Subsequent drier climates and lowering of the watertable that followed sea-level retreat in the Quaternary resulted in the actual formation of the pocket valleys, which, combined with periodic heavy rainfall events and discharge due to impeded drainage, caused the retreat of the pocket valleys from the edge of escarpments. The pocket valleys are at present predominantly subject to slope processes and occasional fluvial erosion on their side walls and downstream ends.

Keywords: karst, pocket valley, Nullarbor Plain, geomorphology, palaeoclimate

1. Regional Setting And Methods

Nullarbor Plain is a relatively flat limestone plain and with an area more than 200,000 km^2 one of the world's largest limestone outcrops. It stretches from the Great Victoria Desert in the north towards the Great Australian Bight in the south, ending abruptly with up to 90 m high cliffs known as Nullarbor Cliffs and Baxter Cliffs. In two places, the former coastal cliff retreat was abandoned when sea withdrew, forming two low-lying coastal areas of the Israelite and Roe plains (James *et al*., 2006). These two plains rise from sea level to ~40 m inland ending with up to 100 m high Wylie and Hampton scarps.

Numerous short and steep-headed valleys occur on both Wylie and Hampton scarps, and although the karst on the Nullarbor Plain has been largely studied and described (e.g., Lowry, 1968; Webb & James, 2006; Miller *et al*., 2012; Burnett *et al*., 2013), these valleys only received attention and were firmly described as special and independent landforms by Lipar & Ferk (2015). The aim was to discover whether these might be karst pocket valleys, and if they were, what could they tell us about the karst and overall past and present environment on the Nullarbor Plain.

Spatial analysis based on digital elevation model and satellite images were conducted, followed by field-work, sampling, mapping and measuring physical characteristics of the valleys on the Wylie and Hampton scarps. Thin sections of rock and sand samples were examined for mineralogy and texture and X-ray powder diffraction (XRD) analysis at La Trobe University was used for qualitative mineralogical analysis. A flowstone sample collected in one of the valleys was dated using U-Pb method at the University of Melbourne.

2. Pocket Valleys And Associated Caves

There are three major types of karst valleys: blind valleys, pocket valleys and dry valleys (Gams, 1974; Gunn, 2004; Ford & Williams, 2007). Blind valleys form where the stream flows into the karst (disappears underground) at a point or series of points. Mechanical erosion and karst corrosion at these points result in a creation of a valley that is closed abruptly at its end by a cliff or slope facing up the valley. Sometimes aggradation buries stream-sinks and reduces their absorbance capacity. More frequent overflow then occurs and the valley is considered semi-blind.

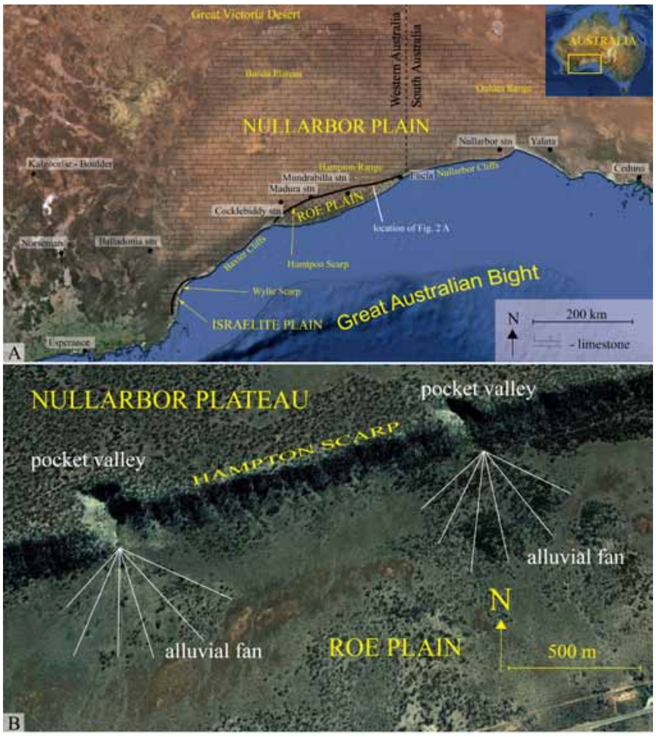

Figure 1. Location map of the Nullarbor Plain and associated Wylie Scarp and Hampton Scarp (A), and detailed satellite image of two pocket valleys on the Hampton Scarp.

Figure 2. Pocket valleys and their steep upstream ends. Collapsed cave passage of one of the pocket valleys on the eastern part of the Hampton Scarp (A); freshly exposed flowstone deposits in the pocket valley on the western part of the Hampton Scarp (B); large steep-headed walls (pocket) of the pocket valley on the southern part of the Wylie Scarp (C); a pocket valley in the northern part of the Wylie Scarp with Israelite Plain in the background (D).

Pocket valleys are the opposite of blind valleys. They are usually short with amphitheatre-like steepheads (pockets), with their formation as the result of a trigger process, which is usually the emergence of water from a karst aquifer when it can no longer flow underground, and later processes that include retreat of the valley either by gravitational undermining (spring sapping) and slumping of a slope or by irregular collapse of a cave roof above a subterranean water flow.

Dry valleys usually have steep slopes and flat floors, and are usually dry. They formation can be due to many factors, but most common is due to the legacy of a former cover of impervious rocks on limestone. Once the cover is removed by erosion, rivers cut into the limestone beneath until the drainage becomes solely underground.

Caves and impassable solutional voids were discovered in the upstream ends of some of the valleys on the Nullarbor Plain. Whilst caves are defined as natural underground openings enterable for humans (Ford & Williams, 2007), solutional voids are much smaller, yet both share the same genesis without significant differences related to size (Goudie, 2006). Fissures and cracks were found within caves, indicating joint-controlled passage formation.

Cave entrances below the steep-headed walls in the valleys on the Nullarbor Plain are in places partly or completely filled with porous to compact horizontal-laminar flowstone deposits. Recent collapses removing the younger calcrete exposed up to 1.5 m thick outcrops of flowstone.

The evidence of an underground outflow of water within these valleys, demonstrated by caves and smaller solutional voids, is one of the main characteristics indicating the karst origin of these valleys. Flowstone is also a feature for recognising karstification (Frisia *et al.*, 2000) and therefore an important element for defining a pocket valley. Additionally, lack of fluvial catchments and valley's sudden transition into steep walls at their upstream end that usually forms amphitheatre-like pockets is another specific element of karst pocket valleys.

3. Formation Of The Pocket Valleys And Palaeoenvironmental Reconstruction

Later laboratory analyses of rock, sand and flowstone samples helped us to establish three stages of pocket valleys formation and associated environmental conditions:

1. the early-mid Pliocene (~5 – 3.5 Ma) characterised by the formation of joint-controlled solutional channels (and caves) predating the pocket valleys. A speleothem U–Pb age places the initial solutional formation and deposition of flowstone in the generally wetter climate of the Pliocene (3.6 ± 0.12 Ma). The locations of the caves and speleothems clearly indicate the palaeohydrological conditions at that time and their relation to shallow caves on the Nullarbor Plain.

2. the late Pliocene (~3.5 – 2.5 Ma) characterised by commenced retreat of the pocket valleys from the edge of the escarpment by gravitational undermining, exudation and slope processes. It began with the sea regression from the Israelite and Roe plains in the late Pliocene and the simultaneous drop of the water table. Solutional formation of pocket valleys was probably enhanced by mixing-zone corrosion at the saltwater–freshwater interface. The occurrence of pocket valleys is limited to the Hampton and Wylie scarps, but caves and springs probably also occurred throughout the Nullarbor and Baxter cliffs. However, any pocket valley that may have formed along the Nullarbor cliffs would have been eroded away by the active retreat of these cliffs.

3. the Quaternary (~2.5 Ma to present) characterised by reshaping of the pocket valleys due to variable gravitational and hydrological processes. Occasional high rainfall events in the Quaternary formed alluvial fans in front of the

pocket valleys. At present, the pocket valleys are predominantly subject to slope processes and occasional fluvial erosion on their side walls and downstream ends.

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(Abstract) **Notes from the northern Nullarbor**

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Abstract

The limestone that forms most of the Eucla Basin, and is generally known as the Nullarbor Plain, is a fascinating place, not just for its karst and caves, but also for its present day topography and geomorphology, aboriginal and pastoral heritage, and the animals and plants, including far more trees than the name implies.

Members of our club have been visiting and documenting features in various parts of the Eucla Basin/Nullarbor Plain fairly regularly for nearly two decades. Although there are still plenty of discoveries to be made further south as well, for most of that time, our main focus has been around, or north of, the railway line, closer to the margins of the limestone than most cavers are looking.

We have used a variety of methods over the years to positively identify known but poorly located karst features, and to identify and document newly recognised features. Identification involves recording GPS co-ordinates and feature descriptions. These are compared with existing data from various sources including talking to local residents, careful reading of historical accounts and records, reviewing cavers' documentation, and reviewing satellite and air photo imagery.

While we have only identified a limited number of significant caves in this area, there are lots of clearly karst-related features such as blowholes, rockholes and dolines. And while the identified distribution of these features is somewhat related to access issues, it seems likely that the distribution is related to paleo-shorelines.

There are also other present-day landscape features, such as paleochannels and 'dongas' that may actually have a long and probably karst- related history too. We hope our ideas and illustrations will stimulate further research and discussion on karst development in the Eucla Basin.

Karst in Southern Bali and in Nusa Penida, Sunda Islands, Indonesia

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Abstract

Bali is a mainly volcanic island connected to an outlying southern limestone area (called the Bukit) by a sandy isthmus. Nusa Penida is a separate island to the South-East of Bali.

Both the Bukit and Nusa Penida are covered by thick Late Cenozoic limestone that is irregularly indurated.

Three main stair-like successive plateaus exist on the Bukit, the higher being to the South and the lower being to the North almost at sea level. The karst landscape is characterised by rare dolines, valleys, hills and cliffs. Lapies are not so common. No permanent river is present on the plateaus. Neither are springs. The only spring so far known is near sea level.

Caves are common but a few of them only reach a significant extension. On the middle plateau, goa Petang is a 300 m long large passage accessible through a roof collapse. A gigantic boulder pile leads to a static water level at both ends. Other caves are encountered on the plateau, either as passages a few tens of metres long or as small chambers. Marine caves are present around the Bukit, either fossil at the foot of cliffs beyond beaches or active a part of the year directly along shore.

Nusa Penida offers a similar landscape and displays longer caves, as far as it is known: goa Karangsari is a subhorizontal fossil through cave which is several hundred metres long. Goa Paon is a subhorizontal maze-like cave higher in altitude that develops around 1.5 km and Goa Sung Su is a more sloping cave near the northern shore of the island.

The paper documents surface karst and endokarst. Both show many interesting features.

Keywords: Bali, Nusa Penida, karst, cave, karst cave, marine cave, bat

Bali is a world-famous place, especially because of its culture and sea-related pleasures. Together with neighbouring Nusa Penida (Fig. 1), it also has limestone areas which are less known. They mainly show small caves, though there are exceptions. Two caves related to Hinduism have been known for a long time; a man-modified goa Arca Buddha (goa means cave in Balinese language) and goa Lawah, a cave temple which is a fossil marine cave with pillow-lavas at the entrance. Goa Lawah is inhabited by thousands of fruit-eating bats (*Roussettus amplexicandatus intumatus*; P. Strinati, 1988, pers. comm.).

Heinrich Kusch and Ingrid Staber (Kusch, 1980) seem to be the first authors to have made an approach to the karst, but only in Nusa Penida, where they explored goa Gede, on the 3 April 1977. I Made Sutaba (1980) in his book on Balinese prehistory mentions goa Selonding and goa Karang Boma, with artefacts. In 1985, C. Chabert and M. Chocat mapped goa Arca Buddha. In 1985 also, C. Mouret and Nguyen Dan De Dung located goa Apetaungan (Mouret, 1994), goa Karang Borna and goa Selonding. From 25 October to 1 November 1986, C. Chabert and C. Mouret, with N. Boullier, mapped the caves already located and others, known by the author from Eisemann's book, or from talks with locals. They also visited Nusa Penida and mapped goa Karangsari (Giri Putri) and the entrance part of goa Paon. A second trip of C. Chabert and C. Mouret took place from 6 to 13 February 1988, up to 19 February for the author (Mouret, 1997; Mouret, 2009). Indonesian cavers from FINSPAC and from Denpasar Speleoloji Club (DSC, Bali) joined the team: Farid Amanta Patria, Fathoel Arifin Rachman, Juda Surja Putera, Siek Liang Swan, Winarto, L.B. Bumiputera, Jedi Supriadi, Lalu Sandi W., and Nyoman Suwena, from Sawangan.

At the time, DSC cavers had explored, but not mapped, some of the caves, e.g. goa Petang in 1986 and the entrance to goa Paon in 1987. We showed them the caves they did not know yet. They showed us goa Lawah in Suluban, Bali, and Song Su in Nusa Penida.

Pierre Strinati and Villy Aellen, from Geneva's Museum joined the team but focused on fauna in the two goa Lawah (namely cave of Bats) (Mouret, 2003). Turkish cavers also joined for a quick visit.

No doubt that since then, Indonesian cavers have continued explorations.

1. Climatological and geological background

Rains are moderate in the South and much higher on the slopes of mountainous mainland Bali. Temperatures are very high and fit the subequatorial location of Bali and Nusa Penida. Accordingly, evapotranspiration is higher in the South, where more xerophytic vegetation develops on limestone areas, though it may become very green during the rainy season. Rivers flow mostly during heavy rains. All is in contrast with luxuriant Bali mainland. Details are shown in Table 1.

Limestone is present in the southern part of Bali, where it forms the Bukit ("The Hill", also called Bukit Badung, Eise-

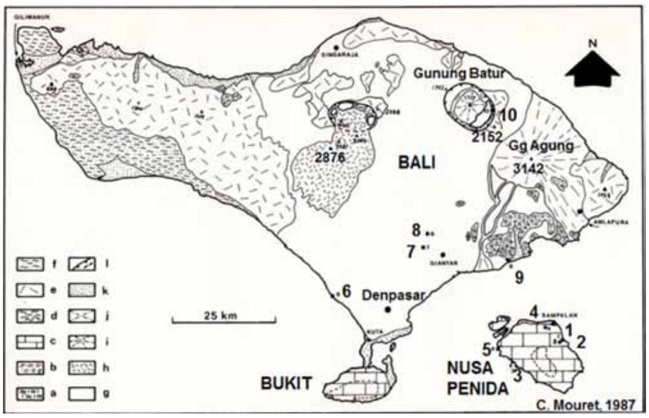

Figure 1. Geological formations of Bali and Nusa Penida. They are named « a» to « l », from the older to the younger one. Most of them are volcanics or volcano-sediments, from likely Lower Miocene to Present. The bulk of limestone (c) belongs to the Mio-Pliocene Selatan Formation. Some limestone is also present in the possibly Pliocene Prapatagung Formation (d). The caldera of Batur is shown to the NE, as well as Agung volcano. Both of them are fully active. Geological and hydrogeological data derive from Purbo-Hadiwidjojo (1971, 1972, 1978)
Numbers refer to caves (goa): 1. goa Giri Putri ; 2. goa Paon; 3. Karst spring; 4. Song Su; 5. Gigantic shaft with sea water; 6.goa Tanah Lot; 7. Goa Arca Buddha; 8. Goa Apetaungan; 9. Goa Lawah; 10. Goa Trunyan. Caves on the Bukit are located on Figure 2.

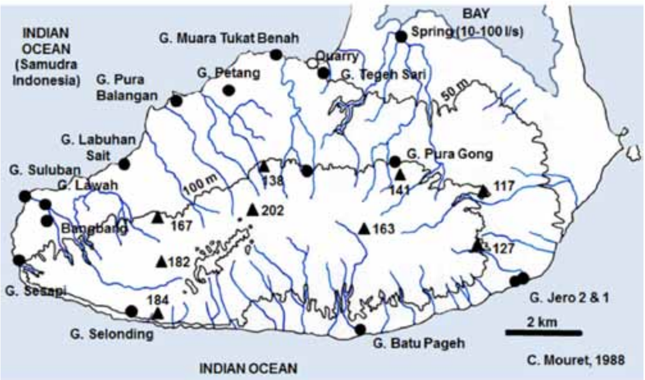

Figure 2. Bukit elevations (m ASL), rivers and caves. Triangles: summits; dots: caves.

mann, 1986) and in on-trend Nusa Penida. Limestone is usually poorly compact and very porous. It can even be very soft: in the virgin part of goa Petang (X-Y, Fig. 4), collapsed boulders lying on the floor (Fig. 2) were falling into powder when stepped on. However, in a number of places, limestone may be well cemented, much less porous and resistant. This is the case where karren are present, or below some river beds, also along some fractures. Small caves may show indurated wall rocks. Harder rocks correspond to places where they are in contact with meteoric or underground water. Limestone intervals with very large bioclasts are usually compact but no cave in them has been found so far.

Bukit Badung and Nusa Penida display large scale terraces (Fig. 1 and 3). On the Bukit, steep slopes most often between 100 and 140 m a.s.l. largely surround the upper terrace. Elevations seldom exceed 200 m and the terrace is moderately carved by erosion. The middle terrace is bounded by steep slopes between 5 and 50 m a.s.l. The lower terrace is just above sea level and progressively passes to mangroves and mud flats along central bay.

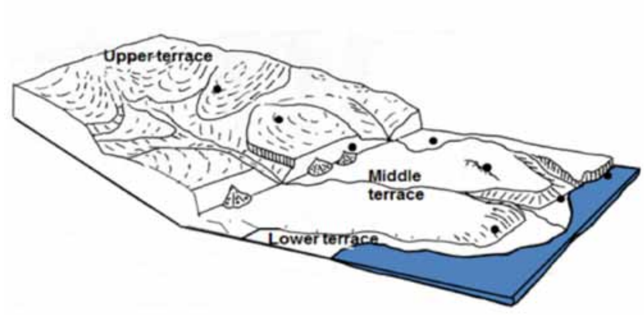

Figure 3. Sketch representation of the three terraces on the Bukit with setting of some cave locations. North broadly to the right.

Figure 4. Cave roof collapse created the entrance to goa Petang, on the middle terracve of Bukit. Vegetation is xerophytic, but some big trees are present. Local people use this way to collect their drinking water at the bottom of the cave.

The southern and western edges of the Bukit have been significantly eroded by Indian Ocean. Cliffs higher than 100 m and slopes higher in elevation reach up to the upper terrace. Slopes are gentler to the East and Northeast, and show remnant hills. The lower terrace is present only on the north-eastern side of the Bukit.

Table 1. Rainfall depths (intensity), temperatures and relative humidity in karst areas of Bali and Nusa Penida.

Data	RAINFALL DEPTH					TEMPERATURE (°C)		HUMIDITY, REL. (%)
Place	Ngurah Rai		Besakih		Sampalan	Ngurah Rai	Besakih	Ngurah Rai
Use	Bali airport		Major temple in Bali		Nusa Penida	Airport	Temple	Airport
Elevation a.s.l. (m)	5		1000		5	5	1000	5
Period	1972-1981		1976-1982		1975-1980	1972-1981	1976-1982	1975-1980
Units	Days	mm	Days	mm	mm	°C	°C	%
PER YEAR	126	1725	150	3047	1175	30.3	26.4	75.3

In Nusa Penida, terraces are higher in elevation. The upper one culminates at 529 m ASL and dips towards the South-east. It is bounded by slopes at between 300 and 500 m ASL to the NE and between 200 and 400 m ASL to the SE. The middle terrace is bounded by steeper slopes between 0 and 200 m ASL, to the NE. To the SE, South and West, there are high cliffs generated by oceanic erosion. The lower terrace is a narrow strip of land on the northern side of the island. Correspondence between terraces on both islands is not straightforward.

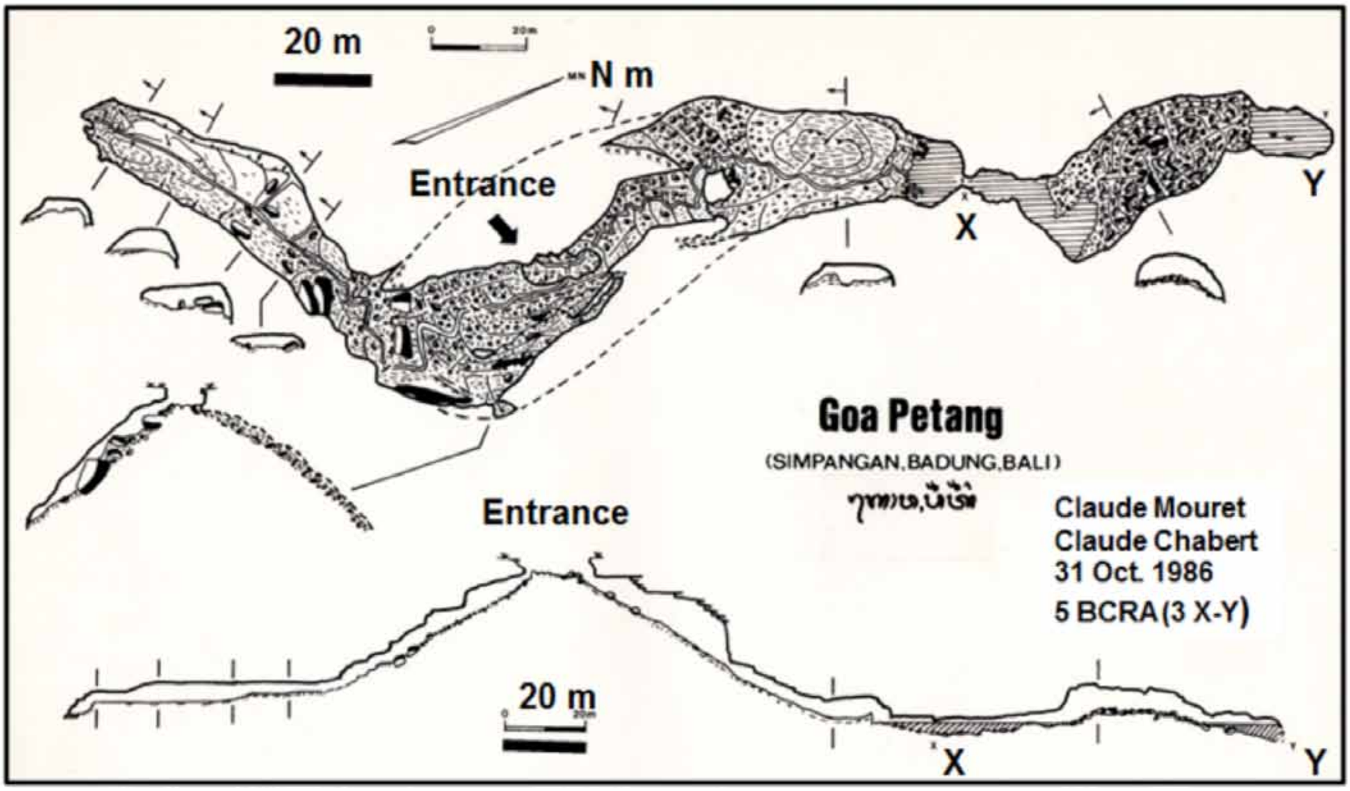

Figure 5. Goa Petang. Bottom water is at phreatic level.

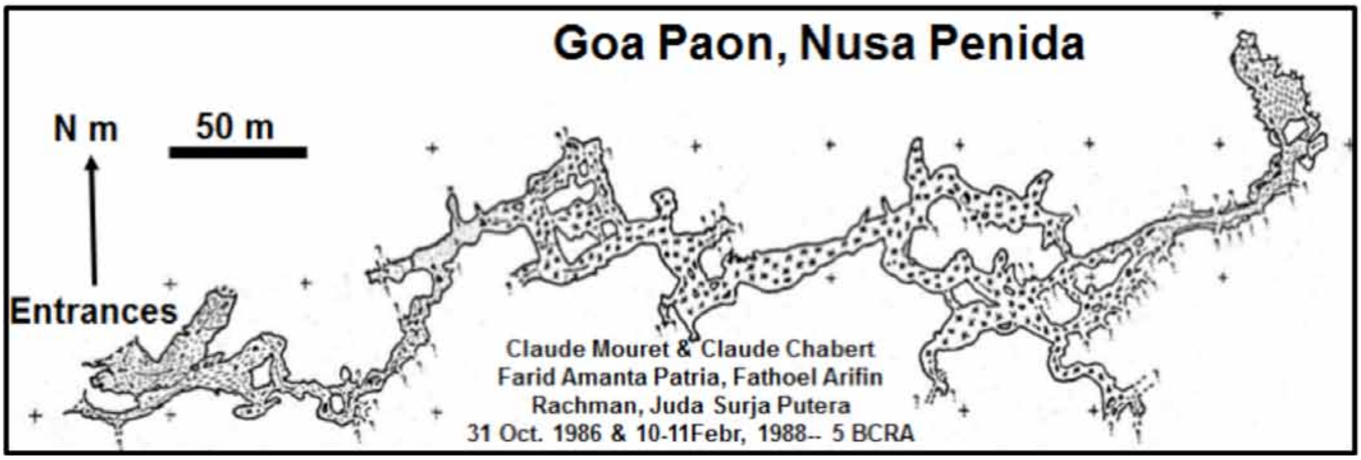

Figure 6. Goa Paon. Stars represent guano. Nearly 50 question marks are shown on the map.

2. Karst landscapes

The karst is fluviokarst with radial valleys which cross the steep slopes and cliffs around the terraces through narrow valleys and gorges. They flow into large open valleys on the next lower terrace plateau, then deepen again near its edge. In sea cliff areas, longer valleys often abruptly incise the cliffs through deep, steep, gorges, the bottom of which may be flooded at high tide. Shorter river valleys either get deeper near the sea or show waterfalls during the rains; their stream may also enter narrow shafts and reappear at some elevation in the coastal cliff (goa Labuhansait). On the lower terrace which gently dips seaward, rivers may follow minor talwegs.

Dolines seem to be very rare. A cenote-doline, named Bang-bang, lies to the extreme West of Bukit. Perhaps, some man-built cisterns have been built in (and therefore hide) such small dolines, but this remains to be confirmed. Cone-karst is usually present along the eroded edge of terraces. Low relief tower karst is present at a small scale, especially near higher elevations on the western tip of Bukit.

Soils are mostly thin to very thin, with pocket-like thickenings. They are commonly mixed up with subrounded to rounded pebbles or cobbles. Bare rock is often apparent, but on small areas only. Karren are rarely well developed et seldom exceed one metre of elevation.

In Nusa Penida, we observed only the northern part. However, radial valleys are present and show the same adaptation to terrace features as on Bukit. The valleys have cut through older, formerly phreatic, caves. Near the West coast, there is a large shaft with sea water at the bottom, which is well visible from plane. In the cliff to the South, a large spring flows out of a passage, according to Balinese cavers, but there are more springs. We refer to Kusch (1977) for a detailed description of the surface karst.

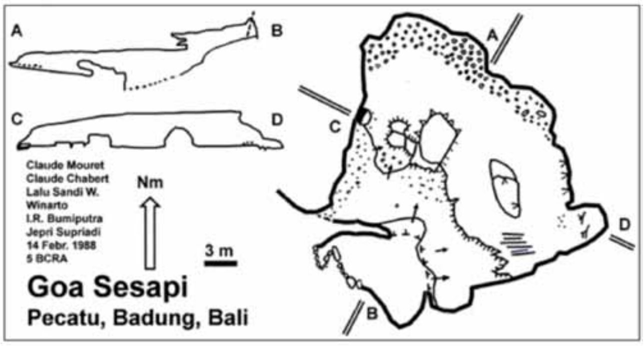

Figure 7. Goa Sesapi

3. Underground karst

Caves are mostly short. On Bukit, goa Petang (Mouret, 2005) is the longest cave and is located on the middle terrace. It is 340 m long and 42 m deep. It consists of a large single passage largely filled by boulders fallen from the porous rock of the roof. It shows water pools at the base of the large entrance boulder pile. It is a beautiful cave, though it has been completely darkened by smoke from oil lamps and torches of many water collectors. Beyond “X” (Fig. 5), the cave was virgin and completely white, with no speleothems.

Goa Petang is the only cave where we saw water. No karst circulation is known on the Bukit and springs are or seem rare. One was mentioned by Purbo-Hadiwidjojo (1972), with a flow between 10 and 100 l/s (Fig.2). Around the beginning of the 1980s, a narrow passage (1x 0.5 m) with water (full?) was incidentally opened in a quarry (Fig. 2) located to the North near the tombolo connecting Bukit with mainland Bali. It was still visible in 1988 but did not flow. No submarine spring was reported to us; however, freshwater has to exit somewhere.

Some fossil caves (Fig. 2) are opening in cliffs, either coastal (goa Selonding, 16 m long, at + 150 m in South cliff, goa Batu Pageh, 26 m long, at +40 m) or along terrace edges like goa Pura Gong or goa Tegeh Sari 1 and 2, which are respectively 15 and 46 m long, at elevations of 45 and 40 m a.s.l.). Fossil caves also open in canyons (goa Lawah in Suluban, 21 m at +50 m) or in valleys (goa Karang Boma, 52 m at + *ca* 120 m, with a chimney open to the sky at the end). All these caves are former phreatic passages, as indicated by rounded shapes and cupolas at the ceiling. At goa Lawah in Suluban, there are also cylindrical cupolas, much higher than large, associated with underlying potholes (up to 0.4 x 0.4 m) which are due to floor corrosion by manure from bats in cupolas. Speleothems are present, though not abundant, as stalactites, stalagmites and flowstones. In goa Batu Pageh, there is a 4 m high pillar.

In Nusa Penida, the longest known cave is goa Paon (Fig. 6), explored over 1.5 km but still ongoing. It opens at 60 m a.s.l. It is a maze of phreatic passages, which has been cut through by a valley. Late vadose incision is visible in some parts. It is overall a subhorizontal cave, though three levels in elevation can be observed in the detail. The middle level makes up most of the mapped part. The section of the passages is simple, overall low and large, with a shape from half-a-cylinder to a surbased arch, the latter probably along less resistant limestone layers. The end passage to the Northeast is higher. Between it and the western end of more than 30 cm-thick guano deposits (stars on Figure 6), passages are broadly at man’s height, meanwhile crawling is necessary to the West of the guano. There was

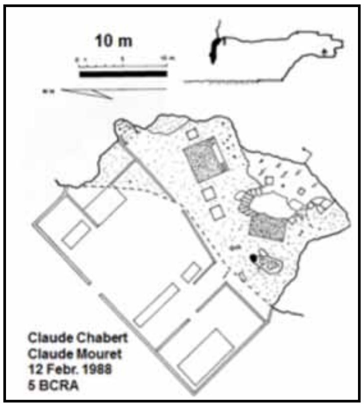

Figure 8. Goa Pura Balangan.

almost no bat when we explored these parts in 1988, but a big python was closing the way (for a while!) in a narrow section near the entrances. Speleothems are rare and located almost only in the larger part to the NE of the map. We found the cave to be apparently unexplored after a distance of 150 m from the entrance.

Goa Giri Putri in Karangsari is a large subhorizontal fossil through cave between two valleys. Openings are at +36 m a.s.l. and nearly chocked. Some side passages seem to lead to lower levels. We (C. Chabert and C. Mouret) explored and mapped the cave on 28–29 October 1986. Total length is 527 m and difference in elevation is 12 m.

Song Su is a sink point in a temporary flowing talwegs. The entrance is a large vault, which is low because of collapsed boulders. The cave consists of a large void, half-cone-shaped with a horizontal axis, and filled with very big boulders. It ends on a very low flat passage at 5 m a.s.l. Song Su is 79 m long and -21 m deep. Goa Gede is a spacious fossil cave located at +185 m a.s.l., explored by Kusch (1977).

4. Marine caves in limestone

In Bukit, two marine caves are present on the western coast, on the Indian Ocean. Goa Sesapi (Fig. 7) is hardly reached at low tide (and closed with metal bars and a lock): it shows almost smooth bare rock with some cobbles and some sand. Goa Pura Balangan (Fig. 8) is now higher than present-day sea level and it sheds a Hinduist temple.

5. Conclusion

This brief presentation shows interesting karst features in an unusual setting. The combination of marine terraces at different elevations, probably the result of crustal deformation along the Sunda Arc, the associate morphology and the caves make up a rich subject. We are planning to return there for more studies.

Acknowledgements

While writing this paper, nice explorations with late Claude Chabert and with Nicky Boullier came again to author’s mind. Many thanks to them. Many thanks also to the friendly Indonesian and other cavers.

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Flank Margin Cave Development and Tectonic Uplift, Cape Range, Australia

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Abstract

This extended abstract is a summary of a recent complete paper (Mylroie *et al*., 2017); as the 17th International Congress of Speleology is being held in Australia, the Congress participants are alerted by this abstract to the paper's existence. Cape Range, Australia, on the northwest coast of the continent at 21 °S, 113 °E (Fig. 1), is a NNE striking anticlinal ridge 315 m high, 100 km long, and 20 km wide extending into the sea, consisting of Miocene carbonate rocks with a series of coastal terraces of Pliocene and Quaternary carbonates and siliciclastic dunes.

Inland escarpments representing former sea cliffs, and deep valleys cutting the limbs of the anticlinal ridge, host many cave entrances at a variety of elevations (Fig. 2). The lowest unit, the Mandu Formation, a chalky and marly limestone, contains many tafoni (pseudokarst) caves with simple, single chamber plans and widths up to 15 m or more, and heights up to 10 m (Fig. 2a). The higher, purer Miocene limestones, and the younger Pliocene and Pleistocene coastal terrace limestones, host numerous flank margin caves from 300 m elevation in the Miocene rocks (Fig. 2b-d) to sea level in the Quaternary rocks. Classic epigene stream caves are also found. The flank margin caves have entrances up to 30 m wide and heights of 6 m, with single chamber caves being common but complex chamber caves also present. Some flank margin caves are entered by small entrances that lead to large phreatic chambers, which eliminate both sea caves and tafoni as possible explanations (Fig. 2c).

The close association of these caves with sea cliffs and incised valleys argues against a deep hypogene origin, which would leave a cave pattern unrelated to the surface configuration. Miocene uplift tapered off in the Pliocene but was still active in a subdued manner in the Quaternary. The flank margin caves in the paleo sea cliffs and incised valleys represent the outcome of the interplay of that tectonic activity and glacioeustasy over a 300 m vertical range, with lowstands causing valley incision; highstands raised the fresh-water lens and allowed cave development in the valley walls. Cave development began with the first tectonic-driven subaerial exposure in the Miocene and continued through to the last Pleistocene interglacial.

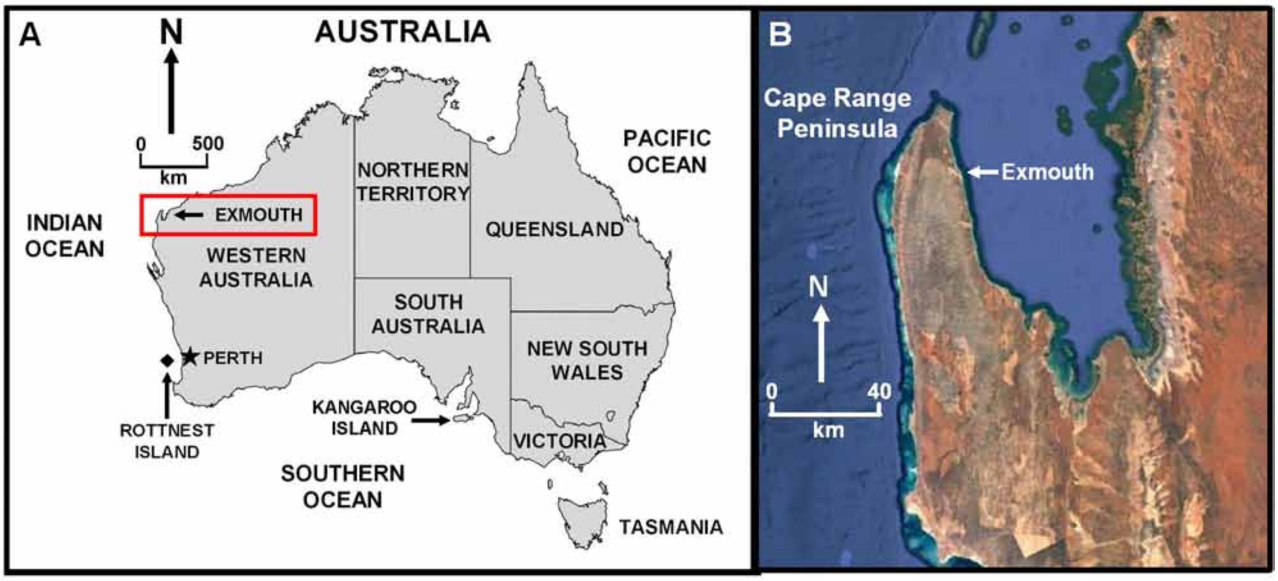

Figure 1. Figure 1: A) Location of Cape Range and the town of Exmouth in Australia. B) Google Earth image of the Cape Range Peninsula; the anticlinal axis runs approximately north-south along the middle of the peninsula.

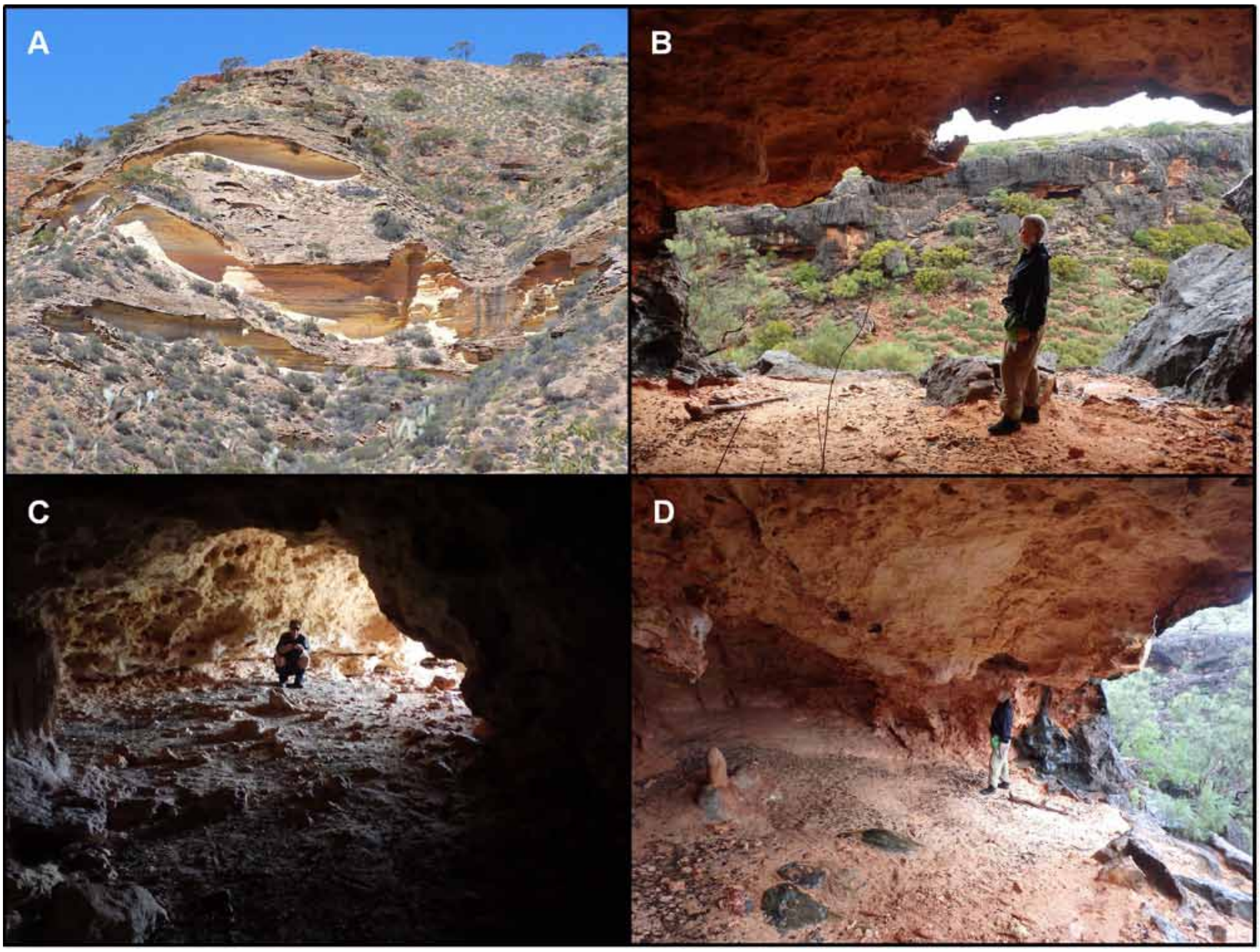

Figure 2. Figure 2: Caves in Cape Range. A) Tafoni in the Mandu Formation. B) A flank margin cave entrance at ~100 m elevation, on the wall of an incised stream channel; entrances to flank margin caves can be seen on the far wall of the valley. C) Large flank margin cave chamber entered from a small entrance, indicating it is a dissolutional cave and not a tafoni or sea cave. D) Another view of the cave in (B), showing speleothems and a ceiling with dissolutional pocketing.

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Eastern Australian Karsts and European Karsts: Some Comparisons

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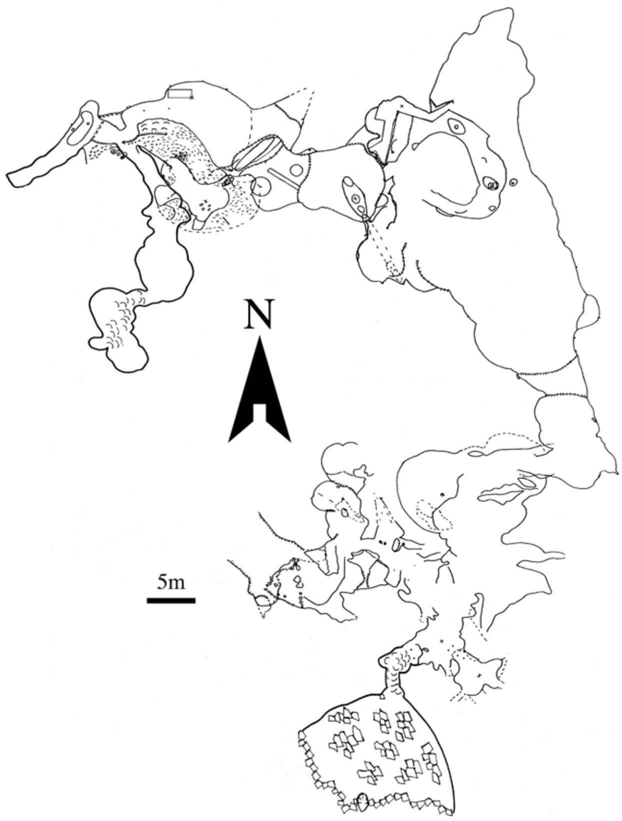
Abstract

At this first UIS Congress in Australia and the second in the southern hemisphere, we should consider the similarities and differences between the karsts of Pangaea and those of the Gondwana fragments. As we are meeting in Sydney, the karsts of Eastern Australia are used for comparison.



The first point for comparison is bedrock age, type and karst size. Eastern Australian karsts are almost all developed in high purity, Palaeozoic limestone. Dolostone is rare, and salt and gypsum beds are unknown. The karsts are generally small north-south trending bodies impounded by insoluble rocks. There is no Mesozoic limestone in Eastern Australia and the limestone is folded, most by multiple events. Dolines are not abundant, except in Tasmania, which due to its wet climate, large area of limestone, and high relief has karst features more like those of the Classical Karst than anywhere else in Australia. These include: abundant dolines, open active ponors, a valley that looks like a polje and a hum.

While your Alps are going up, we are crashing into New Guinea. There is some neotectonism, but the last big uplift was 90 Ma ago and the last folding in the Early Carboniferous and Permo-Triassic. Consequently old features survive here and some caves have Palaeozoic origins. The continent as a whole is flat, mostly less than 300 m high. The Eastern Highlands, including the snowfields, is a system of eroded plateaux, not mountains, despite what the tourist guides say.

Water is scarce, except in Tasmania and the coastal strip. Our largest river usually doesn't reach the sea. Once covered by rainforest, Australia's move northwards and global cooling turned the once green continent brown, and schlerophyll fire-resistant species became dominant. The Pleistocene in Australia was dry; forests shrunk to small refugia and salt-bearing red loess blew eastwards, cloaking the land and filling the caves.

Eastern Australian caves are small, most less than 2 km long and 50 m deep, and show a high degree of structural guidance. Cave streams are small and mostly ephemeral. Many caves have neither ponors nor springs. Some caves intersect static water tables, while others are completely dry. The best known caves in Eastern Australia; Jenolan, Wombeyan and Yarrangobilly are complex multiphase-multi process caves developed in the incised zones on the sides of the Highlands. These caves intersect palaeokarst and began as hypogene systems, later overprinted by phases of paragenetic and fluvial development.

Caves of the Nullarbor – Their nature and setting.

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Abstract

The more famous deep caves of the Nullarbor are actually uncommon. The typical Nullarbor cave is short, shallow and present in thousands. Examples for this paper are from South Australia only, near the coast but beyond timbered ground. The plain appears little modified from its inferred state at the finish of Nullarbor Limestone deposition; an idea supported by the survival of fossil shorelines at the inland margin of the plain; notably the Ooldea Range. Their presence constrains what can be allowed for later erosional lowering of the plain. The donga areas, which are closed depressions, are incised some 5m below the net of rises surrounding them. They are usually aligned features some and possibly all following structural trends. Extra general lowering is indicated by breccia clasts in fossil cave fills that are not Nullarbor Limestone and come from strata that no longer exist. At present there is buildup of a windblown dust and calcrete cover studded with float blocks. Enterable caves develop from breaching of a cupola topping an aven made up of ellipsoidal swellings. The smooth form indicates development under phreatic conditions with a water table above the present surface; so the caves are fossil features. Once the breach is made there is space to put the cover materials away and a doline develops through stripping of cover down to limestone pavement. The cave then tends to fill up with sediment, it does not to grow in response to modern water input. If a suitable seal develops a cave converts to a rockhole and holds water. Where a cave is small but more than just a shaft entry, passages with smoothly rounded phreatic-style forms can be followed a short distance before degenerating into spongework or anastamosing tubes. It is common to have remnants of earlier episodes of cave development such as wall pockets with miniature cave scenes and breccia-filled former caves truncated by the solution-style or break surface of the present cave. In the case of larger caves more broken rock is present tending to the form of the deep caves; arch sections with an up-and-down central hump of broken rock. But in these caves there is evidence for solutional attack on the actual fallen blocks and of a crystal crust shed prior to the water table dropping away.

Keywords: Nullarbor, caves, fills, surface.

1. Introduction

The Nullarbor Plain is a surface feature covering most of the Cenozoic Eucla Basin (carbonates) and the Cretaceous Bight Basin (clastic sediments) beneath it. The crystalline basement can be as much as 700m below sea level and though rising away from the coast is still around 100 m below sea level North of the railway line (Hou et al 2008).

To the South the boundary of the plain is present-day sea cliff linked with stretches of fossil sea cliff a short way inland. Eastward from Head-of-the-Bight a dune-field progressing eastward from that source marks the boundary. To the North there are fossil shoreline features, extraordinarily well-preserved of which the latest (the Ooldea Range) is probably the shoreline for Nullarbor Limestone deposition (mid Miocene) behind the shoreline barrier there are coastal lagoon features which tend towards circular lakes and even the former outlets through the barrier dunes are discernible. A complication is that commercial beach sand heavy mineral deposits which have been related to the Ooldea Range are considered a lot older. Once inland of the beach ridge zone the Eucla Basin deposits transform to mostly non-marine in valley fills with a lot of lignite. For most of this Northern boundary the fossil shorelines are at a consistent height (c 260m) but the old shoreline becomes lower as it curves back towards the coast. Some tectonic shift is involved not necessarily very much. There are fossil watercourses extending on to the plain and one of these has a segment that now goes up hill (O'Leary et al n.d., Scheib et al 2016).

The Nullarbor's reputation is as a flat and treeless limestone plain, devoid of watercourses, and with numerous caves. All points which require some qualification to fit with reality.

Figure 1. This is a representative sample of the Nullarbor from East of Cook Road. The NE trending feature is a former drainage line, the NNW trending grain of the country is probably a structural control (joint pattern) influencing the spacing and orientation of the dongas. Image from Google Earth

2. Flat

It is without the kind of dry watercourses which would be expected in a non-limestone terrain in a similar climate; but the name is actually Latin though it looks like an aboriginal word. The flatness is such that a person standing can perceive curvature of the horizon, but totally flat it is not. There is a karstic alternative in the form of alluviated flats, always closed depressions (locally termed dongas). These are incised a few metres below the surrounding country which makes up a continuous net of rises. The vegetation differs with the dongas favouring herbs and saltbush and the rises favouring bluebush. The ground marginal to the dongas has a slight slope and here are also bare claypans which hold water after rain, also slightly incised into the landscape and typically with small raised rims edging their temporary beaches. They are considered to be deflation hollows. Their vegetation is also distinctive favouring emerald-green samphire. (Figure 1)

3. Treeless

Significant areas are treeless but towards the coast is a mallee eucalyptus forest/woodland inland from coastal heath. Further inland is a patchy acacia woodland "mulga" of which much is just dead sticks. This vegetation community fades out northwards. Patches of rock outcrop, virtually all associated with cave/doline features have other tree species as well.

4. Limestone

Bits of limestone can usually be seen at the surface but this is float and not in situ Nullarbor Limestone outcrop. The default surface material is a pinkish silt below which there is a distinct concretion layer grading to a solid calcrete. The growth of this material in various joints in the limestone bedrock has detached blocks. It is this unit that makes up general the Nullarbor surface. What is known about this surface cover comes from exposures related to cave entrances.

5. Caves

As an initial classification, there are "deep caves" and by default "shallow caves"- less than 30m or so deep. The more celebrated deep caves ideally reach the water table, have large collapse doline type entrances leading to wide passage with rock fracture walls, floored with broken rock forming a central hump and going up and down until the passage terminates either as a level wash area or a lake. Divers records show extensions of the order of kilometres. Only nearing or below the water table is there evidence for solutional attack on the limestone and not universally. The implication is that the caves developed mostly below modern sea level and stoped upwards to their present position. There are not many of them; maybe 30.

The shallow caves are mostly simple blowholes, so-called because of the strong draughts found at the entrance. There are thousands of these. Then there are larger caves with at least a cavern of sorts; not necessarily with headroom. There are some hundreds of these e.g. N 85, Fig 2). There is just one extensive cave with several kilometres of passage: Old Homestead Cave. What they have in common is wall sculpture of rounded-off forms indicative of solutional attack in phreatic conditions even at the entrance. Break surface and centreline rockpiles occur more frequently with bigger caverns. Even so, there are examples of rounded-off form on the rockpiles. The implication is that these caves with the rockpiles in them are all ancient features developed with a water table above the present surface. In VSA work on the SA portion of the plain a zoning of cave types has been noticed with a Northern belt of numerous small blowholes, a gap; then a Southern belt with fewer but larger caves (Burnett et al 2013).

An example of one of the more substantial caves as found in the more southerly belt of entrances. There is an extensive caprock pavement around the doline (not shown). The doline is interpreted as a collapsed cavern. The daylight hole is typical of a blowhole entrance. The floor is mostly washed-over,

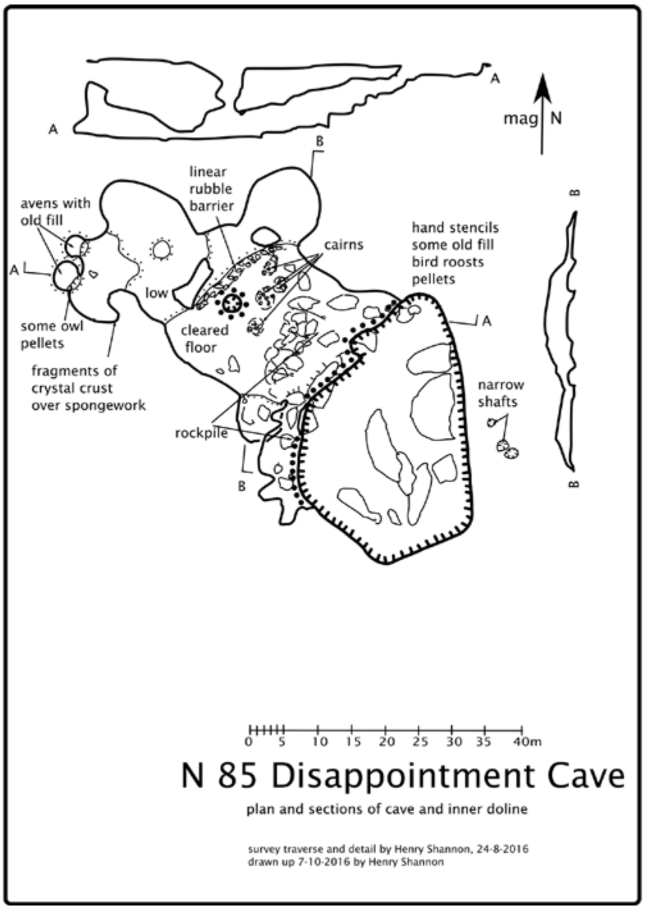

Figure 2. Disappointment Cave (N 85)

from occasional storm runoff. The cairns resemble others attributable to prehistoric work but in this case may relate to rabbiters camping underground with need for a clear floorspace. The hand stencils would be prehistoric. In the area of the far end avens there is exposure of palaeokarst breccia fill and the surface is modified by flaking-off of rock chips with some degradation to powder; both forms related to rock shelter type weathering activity. Nearby some original surface survives with a crystal crust attributed to a change to calcite-saturated groundwater as the phreatic stage of the cave was ending. Under subaerial conditions a pug develops under the crust which can then peel off. Bird roosts with pellets produce drifts of guano/earth with abundant small bones.

For the simple blowholes each cave will start (and can end) with a vertical bit; where the original form survives it is a stack of ellipsoid swellings aggregating to a shaft. For even the smaller caves mostly there is some horizontal development and where washed-in sediments do not obscure things the passage goes to a complex of small domes and narrowing shafts with spongework. With increasing size there is a roundish cavern and central rockpile, with sometimes extensions as winding galleries with up-and-down floor. Most entrances have developed from a breach of a cupola topping the stack-of-ellipsoids shaft. Consequently a doline of sorts develops as the cover materials go down the hole exposing a caprock of bare outcrop surrounded by slopes with loose boulders and calcrete. If the cave becomes sealed a rockhole can form; essentially a blocked cave with associated hard catchment that collects and holds water. If the initial larger cavern breaks down a rock-cliff doline develops with shelter caves in undercuts (Fig. 3).

Figure 3. A blowhole entrance N4626. In this case the calcrete surround has begun to open out into a doline form. The inner hole is partly in fully-lithified breccia (note the dark grey clasts towards the centre of the image). The beginnings of a caprock surrounds the hole. Inside the hole a flange is visible between two of the swellings that make up the stack-of-ellipsoids style shaft.

Most of the caves are developed in a mix of Nullarbor Limestone and various palaeokarst fills, not simply in the Nullarbor Limestone itself. The older caves now filled with breccia seem to be like the present ones. The breccias are of four generations at least. There are also travertine deposits with stalagmites, deposited in airspace which have been buried in horizontally stratified travertine likely deposited under water. The rounded-off phreatic style wall surface cuts across fills and Nullarbor Limestone without distinction and include Anastamosing tubes and spongework are universal and are responsible for the strong draughts found in most of the caves. The oldest travertine deposits (always dark) occur in small pockets cut across by the cave walls. Generally larger travertine deposits; flowstones and the like have formed inside the present caves and are old features usually broken, but are deposited on the cave walls.

The oldest? Of the lithified fills has been found in just one cave (Footprints Cave N4745) (Fig. 4) the clasts within it look like bones of a large animal but are actually concretions developed around roots, of the form common in dunes associated with coastlines (pseudofulgarites). The exposure in the ceiling of Footprints Cave is of the order of 20m across which is large for a pipe fill feature, so it may have been an open sinkhole collapse. There is a smaller pipe within it, which contains dark grey limestone clasts. Both forms are fully lithified.

The breccia fill with the big and abundant dark limestone clasts is a common feature found in lots of caves and usually seems to be later than pink-matrix breccia with either no dark grey clasts or fewer and only small ones. Since none of this material is seen as bedded rock in any cave section it would seem to have been in strata that were originally present above the Nullarbor Limestone and have been stripped off. The present open caves are the last in a sequence of earlier caves that have been filled and re-excavated in more-or-less the same sites. There are also flowstone remains in the fill which are truncated by smooth surfaces that cross uninterruptedly to Nullarbor limestone.

Figure 4. A ceiling in Footprints Cave (N 4745). The breccia with large grey limestone clasts is a pipe structure inside a much larger pipe (pale brown overall), with clasts that resemble bones but are actually concretions built up around roots. These are typically found in coastal dune deposits. They are not well shown in this picture but there is also a winding feature a filled in anastasmosing tube. Nothing like coastal dunes exists at the present surface and neither does the dark grey limestone as bedded material, but as float it is common in the claypans.

Figure 5. In this image layered travertine and some breccia (without grey clasts) fills an earlier generation cave and is cut by solutional surface of the existing cave wall. The horizontal bedding is thought to have formed underwater

The claypans normally have scattered pebbles left behind as the dust deposit is blown away. Nearly always there are some of the grey limestone clasts, a rock type never seen as in situ bedded strata but common in cemented breccia fills. So the filled caves of earlier generations appear to be a lot more common than present day open caves. Other "foreign" rock types found in the claypans are "bubbly chert" worked flints and tektites. Tektites are found almost only in the more northerly cave belt.

6. Sand

By and large the Nullarbor has dust cover instead of sand. Dunes typical of inland Australia commence at the Ooldea Range and relate to that feature as a sand source. Exceptions are sheets related to stream inputs to the plain such as Serpentine Lakes and beach related sand extending from Head of the

Figure 6. The base of the entrance pitch of Devine Cave N5203; note the similar corrosion style of the ceiling and rockpile boulders, indicative of solution under phreatic conditions. This cave is of interest because after entry a rising crawlway can be followed to a very large cavern in which mummified remains and salt formations are found.

Bight. Marginal to this zone there are a few low dune ridges of yellow sand, considered to post-date the dust accumulation. But some caves and sinkholes contain a red sand which would appear to be preserved inside the present generation of caves from a general cover that was removed prior to the present surface of windblown dust and calcrete.

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Biospeleology, Evolution, Ecology and Problems

(Abstract) Karstic Cave: Life and Soil Environment

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Abstract

To completely understand a cave system, we have to characterize and understand the relationship between the geological, geometrical, physicochemical and biological properties. The main objective of this study is to characterize two caves in the North Coast Karst Belt Region in Puerto Rico. The caves were Efraín López and Ángel Matos in the municipalities of Isabela and Arecibo, respectively. The geological properties provide us with information for the speleogenesis of the cave; this can be found from a literature review of the region. The geometrical properties consisted on the digital cartography of the cave in which the path, area and volume can be calculated using caveGEOmap. The geophysicochemical properties consisted on the chemical composition and properties of bat guano droppings (soil environment) that can be used to understand the mycological settings for guanophillic fungi and mesofauna. The abiotic parameters for this study, to understand the guano as an ecosystem, were the nutritional content (organic matter), water content and pH were measured. The geobiological properties consisted in characterization of the macro- and meso- fauna of the cave by catch-and-release and traps. Although the abiotic parameters measured are indirectly indicators of fungi and bacteria, our study found that the mesofauna abundance and diversity are direct indicators of pathogenic and opportunistic species that can affect the human health.

(Abstract) Water Quality Evaluation of Chimachida Rimstone Pools in Akiyoshi Cave, Japan, Using Physicochemical and Biological Index

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Abstract

Among the previous studies about Akiyoshi Cave, the greatest cave in Japan, most of them surveyed water quality from the perspective of chemistry and physics, whereas few studies proposed a biological index. Chimachida Rimstone Pools are one of the popular tourist spots in Akiyoshi Cave, and are habitats of various subterranean animals such as Pseudocrangonyx shikokunis, troglobitic amphipods, and Gammarus nipponensis, troglophilic amphipods. It is important for preservation of the cave ecology to study subterranean animals and discuss the habitat capability based on quantitative data. The objective of this study is to evaluate the water quality of Chimachida Rimstone Pools in terms of chemical, physical, and biological index. We measured water temperature, pH, dissolved oxygen, alkalinity, total nitrogen, total phosphorus, chemical oxygen demand, the habitat density of Pseudocrangonyx shikokunis and Gammarus nipponensis, total bacteria, and total viable bacteria. The survey was repeated four times in order to observe seasonal changes; in November 2015, February, May, and August 2016. As a result, Pseudocrangonyx shikokunis, which prefers to inhabit water with low content of organic matter, was confirmed in the pools that they would not have existed in the 1970s; thus, the current water quality of Chimachida is better than that time. We concluded that water pollution has not continued, based on the facts that dissolved oxygen was almost saturated, and total nitrogen, total phosphorous, chemical oxygen demand, total bacteria, and total viable bacteria showed low values over the seasons. Therefore, Chimachida Rimstone Pools have an ideal living environment for subterranean animals.

(Abstract) Disturbance caused to cave-roosting bats during ecological monitoring: implications for researchers and cavers

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Abstract

Cave roosting bats are highly susceptible to human disturbance with the potential for significant impacts on population numbers and viability. Ecological monitoring is essential to determine status and population trends, however it is critical that this monitoring does not have unintended negative impacts. Short-term disturbance to roosting bats can be readily apparent, however, long-term impacts from people entering caves is more difficult to assess. The Critically Endangered Southern Bent-wing Bat (Miniopterus orianae bassanii), is an obligate cave roosting bat in south-eastern Australia whose population has significantly declined over recent decades. Regular monitoring is undertaken at two key maternity caves, but little is known of the use of key non-breeding caves. This study aimed to determine the relative numbers and seasonal patterns of bats using non-breeding caves. Daily estimates of relative activity were recorded in six caves over a 2-year period, with the efficacy and potential risk of disturbance of this monitoring investigated.

Bat call recorders were set within or at the exit of caves to record relative levels of activity each night. The number of bat call pulses were tallied to obtain an index of nightly activity. Caves were entered once a month to change the batteries on the recorder, with one or two flash photographs quickly taken of the roosting bats to estimate numbers and help interpret the recorder results. Other light, noise and time spent in the cave was kept to a minimum.

The bat call data revealed variation in activity reflecting weather and seasonal patterns. In addition, substantial activity spikes were observed following visits where flash photography was used. While some immediate increase in activity due to bats taking flight was expected, what was unexpected was that activity levels remained elevated for several weeks after the visit. As a result, flash photography has now ceased, resulting in reduced activity spikes after battery changes. In an attempt to obtain accurate population estimates with minimal disturbance, remote, time-lapse, infrared cameras are now being used. These cameras are completely covert, producing no visible light or sound. They are set opposite roosting bat colonies and take a photograph once an hour for 3-4 months, between battery replacements. This reveals population estimates, activity patterns and roosting behaviour. These findings have implications for bat researchers, cavers and members of the general public entering bat caves, with disturbance potentially having an impact long after people have left the cave.

Faunal Diversity On Arid Lands Caves In The Sonoran Desert, Mexico

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Abstract

Biospeleological studies in Mexico are scarce, particularly ones to explain the interaction between species in caves, as well as the relationship with their physical environment. The Sonoran Desert is located in the northwest of Mexico and southwest of USA, and most of this desert belong to the state of Sonora. There is a shortage of knowledge of the biospeleology from Sonora, representing only 1.2% of Mexico speleological studies. The objective of this work was to determine biotic factors that have a role in the fauna diversity in two karst caves in the central region of Sonora. In order to accomplish the objective, we surveyed the Cueva de la Mariana and Cueva El Tigre for a year (April 2015 - April 2016). Two sensors were placed in each cave in the transition zone and deep zone of the caves to determine the temperature and relative humidity; also the fauna (vertebrate and invertebrates) was collected and preserved through different methods. The climate of the caves was different, with a mean annual temperature of 26.5 °C and 52% annual relative humidity for Cueva de la Mariana and for Cueva El Tigre was 29.3 °C and 67%, respectively. The fauna found in both caves were represented by 23 orders, 38 families, 51 genera and 52 species. This cave community depends of the guano produced by seven species of bats, being the Mexican free-tailed bat (Molossidae: *Tadarida brasiliensis)* the most important, with a population of half of a million in Cueva de la Mariana and a million individuals in Cueva El Tigre in summer. The alteration on elimination of the bat populations inside both caves can produce local extinction of 80% of the species registered. This is the first biospeleological study on arid lands caves from Mexico.

Keywords: Biospeleology, faunal diversity, invertebrates and vertebrates, arid lands caves, guano.

1. Introduction

The Sonoran Desert is located in the northwest of Mexico and southwest of USA and most of this arid lands belong to the state of Sonora in Mexico (Molina-Freaner & Van Devender, 2010).

The Sonoran Desert is considered to be the most "tropical" and youngest of the North American deserts. The development of this unique regional and evolution of characteristic desert-adapted communities of plants and animals is quite recent, at least about 8 million years ago in the late Miocene; also it is called the most "tropical" desert because Sonora is the transition of two biogeographic regions Nearctic and Neotropical (Van Devender, 2000; Molina-Freaner & Van Devender, 2010). For those reasons the Sonoran Desert is the transition and connection from temperate and tropics zone communities, give us diverse ecosystems inside the Sonora Desert.

Seven years ago, Molina-Freaner and Van Devender (2010) published a summary about the biological diversity of Sonora, focused on the physical environmental and living forms inside this state, however they show us the empties spaces in some areas like subterranean habitats.

2. Background

From the speleological point of view, Mexico is one of the most interesting countries in the world, because in almost all the states there are caves of different composition, size and origin. About 20% of Mexico have the conditions to form all type of caves and it is estimated more than seven thousand caves and caverns (Lazcano, 1983; Hoffmann *et al.*, 1986; Espinasa, 1994).

Although in numerical terms, Europe and the United States surpass Mexico in the explorations and number of subterranean environment registered in the world, in terms of species, Mexico represent a great diversity of cavernicolous species (Reddell, 2005; Culver & Pipan, 2009; Romero, 2009; Palacios-Vargas *et al.*, 2014). Many of the Mexican caves have been studied by geologist and more by speleologist with sporting purposes. Comparatively, few are those have been explored for biological reason.

Mexico has one of the richest and most diverse cave fauna in the world. This has been explained in part by the existence of vast cave systems, located in a wide variety of ecosystems such as desert, forests, high mountains, scrubs, jungles and other types (Aguilar-Morales and Ruíz-Castillo, 1995; Hoffmann *et al.*, 2004, Reddell, 2005; Reddell, 2006, Bribiesca-Contreras and Solís Marina, 2014; Palacios-Vargas *et al.*, 2014).

In Mexico, more than 2,000 species of fauna have been registered, including mammals, birds, reptiles, amphibians, fishes, insects, arachnids, crustaceans and other invertebrates that use or live in caves (Palacios-Vargas *et al.*, 2014). The group of arthropods are, of course, the most abundant (Hoffmann *et al.*, 2004).

However, Sonora is a lagging region in speleology, compared with the knowledge for the central and southern of Mexican caves, we represent 1.2% of the current knowledge in Mexico and less in biospeleological studies (Calva & Castillo-Gámez, 2014; Calva, 2017).

There is not any biospeleology study in the Sonora Desert, they were a few studies on specific groups of species or random collection. The oldest record about fauna inside caves of Sonora is about the presence of bats inside unspecific caves between 1920 and 1930 (Caire, 1978), later Villa and Cockrum (1962) focus again in bats on the Mexican free-tailed bat

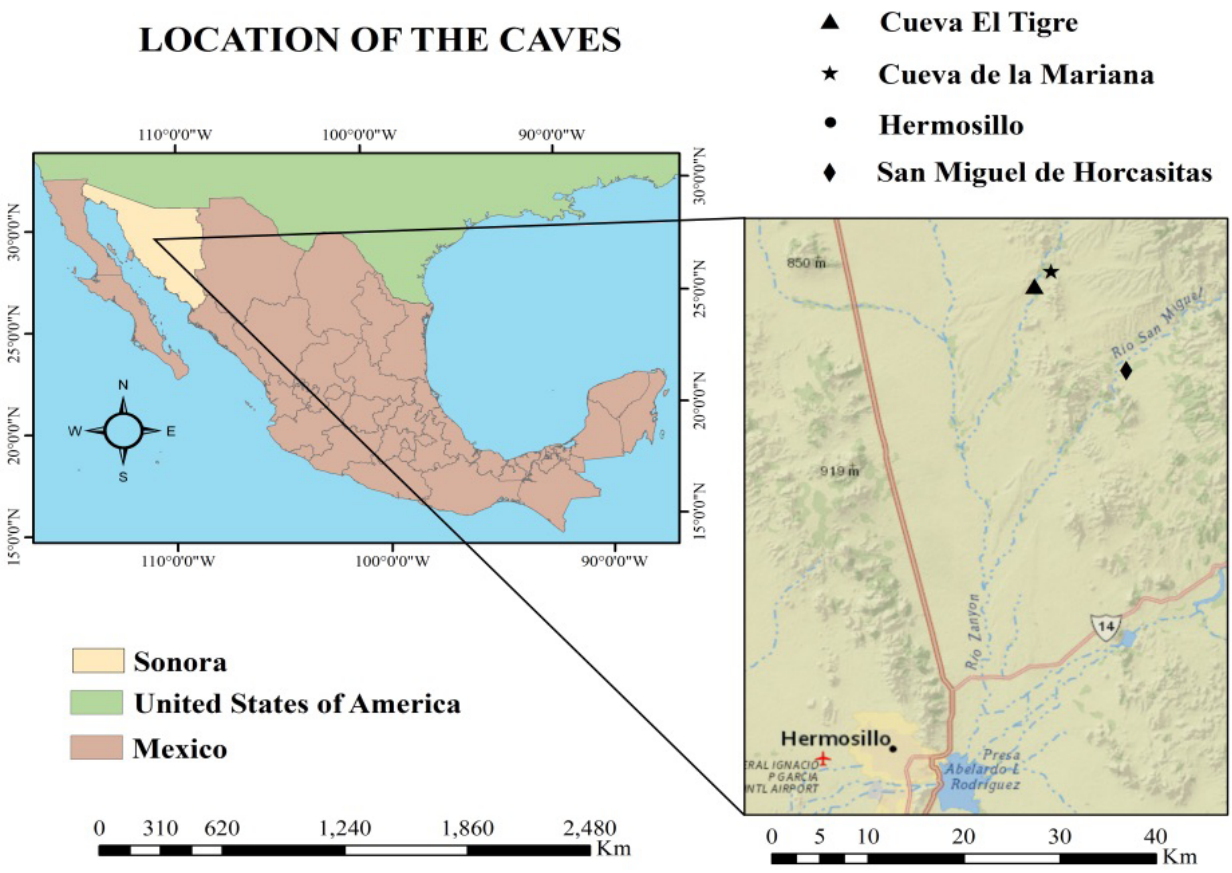

Figure 1. Location of Cueva de la Mariana and Cueva El Tigre from Sonoran Desert, Mexico.

(*Tadarida brasiliensis*) inside "Cueva El Tigre" and some years later, Mitchell (1964) and McFarlane and collaborators (1995) investigated the environmental aspects of the same cave. The recent checklist of Mexican cave fauna mentioned several caves with records of bats and some arthropods for Sonora (Palacios-Vargas *et al*., 2014), however it is nothing compared with the rest of the states and only represent a tiny part of the great potential of fauna who can live in arid lands caves.

3. Methods

The Cueva de la Mariana and Cueva El Tigre were located between the towns of San Miguel de Horcasitas and Carbó of the central region of Sonora. They were located approximately 60 km of northeast from the capital Hermosillo (Figure 1). The climate of the surface where the caves were located present warm and dry climate with an average annual maximum temperature of 30.5 °C and minimum of 17.4 °C. The rainfall occurs during the months of July to September with an average annual of 294 mm (Armienta *et al*., 2011).

Physical environmental (temperature and humidity relative) and cave fauna were recorded and collected, respectively, from one year (April 2015 to April 2016) in both caves. Invertebrates were sampled by different methods and preserved in 70% alcohol. Vertebrates were collected also by different methods "*in situ*" and photographed (more details in Calva, 2017).

The specimens were determined using taxonomic guides for each group and by various specialists as far as possible, these remained in their respective collections.

4. Results and discussion

4.1. Physical conditions of both caves

Geologically, the area where the caves were located corresponds to the early Cambrian (more than 500 mya), being one of the oldest units recorded for Sonora. The caves were composed by limestone rock, dominate by dolomite.

The most richness and abundance of cave fauna was located on the deepest zone of each cave. For that reason, we measured the temperature and humidity in those places. The results for the Cueva de la Mariana (CM) was an average annual of temperature of 26.5 °C and 52% relative humidity and in the case of Cueva El Tigre was 29.3 °C and 67% of humidity. The high temperature that we recorded was related by the bat activities and superficial climate. In summer we detected (July to September 2015) the maximum records from both caves approximate about 30 °C. Humidity change through all the study but also in summer the maximum humidity was detected (90%) in Cueva El Tigre and less in Cueva de la Mariana (80%).

Figure 2. Acaropsella *(mite) collected on bat guano*

Figure 3. Phrynus *(amblypygi) inside Cueva de la Mariana, Mexico*

Figure 4. Primicimex cavernis *(bedbugs), one of the eutroglophiles recorded on Cueva de la Mariana*

Figure 5. Black-tailed rattlesnake Crotalus molossus

4.2. Cave fauna

Despite the hot condition inside both caves compared with other templates caves (Culver y Pipan, 2009; Romero, 2009), 52 taxa were determined at least to generic level for both caves. In the Cueva de la Mariana 43 species of invertebrates and vertebrates were recorded, while in Cueva El Tigre only 28 species were found and both caves shared 19 species.

However, in contrast to the species reported by several authors about cave fauna from Mexico (Hoffmann *et al.*, 1986; Hoffmann *et al.*, 2004; Reddell, 2005; Palacios-Vargas *et al.*, 2014), where dominated species corresponds always to invertebrates, specifically arthropods, in these caves the fauna found it was equal in terms of richness between invertebrates and vertebrates. The dominates groups corresponds to insects for invertebrates and mammals in the case of vertebrates.

4.3. Invertebrates

The unique groups of invertebrates in both caves were arthropods and both caves were represented by centipedes, arachnids and insects. The centipedes were exclusive for Cueva de la Mariana with two species *Orphnaeus brevilabiatus* and *Scolopendra sp.* The arachnids were represented by pseudoscorpion, amblypygi, mites and spiders and at least one species from each group were found in both caves. The dominated group was the mites with fives species (Figure 2), however, two of them are the only ones who are not determined to generic level. After them, the group of spider was represented by four species. *Neoallochernes steroreus* (pseudoscorpion) and *Phrynus sp.* (amblypygi) were collected in both caves (Figure 3). Five groups of insect were described inside both caves. This groups were psocids, bedbugs, net-winged insects, wasp and beetles, being the last group the dominated by richness and abundance. One surprise was the bedbug *Primicimex cavernis* (Cimicidae), who is a rare parasitic species of bats living inside caves. Reinhardt & Roth (2013) published the possibility that this specie was extinct because the last recorded corresponds from one cave from Guatemala (1948), Mexico (1967) and USA (1970). These authors explored seven caves from Texas, USA tried to collect this species, however the search was unsatisfactory. We founded and collected a healthy population of *Primicimex cavernis* in Cueva de la Mariana (Figure 4).

The high richness was found it inside Cueva de la Mariana but the high abundance corresponds to the Cueva El Tigre. For the same reason that the exploration of caves from Sonoran Desert is recent, it is not surprise that 20 species of arthropods were new record from Sonora.

4.4. Vertebrates

We recorded four of the five principal group of vertebrates, fishes being the exception in both caves, even we found some water inside, but they required more exploration. Amphibians, reptiles, birds and mammals were described in both caves, found it a total of 28 species of them. In the case of amphibians and reptiles only one species was described for each group; the toad *Anaxyrus punctatus* (Bufonidae) was recorded exclusive in the entrance of Cueva de la Mariana and the black-tailed rattlesnake *Crotalus molossus* (Viperidae) was collected in both caves (Figure 5). This last species was found always in both entrance using the cave like a shelter and also to feeding with bats when they came out in the night.

The next group inside both caves was the birds, and they showed an interesting behavior inside Cueva El Tigre. First, the Cueva El Tigre recorded the major number of species of birds and a preference in some period of the year (between April to July of 2015). The Black Vulture *Coragyps atratus* (Cathartidae) was inside both caves, however we detected a relation with Cueva El Tigre. Using trap-camera, we recorded all the life cycle of two individual from this species. A female of *C. atratus* used the entrance of Cueva El Tigre to nest, take care and teach how to fly and thermoregulation to her offspring (Figure 6). This happen again the next year (2016) because we found two new eggs in the same place that the year before. Even that we photographed potential depredators, the place where they used the shelter was a barrier by the levels of ammonia by the decomposition of guano and bat pee.

Figure 6. A female of Black Vulture Coragyps atratus *and her offspring on Cueva El Tigre*

Finally, the group of mammals were represented by different species from small rodents and bats until big cat. The dominate groups were rodents and bats with seven species for each group, however bats are the most abundances species inside both caves. Even that we detected seven species of bats, only four species appear in Cueva El Tigre. A particularly species were present in both caves and all the time, the Mexican free-tailed bat *Tadarida brasiliensis* (Family: Molossidae) with a population of half of a million inside of Cueva de la Mariana and more than one million of Cueva El Tigre (Figure 7) during summer 2015 (June to September). These populations are the principal resources of energy of this arid lands caves by guano produced in both caves and a lot of species depends of this resources, particularly the arthropods that we recorded (Calva, 2017).

Figure 7. A breeding Tadarida brasiliensis *inside Cueva de la Mariana*

Also, by using the trap-camera and during the exploration, we photographed medium and large mammals. Seven species of mammals were recorded: the gray fox (Canidae: *Urocyon cinereoargenteus)* two Felidae species, Bobcat (*Lynx rufus*) and Mountain Lion (*Puma concolo*r), two Procyonidae, Ringtail cat (*Bassariscus astutus*) and Coati (*Nasua narica*) and two Mephitidae, Western Spotted Skunk (*Spilogale gracilis*) and American hog-nosed skunk (*Conepatus leuconotus*). The Gray Fox and Spotted Skunk were inside both caves. The first one was photographed entering both caves to eat his prey, however a female used Cueva El Tigre to protect her cubs during the dry conditions outside (May to July 2015), even they shared this caves with the Black Vulture during the same time without problem. The Spotted Skunk visited both caves and was the only medium mammals who entered through all the caves (Figure 8), we found it in the deepest part of the caves and also his scats.

Figure 8. Western Spotted Skunk (Spilogale gracilis)

4.5. Trogloxenes, subtroglophiles and eutroglophiles

Based on the ecological classification of the cave fauna redefined by Sket (2008), three of the four groups were found it. Trogloxenes (n = 15) were represented by medium and large mammals, birds and some invertebrates; Subtroglophiles (n = 14) representing again by mammals and arthropods, dominated by the order Chiroptera and Rodentia and Eutroglophiles (n = 4) represented by the order Geophilomorpha (n=1), Araneae (n=1), Hemiptera (n=1) and pseudoscorpionida (n=1). At the moment, no species were found that represent the last classification (troglobites) since the conditions of the underground environment were not found. See Table 1.

5. Conclusions

Although a substantial amount of information on the cave fauna of Mexico has been gathered so far, Sonora and his desert area in still in the stage of discovered. This is the first complete inventory and ecology study of a biospeleology work from caves of Sonora and we found a surprise with all the richness than we recorded. From all the species that we found in both caves, 38 were a new record from caves of Sonora, representing 73% of the total species recorded. However, we do not found a troglobites species because this caves not present the physical condition to support this kind species, maybe we will find later this conditions and we can have the first troglobites from arid lands caves of Mexico.

There is still abundant work to be done and new question to try to answer, if the geologic evolution of the Sonoran Desert is recent (8 mya) and even more recent the desert condition, we think that some species are in the process to colonized this subterranean habitat and we can appreciate with the low number of eutroglophiles. The potential of discovered new caves and species is huge considered that this project was only in two caves from Sonora, and the speleology in this part of Mexico is practically recent.

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Table 1. List of species described from Cueva de la Mariana (CM), Cueva El Tigre (C) or Both (B) of the Sonoran Desert and his ecological classification.

Group	Family	Species	Cave	Classification
Chilopoda	Oryidae	Orphnaeus brevilabiatus	CM	Eutroglophile
	Scolopendridae	Scolopendra sp.	CM	-
Arachnids	Chernetidae	Neoallochernes steroreus	B	Eutroglophile
	Phrynidae	Phrynus sp.	B	Subtroglophile
	Gnaphosidae	Urozelotes sp.	CT	-
	Pholcidae	Psilochorus sp.	CM	-
		Physocyclus tanneri	CT	Eutroglophile
	Sicariidae	Loxosceles sp.	B	-
	Argasidae	Orthithodoros sp.	CM	-
	Cheyletidae	Acaropsella sp.	CT	-
		Chelachecaropsis sp.	CM	-
Insects	Liposcelidae	Liposcelis bostrychopila	B	-
	Cimicidae	Primicimex cavernis	CM	Eutroglophile
	Reduviidae	Triatoma recurva	CT	-
		Triatoma sp.	CM	-
	Myrmeleontidae	Eremeleon longior	CM	Subtroglophile
	Vespidae	Polistes sp.	B	Trogloxene
	Dermestidae	Dermestes maculatus	B	-
	Tenebrionidae	Eleodes sp.	CM	Subtroglophile
		Coniontis sp.	CM	-
Amphibians	Bufonidae	Anaxyrus punctatus	CM	-
Reptiles	Viperidae	Crotalus molossus	B	-
Birds	Columbidae	Zenaida sp.	B	Trogloxene
	Cuculidae	Geococcyx californianus	B	Trogloxene
	Cathartidae	Coragyps atratus	B	Trogloxene
	Strigidae	Bubo virginianus	CT	Trogloxene
	Tytonidae	Tyto alba	CT	Trogloxene

Group	Family	Species	Cave	Classification
Mammals	Muridae	Neotoma albigula	CM	Trogloxene
		Peromyscus sp.	B	Subtroglophile
		Sigmodon sp.	CM	Subtroglophile
		Reithrodontomys sp.	CM	Subtroglophile
	Heteromyidae	Perognathus sp.	CM	Trogloxene
	Sciuridae	Ammospermophilus harrisii	CM	Trogloxene
		Spermophilus variegatus	B	Trogloxene
	Molossidae	Tadarida brasiliensis	B	Subtroglophile
	Mormoopidae	Mormoops megalophylla	CM	Subtroglophile
		Pteronotus davyi	B	Subtroglophile
	Natalidae	Natalus mexicanus	B	Subtroglophile
	Phyllostomidae	Leptonycteris yerbabuenae	CM	Subtroglophile
		Macrotus californicus	B	Subtroglophile
	Vespertilionidae	Myotis velifer	CM	Subtroglophile
	Canidae	Urocyon cinereoargenteus	B	Trogloxene
	Felidae	Lynx rufus	CM	Trogloxene
		Puma concolor	B	-
	Procyonidae	Bassariscus astutus	CM	Trogloxene
		Nasua narica	CM	Trogloxene
	Mephitidae	Conepatus leuconotus	CT	Trogloxene
		Spilogale gracilis	B	Subtroglophile

Taxonomic review of the cave-dwelling springtail family Tomoceridae (Collembola) in Korea

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Abstract

Cave dwelling springtail studies in Korea were initiated during 1960s by the Japanese Collembola researcher, R. Yosii, and comprehensive taxonomic studies on Korean Collembola were conducted by B. H. Lee during 1970-1990s. The new family Gulgastruridae was established using the type species Gulgastrura reticulosa from the Gossidonggul cave in Gangwon-do, Korea. Eight families of cave-dwelling springtails are known in Korea, and the family Tomoceridae is the most abundant and diverse group of cave-dwelling springtails with 12 known species belonging to 4 genera in Korea

Keywords: cave-dwelling springtails, Collembola, Tomoceridae

1. Introduction

In Korea, more than 75% of caves are distributed in Gangwon-do, Chungcheong-do, and Gyeongsangbuk-do (Hong, 2004, Oh, 2008) (Fig. 1). These are mostly limestone caves except some lava caves on Jeju-do Island. Cave environments can be divided into three zones, entrance zone, twilight zone, and dark zone with varying temperatures; Temperature in dark zone is normally constant (Fig. 2) (Choi *et al*, 2011, Howarth, 1991). According to these divisions, cave dwelling organisms also can be classified into three types: regular visitors which visit caves regularly as a part of their life cycles (including 'trogloxenes'), troglophiles which live sometimes in caves but also occur elsewhere (including 'stygophiles'), and troglobites which are fully adapted to life in darkness (Choi, 2005, Howarth, 1991).

In Korea, *Antrokoreana gracilipes* (Diplopoda) was reported for the first time as cave dwelling organism by Verhoeff in 1938 (Choi, 2006). In 1966, 23 papers were published for Korean caves (21 limestone caves, 2 lava caves, and 49 wells) from the "Korea-Japan Joint Survey of Speoleogy in South Korea". One hundred and one species, 71 genera, 50 families, in 3 classes were identified and published in those papers. Since then, 5 new species of cave Collembola were reported by Lee. During 1970-1990s, BH Lee comprehensively studied Korean Collembola, including a new family Gulgastruridae based on *Gulgastrura reticulosa Yosii*, 1966 described from the Gossidonggul cave in Gangwon-do. KH Park and BH Lee also described new species of Tomoceridae in 1995 and provided a list of cave dwelling springtails in Korea (Park & Lee, 1995). So until now, 6 genera 23 species of Tomoceridae have been recorded in Korea, especially 6 genera 16 species of those are cave adapted species.

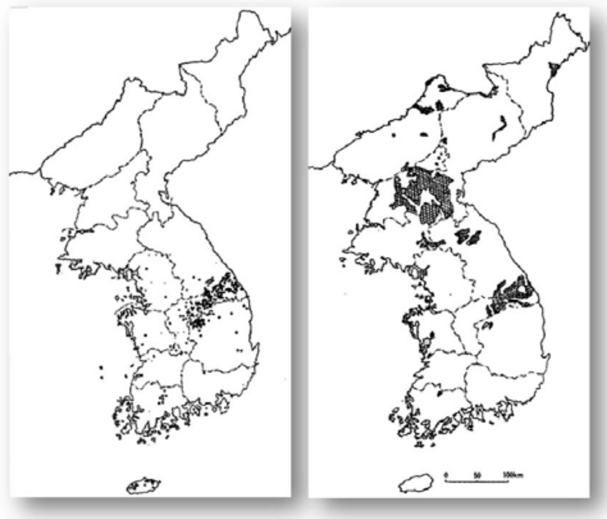

Figure 1. A. Distribution of limestone caves distribution in Korea; B. Distribution of caves in Korea. [Cited from Hong, 2004]

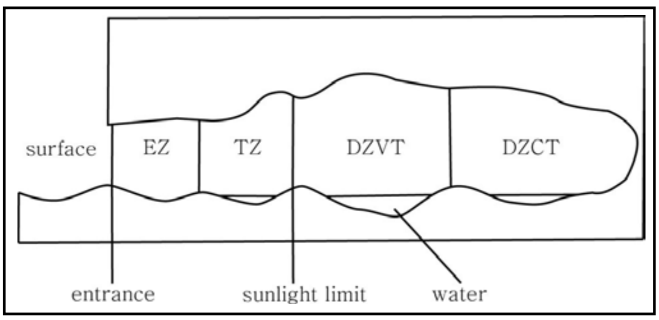

Figure 2. Ecological zones in limestone caves of Korea [Modified from Choi, 2011] (EZ : Entrance zone, TZ : Twilight zone, DZVT : Dark zone with varying temperature, DZCT : Dark zone with constant temperature)

2. Material And Methods

Springtails were collected by aspirator and preserved in 20 ml plastic vials with 95 % alcohol. After collecting, specimens were sorted under a dissection microscope and permanent slides were prepared for identification by cleaning with KOH, lactic acid, or Marc Andre I solutions, dependent on the condition and colorization of specimens. After decolorization, the head, legs, and furca were dissected from the body. Abdomens were also dissected and flattened to check the chaetotaxy of body. For mounting, Hoyer's solution or Marc Andre II was used and specimens were dried at 40–45 °C in the dry oven for one to 2 days. Specimens were observed by using an optical microscope at X200 and X400 magnifications. X800 magnification was used especially for pseudopore, and the sockets of macrosetae on bodies or other smaller organs.

Specimens were deposited in The Korean Institute of Biospeleology, Daejeon, Korea.

3. Results

A total of 16 species in 6 genera of springtails of the family Tomoceridae have been reported from Korean caves (Table. 1). Especially, 6 genera 14 species were sampled from cave, and we examined some characters of those species which may represent full adaptation to cave environment (Table. 2).

The genus Lethemurus contains only three species worldwide, *Lethemurus finitimus* in Japan, *Lethemurus missus* in USA, and *Lethemurus coreanus* in Korea. All the three species are troglobites. They showed differences in labral setae, trochanteral organ, and dental spines formula (Table. 3).

The genus Aphaenomurus had included two species, *Aphaenomurus vicinus*, and *Aphaenomurus interpositus*. However, *A. vicinus* was synonymized with *A. interpositus*. Yosii (1967) described some difference in dental spines formula, but it is maybe the variation of same species. *A. interpositus* has one subspecies, *A. interpositus denticulatus*. It was collected from Japanese cave and has some difference between genus in corner toothlet to the outer basal tooth of mucro (Yosii, 1967).

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Table 1. List of cave dwelling springtails of family Tomoceridae of Korea.

Class	Collembola		
	Family	Tomoceridae	
		Genus	Aphaenomurus Yosii 1956
			Aphaenomrus interpositus Yosii 1956
		Genus	Lethemurus Yosii 1970
			Lethemurus coreanus Chang & Bae 2014
		Genus	Monodontocerus Yosii 1955
			Monodontocerus odognyeuensis Park & Lee 1995
		Genus	Plutomurus Yosii 1956
			Plutomurus diversispinus Yosii 1966
			Plutomurus gul Yosii 1966
			Plutomurus leei Yosii 1966
			Plutomurus riugadoensis Yosii 1939
			Plutomurus suzukaensis Yosii 1939
			Plutomurus vigintiferispina Lee 1974
		Genus	Tomocerina Yosii 1955
			Tomocerina liliputanus Yosii 1967
		Genus	Tomocerus Nicolet 1842
			Tomocerus denticulus Lee 1975
			Tomocerus jesonicus Yosii 1967
			Tomocerus kinoshitai Yosii 1954
			Tomocerus laxalamella Lee 1975
			Tomocerus ocreatus Denis 1948
			Tomocerus spinistriatus Lee 1975

Table 2. Data on cave dwelling springtails species types with diagnostic characters of each species (pigments and eyes) and their collecting sites (Abbreviation : EZ, Entrance zone ; TZ, Twilight zone ; DZVT, Dark zone with varying temperature ; DZCT, Dark zone with constant temperature ; H, High ; M, Middle ; L, Low ; TB, Troglobites ; TP, Troglophiles ; RV, Regular visitors).

Species	Collecting site	Level of pigment (H / M / L)	Eyes	Type
Aphaenomurus interpositus	TZ (about 10-30 m)	M (brown)	6+6	RV
Lethemurus coreanus	DZCT (about 250-250 m)	M (almost white with blue pigments)	none	TB
Plutomurus leei	DZVT (30-70 m)	M (blue pigments on each segments)	3+3	TP
Plutomurus diversispinus	TZ (about 20 m)	L (light gray with dark blue pigments)	2+2	RV
Plutomurus gul	DZCT (about 250 m)	L (light gray with dark blue pigment especially on base of antenna)	none	TB
Plutomurus riugadoensis	DZVT (about 20-30 m) and DZCT (about 150 m)	M (almost white with blue pigments)	5+5	RV
Plutomurus suzukaensis	DZVT (about –7 m)	L (light gray with dark blue pigment)	none	TP
Tomocerina liliputanus	DZVT (about 20-40 m)	H (purple pigments on head and lateral body part)	6+6	RV
Tomocerus kinoshitai	TW (about 20-30 m)	L (almost white with brown pigments, antenna with purple pigments)	6+6	RV
Tomocerus denticulus	DZVT (about 150-200 m)	M (light brown with dark purple pigments)	6+6	RV
Tomocerus jesonicus	TZ (about –50 m)	M (light brown, leg with blue pigments)	6+6	RV
Tomocerus laxalamella	DZCT (about 70-100 m)	M (light brown)	6+6	RV
Tomocerus ocreatus	EZ (about 5 m) and DZVT (about 30-60 m)	L (white)	6+6	RV
Tomocerus spinistriatus	EZ (about 3-5 m)	M (light brown)	6+6	RV

Table 3. Diagnostic characters of Lethemurus finitimus Yosii 1970, Lethemurus missus Mills 1948, and Lethemurus coreanus Chang & Bae 2014.

Characters	Lethemurus finitimus	Lethemurus missus	Lethemurus coreanus
Distribution	Japan	USA	Korea
Habitus	Cave	Cave	Cave
Tenant hair	Spiny	Variable	Spiny
Unguis and Unguiculus teeth	1 & 2-3	1 & 3	1 & 3
Lateral macrochaetae on dente	None	None	None
Dental spines	10 / 2, I, 1, I-II	5~8 / 3-5, I	8-10 / 2, I, 1, I, 1, I, 1, I
Mucro teeth	2 / 1 / 2	2 / 1 / 2	2 / 1 / 2
Antenna length	3 segment on one side and 2 on the other. Not seemingly very long	2 times longer than head diagonal	More than 5 times longer than head diagonal
Trochantral organ	4 spiny and some 7 minute setae in trochanter, irregular assembly of about 8, some of them are very long in femur	4 setae in trochanter and 14 setae in femur. Setae size is irregular.	More than 40 setae in trochanter, also almost 40 setae in femur
Labral setae	8 / 5, 5, 4	6 / 5, 5, 4	6 / 5, 5, 4

The Gcwihaba Caves Research Project: Past, present and future undertakings

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Abstract

Tourism in Botswana is a major contributor to the GDP with the Okavango Delta and Makgadigadi Pans serving as world-renowned tourist destinations. In line with expanding its tourist industry, the Botswana government launched the Gcwihaba Caves Project that is aimed at providing an adventure caving destination for tourists. The Gcwihaba Caves, located in Ngamiland (North-Western Botswana), constitute a series of caves with natural entrances and caves discovered by means of gravimetric surveys followed by exploration drilling. Consequently, these subterranean landscapes differ considerably in terms of atmospheric conditions, geological formations, and ecosystem structure, which jointly presents the main study focus of the Gcwihaba Caves Research Project. Since its inception in 2010, this research project has produced several peer-reviewed works that have illustrated the singularity of these subterranean landscapes.

This paper will provide an overview of challenges faced in exploring previously sealed subterranean cavities, summarize the scientific investigations till date, and discuss the potential for further research. The first published work focused on the description of a new troglobitic pseudoscorpion (*Botswanoncus ellisi*), which was followed by a biodiversity study on invertebrates associated with *Ficus cordata* (Namaqua fig) roots that penetrate the cave's general development level at approximately 50 meters below surface. Furthermore, a new type of biogenic calcite formation (viz. Hairy Stalagmites), as well as its developmental mechanism and association with the fig tree roots, were studied. Ongoing research initiatives demonstrate how x-ray micro computer tomography and additive manufacturing (3D-printing) can collectively be applied to visualize and non-destructively study small and fragile speleothems such as Hairy Stalagmites. Also of importance is a study on the nematode communities associated with different cave habitats, which aims at complementing a comprehensive review on cave-dwelling nematodes. The latter undertaking will provide a better perspective on cave colonization pathways by nematodes, as well as their ecological significance in subterranean ecosystems. Furthermore, ancient mammalian skeletal material has been collected in previously sealed cavities, which has been sent to the Botswana Museum for further analysis. We are also testing the hypothesis that Ficus cordata trees are dependent on the subterranean landscape as a source of water in the semi-arid Kalahari Desert. It is thus believed that clusters of trees might be indicative of a well-developed subterranean cavity. The Gcwihaba Caves Research Project, however, presents even further potential for studying subterranean landscapes that are, although found in the same geological setting, substantially different in terms of biotic and abiotic features.

Keywords: Gcwihaba Caves, subterranean biodiversity, Hairy Stalagmite, micro computer tomography, 3D-printing

1. Introduction

The Gcwihaba Caves Research Project forms part of the greater Gcwihaba Caves Project and is aimed at studying the unique biota and geological formations associated with the various Gcwihaba Caves. On-going investigations are focused on providing the Botswana government with the necessary information for developing these caves, as well as the surrounding region, into a world-class tourist destination. This work not only provides a historical perspective on the discovery and exploration of the Gcwihaba Caves, but also reports on scientific discoveries till data and provides reasoning for the continuation and expansion of this research undertaking.

2. Historical perspective on the Gcwihaba Caves

In June of 1932 Martinus Drotsky, a Ghanzi trader, was shown a cave by Basarwa hunters in the Ngamiland region of Botswana, which would become known as Drotsky's Cave. Although the cave, later renamed the Gcwihaba Cave, was first entered by Drotsky, it was not for another 60 years before more caves would be discovered in this area (Ritter & Garner, 1994). In 1991, an American speleologist named Ron Ritter, together with the British Schools Exploring Society, visited the Gcwihaba Valley with the purpose of resurveying Gcwihaba Cave and exploring other known caves at the Aha Hills. During the next three years, Ron and his team discovered !WaDoum Cave and Bone and Blue Caves associated with the Gcwihaba (Figure 1a) and Koanaka (Figure 2a) Hills, respectively (Ritter & Garner, 1994). These new caves immediately opened up the possibility of further cave discoveries. Reports on the latter, submitted by Ron Ritter to the Botswana National Museum, motivated the Botswana government to commence development of the area and the caves into a national park.

In 1998, His Excellency Ian Khama, then Vice President of Botswana, was the first to champion the Gcwihaba Caves Project. The initial method was to re-search the Gcwihaba and Koanaka Hills in the hope of finding more caves with natural entrances. Later, upon recommendation by South African cavers, the use of gravity surveys and exploration drilling was adopted and in 2008 the first new cave, today known as Dimapo Cave, was discovered at the Gcwihaba Hills. During the next six years, four more caves were discovered, opened, and explored at the Koanaka Hills (Figure 1) of which two (Diviners and Mongongo caves) are substantial systems. Initially, access was gained via a 600 mm diameter borehole (Du Preez *et al*., 2013; Du Preez *et al*., 2015), which was later followed by a 1000 mm borehole. This method used for discovering and opening caves, and indeed the scale at which it occurred, likely remains globally unmatched. After each of these caves were discovered, the next major challenge was to overcome the dangerously high levels of carbon dioxide (CO_2). Since these caves had no natural entrances, they were filled

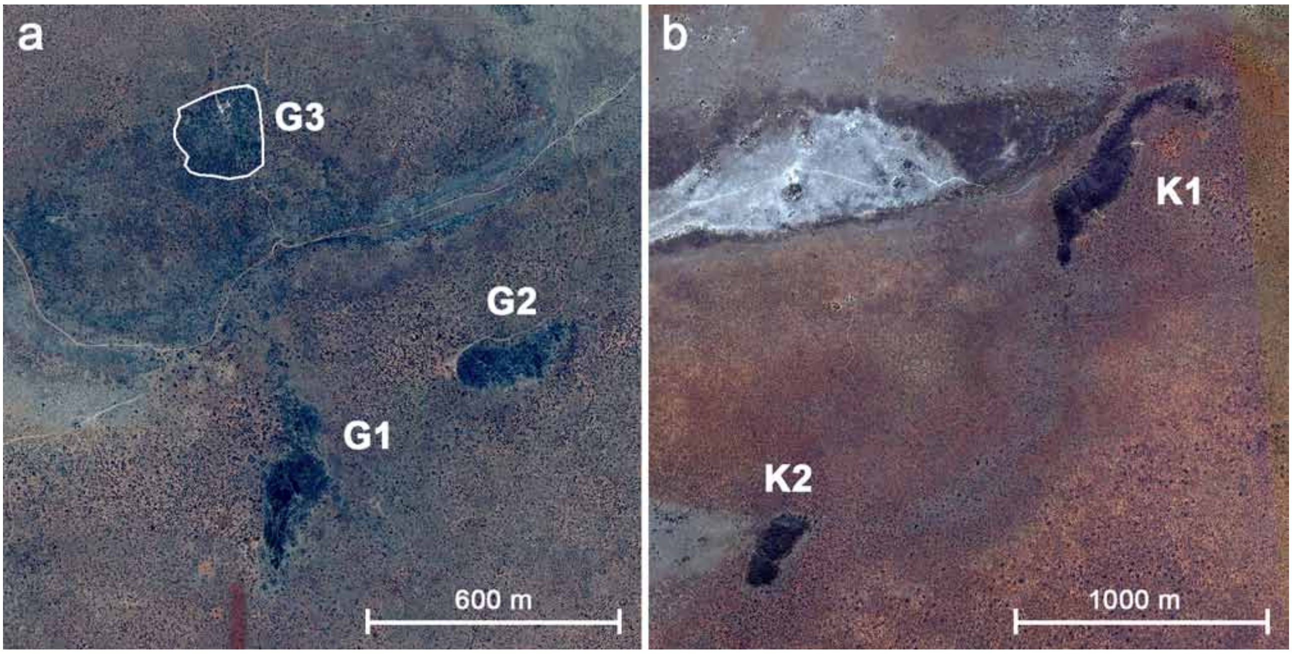

Figure 1. Satellite image illustrating the Gcwihaba (a) and Koanaka (b) Hills in Ngamiland (Botswana).

with CO_2 and it was only after a period of 'breathing' that gas levels diminished and allowed cavers to extensively explore the subterranean landscapes. The cavers (mainly members of the Potch Potholers caving club assisted by the Gcwihaba Cavers) explored and surveyed the caves over a number of years and produced the results that have added the 'borehole' caves to the substantial tourist potential of Gcwihaba Park. Dimapo, Diviners, and Mongongo Caves are characterised by large passages, huge chambers, and rifts with some uniquely decorated sections. Dimapo Cave in particular is spectacular in its rock formations and siderite spars.

Historically the Gcwihaba Caves have not only been subjected to exploration, but also to scientific investigations. From as early as the 1970's, such investigations have delivered a broad spectrum of knowledge on the history and development of the caves. This included geomorphological, radio carbon dating of speleothems, and analysis of cave sediments (Cooke & Baillieul, 1974; Cooke, 1975). From these studies insights were gained on patterns of climate change over the last 50 000 years. In more recent times, further paleoclimatic studies revealed the important fossiliferous breccias in the Gcwihaba and Koanaka Hills (Railsback *et al*., 1994; Robbins *et al*., 1996). Also, the mineralogy of Gcwihaba Cave was investigated (Martini, 1996) and three fossils of a Papio sp. (baboon) were recovered from Bone Cave (Williams *et al*., 2012). These studies represented the prelude to the Gcwihaba Caves Research Project.

3. Activities as part of the Gcwihaba Caves Research Project

Upon involvement of the North-West University (Potchefstroom, South Africa) in 2012, the Gcwihaba Caves Research Project was initialised after which the first published work was presented at the 16th International Congress of Speleology (Brno, Czech Republic) (Du Preez *et al*., 2013). This was a biodiversity study that recorded the occurrence of various invertebrate groups in Bone and Blue Caves (natural entrances), as well as Diviner's Cave (borehole entrance). From the latter, more than 10 nematode taxa were identified, while other biota included a dipluran (Japygidae) (Figure 2), Microtermes

Figure 2. Microscopy image of a dipluran (Japygidae) specimen collected from Diviner's Cave (Koanaka Hills, Ngamiland, Botswana).

sp. (Termitidae), Cryptops sp. (Cryptopidae) and Trichorhina sp. (Platyarthridae), all likely to be new to science (Du Preez *et al*., 2013). Furthermore, a new pseudoscorpion genus and species, *Botswanoncus ellisi*, was discovered and described by Harvey & Du Preez (2014). This also represented the first blind ideoroncid species from Africa.

Following was the description of a new type of biogenic root speleothem, named 'Hairy Stalagmites', which is made up of thousands of hollow calcite tubes that developed around fine roots of *Ficus cordat*a (Namaqua fig) trees (Du Preez *et al*., 2015). This is truly a unique formation that can likely only be found in the Gcwihaba Caves (with borehole entrances) as these subterranean environments provide the right atmospheric conditions (temp: 28 °C and relative humidity: 99.9%) together with the presence of roots extending 50 meters below surface. However, as a result of the small size and fragility of this speleothem, its internal structure wasn't extensively studied as this would've resulted in the destruction of a rare specimen. Subsequently, as part of an on-going investigation, the same specimen was subjected to x-ray micro computer tomography (micro-CT) after which a virtual 3D replica was created. While this replica was subjected to various structural analyses, a physical replica of a section of the original specimen was manufactured on a larger scale using 3D-printing (additive manufacturing), allowing a more real-live, visual inspection of a Hairy Stalagmite.

Another on-going project is aimed at testing the hypothesis that the *Ficus cordata* trees, which are only found associated with the dolomitic Gcwihaba and Koanaka Hills, are dependent on the underlying cave systems as a source of water. Conversely, it is hypothesised that the trees are an approximate indictor of developed subterranean cavities. By using the original gravimetric surveys that was used for finding the caves, together with georeferenced cave surveys and fig tree location (GPS) data, a geographic information system (GIS) modelling approach is used to study the relationship between the *Ficus cordata* trees and underlying cave systems.

Lastly, a survey is being undertaken on the nematode communities associated with Diviner's Cave at different levels of surface exposure, which largely occurred as a result of human activities. Some sites include sections of Diviner's Cave that were sampled only hours after breakthrough occurred via a 30 meter tunnel that was dug by hand. The subterranean nematode communities are also being compared to an epigean community associated with the borehole entrance, as well as other communities from the Koanaka Hills and surrounding region. This research is aimed at complementing an on-going, comprehensive review on all reported cave-dwelling nematodes, which found that many questions surrounding nematode's ecological role in subterranean environments remain unanswered. It is also unclear whether the majority of nematodes found in subterranean environments are accidentally introduced, or indeed truly cave-dwelling. Fortunately, the borehole caves present a unique opportunity to answer some of these questions. Other biotic (fatty acid content and enzymatic activity) and abiotic (soil properties and atmospheric conditions) analyses were also performed as part of the latter on-going study.

4. Conclusion: The future of the Gcwihaba Caves Research Project

The Gcwihaba Caves Project is undoubtedly one of the most unique caving projects ever undertaken. The concept of developing known caves with natural entrances for tourism, while discovering new caves only accessible via a borehole for the adventure tourist, is unprecedented. Ultimately, the Gcwihaba Park will also offer game drives, walks with Bushmen, nature trails, and tours of fossil sites.

However, reaching these goals go hand in hand with gaining knowledge about the caves and the surrounding region. To this end, previous studies, as well as the Gcwihaba Caves Research Project, have made a substantial contribution. However, the continuation of current and commencement of new research undertakings is imperative since these subterranean landscapes, as have been shown, may hold many more secrets. It is the opinion of the authors that the true potential lies in the rare opportunity provided to compare the ecosystem functioning of natural vs. previously sealed caves. Since the abiotic conditions and biota associated with these two cave types are markedly different, the opportunity is presented to study, for example, colonization and evolutionary pathways, trophic food web structures, and singular species. It is thus in the interest of the Botswana government, as well as the scientific community, to maximise the opportunity available to further investigate the features of the Gcwihaba Caves Park. We thus call on all interested parties to join our efforts to establish an international collaboration and continue on the path of generating knowledge.

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Invertebrate and vertebrate cave fauna records for the Appalachian Valley and Ridge

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Abstract

Of the >50,000 caves reported in the United States, nearly 1,140 cave-restricted animals (troglobionts) have been described. One of the most biodiverse karst areas in the United States is the area near the shared boundaries of Tennessee, Alabama, and Georgia (TAG) in the Appalachian Valley and Ridge (AVR) ecoregion. Large sampling gaps in the AVR likely indicate considerable undiscovered biodiversity. From 2013 to 2016, survey teams conducted visual encounter surveys in 95 unique AVR caves, including 64 caves in eastern Tennessee, seven caves in northeastern Alabama, and 24 caves in northwestern Georgia. In Tennessee, most of the caves had never been comprehensively bioinventoried, and some counties were without records for obligate cave fauna. Our effort doubled the knowledge of troglobiont distribution in Tennessee caves alone, simply by increasing the number of caves with new troglobiont records. To date, at least 80 distinct troglobiont species have been identified from caves in the AVR. Species descriptions are ongoing. Among the invertebrates, pseudoscorpions represent some of the most significant terrestrial records. New distribution records now exist for 15 terrestrial and aquatic taxa, and we discovered potentially nine undescribed species, including two species of aquatic hydrobiid snails, five pseudoscorpions, a harvestman, and an annelid. We identified new locations for the federally endangered Gray Bat (Myotis grisescens) and for the only cave-adapted vertebrate in the AVR of Tennessee, the Berry Cave Salamander (Gyrinophilus gulolineatus). We also discovered a new population of Southern Cavefish (Typhlichthys subterraneus) in the AVR of northwestern Georgia, which represents a significant range extension for this species. Collectively, this study emphasizes the importance of bioinventories in understanding the distribution of cave fauna in karst regions. Previous assumptions about the lack of troglobiont or stygobiont diversity in the AVR of TAG were largely due to enduring sampling gaps.

Keywords: biodiversity, cave, Appalachian, invertebrate, vertebrate, sampling gaps

1. Introduction

Over 1,138 cave-restricted species and subspecies from 112 families and 239 genera have been described in the more than 50,000 caves in the United States alone (Hobbs 2012). Karst regions in the United States comprise approximately 20% of the land surface, and 30% of all these caves occur in the states of Tennessee, Alabama, and Georgia, referred collectively to as TAG. TAG has two of the most biodiverse regions, the Interior Low Plateau and the Appalachians (Culver and Pipan 2009; Hobbs 2012). Considerable research has been conducted for over a century to assess cave-restricted fauna in TAG (e.g., Hay 1902; Barr 1961; Lewis 1982; Holsinger and Peck 1971; Peck 1989, 1995; Niemiller and Zigler 2013). Nearly all of the troglobionts (terrestrial obligate cave species) and stygobionts (aquatic obligate cave species) possess conspicuous traits uniquely associated with life in perpetual darkness and limited food resources (Culver and Pipan 2009). Tennessee currently ranks 2nd, with 170 species behind Texas (with 201 species) for the highest richness of obligate subterranean species in the United States. Also on the list, Alabama is 3rd (148 species) and Georgia is 10th (45 species).

The Appalachian Valley and Ridge (AVR) province extends from southeastern Quebec to northwestern Georgia and northeastern Alabama. In Tennessee, the AVR is the second largest karst area after the Highland Rim of the Interior Low Plateau (ILP). The AVR is characterized by parallel ridges and valleys of sandstones with faulted and folded shales and carbonates formed during the uplift of the Appalachian Mountains to the east. The ILP is comprised of horizontal carbonates with limited faulting or folding that extend from southern Illinois and Indiana, southward through Kentucky and Tennessee, and into northern Alabama. The Cumberland Plateau escarpments in Kentucky, Tennessee, Alabama, and Georgia have some of the highest cave densities in the United States, and the Cumberland Plateau in south-central Tennessee and northeastern Alabama is considered to be a hot spot for cave biodiversity, defined by both species richness and endemism (Culver *et al*. 2006). In contrast, the biodiversity of cave species in the AVR is significantly lower than the other karst regions in TAG (Niemiller and Zigler 2013).

Rather than reflecting true reductions in biodiversity in the AVR compared to the ILP, one hypothesis has been that lower biodiversity in AVR caves is due to poorer sampling efforts. Niemiller and Zigler (2013) evaluated cave faunal records throughout Tennessee and identified several undersampled areas in the AVR, defined as 20 x 20 km grid cells. They found only 5.0% of AVR caves in TAG had any records of cave-restricted fauna (Table 1). These results suggested that much diversity had yet to be discovered. Our research focused on addressing sampling gaps by conducting biological inventories in targeted areas of the AVR. By combining these bioinventories with faunal records from previously documented species occurrences, it is now possible to begin to assess geographic extents of some species and examine spatial patterns of biodiversity and endemism, which may highlight additional sampling gaps.

2. Methods

2.1. Bioinventory Efforts

To select caves for bioinventories, we obtained cave descriptions, maps, and locations from state surveys, including the Tennessee Cave Survey (TCS; http://www.subworks.com/tcs/), the Alabama Cave survey (ACS; http://www.alabamacavesurvey.org/main/index.php), and the Georgia Speleological Survey (GSS; http://caves.org/survey/gss/GSSWebsite/Home.html). We were unable to gain access to several caves due to difficulty in finding and obtaining permission from landowners. A secondary challenge was determining if a cave was in the AVR or ILP based on state maps and descriptions.

Bioinventories involved visual encounter surveys for cave life in terrestrial, riparian, and aquatic habitats, such as entrance areas, cave walls and ceilings, mud banks, rimstone pools, and streams. These surveys traversed the cave systematically from the entrance to the farthest extent of the cave explorable by the team. Search effort included lifting rocks and other cover, as well as searching through cobbles, detritus, and organic matter. Depending on the extent of the cave system, each survey typically involved 2 to 4 surveyors (maximum 12), with a search effort of 2 to 36 person-hours per cave visit.

Permits to conduct the research and to collect specimens were obtained from each AVR state. For fishes, amphibians, and reptiles, we made a concerted effort to capture individuals either by hand or with dip nets to confirm identification and to obtain voucher photographs. We also tried to capture representatives of each invertebrate species observed as voucher specimens. Specimens were collected by hand with the aid of brushes, aspirator, or fine-meshed dip nets for aquatic taxa, and placed into 70–100% ethanol. Specimens were sorted in the lab and identified to the lowest taxonomic level possible using published taxonomic keys and species descriptions.

To put our bioinventory efforts in the context of past knowledge of cave fauna in TAG, we also searched for additional distributional records of invertebrates and vertebrates in AVR caves in the scientific literature, unpublished reports, biodiversity databases, and museum accession records. Literature sources included journals, books, proceedings, theses and dissertations, government reports, and regional caving organization newsletters. Literature searches included keyword queries of ISI Web of Science, Google Scholar, and Zoological Record. Database sources included biodiversity databases maintained by the Tennessee Natural Heritage Inventory Program (TNNH) and the Bat Population Database, v2 (http://my.usgs.gov/bpd). We also queried the VertNet database (http://www.vertnet.org), a web portal to search accessions of over 170 vertebrate museum collections from 12 countries. Institutions for which accessions include AVR specimens are Auburn University Museum of Natural History, Carnegie Museum of Natural History, Kansas University Biodiversity Institute, Museum of Vertebrate Zoology at University of California-Berkeley, North Carolina Museum of Natural Sciences, Sam Noble Oklahoma Museum of Natural History, Santa Barbara Museum of Natural History, Museum of Texas Tech University, University of Michigan Museum of Zoology, Smithsonian Institution National Museum of Natural History, and the Western Foundation of Vertebrate Zoology.

3. Results And Discussion

Knowing that <5% of caves in the AVR of Tennessee had never been biologically surveyed, we began the field work by targeting counties that did not have any records for obligate cave fauna (e.g., Loudon, Sevier, Monroe, and Jefferson counties, Tennessee). Other Tennessee counties (e.g., Carter, Grainger, Meigs, and McMinn) had very few troglobiont records from just a handful of caves. For this study, we completed 113 cave trips for 95 unique caves from 2013 through 2016, which totaled bioinventories for 64 individual caves in eastern Tennessee, seven caves in northeastern Alabama, and 24 caves in northwestern Georgia. More than 45 researchers have been involved since 2013 (a list of participants is provided at http://www.speleobiology.com/projects/vrbio/contributors.html).

Species identifications are ongoing, but currently there are >221 identified taxa found from at least one AVR cave. To date, at least 80 distinct troglobiont species from AVR caves have been identified, with the expectation that this number will increase. For Tennessee, the percentage of known troglobionts in 14 of 21 surveyed counties increased, ranging from ≤2% increase in the number of caves with troglobionts (e.g., Carter, Sevier, and Jefferson counties, Tennessee) to as much as 30.8% increase (Monroe County). For some Tennessee counties (e.g., Hamblen, Jefferson, and Loudon), new records for troglobionts were made for all bioinventoried caves. But, for other Tennessee counties (e.g., Blount, Claiborne, Grainger, Hawkins, and Meigs), no new records were added. Collectively, the average increase in the number of caves with troglobionts was 8.0%, from 43 new bioinventories from the 2,255 known caves in the Tennessee AVR. This doubles the current knowledge of troglobiont distribution in AVR caves in Tennessee, and we anticipate a similar increase in knowledge for Alabama and Georgia.

3.1. Invertebrates

Identification of invertebrate specimens is ongoing. At present we have identified 163 taxa. This includes: two flatworms (potentially five after identifications are complete), four annelids, 14 crustaceans (potentially 22), 25 arachnids (18 spiders, three harvestmen, four pseudoscorpions), 16 millipedes, 10 springtails, two diplurans, 18 beetles, six flies, two moths, three crickets, and 20 snails. Seventy-seven of these taxa are considered troglobionts. These data include new distribution records for 15 terrestrial and aquatic taxa, including troglobiont spiders (*Phanetta subterranea*, *Porrhomma cavernicola*, *Nesticus dilutes*), pseudoscorpions (Hesperochernes spp.), millipedes (*Scoterpes blountensis*, Pseudotremia spp., and other genera), beetles (*Pseudanophthalmus assimilis*, *P. pallidus*, *P. rotundatus*, *P. tennesseensis*, *P. unionis*), stygobiont amphipods (*Crangonyx antennatus*), isopods (*Caecidotea richardsonae*), and terrestrial snails (*Helicodiscus barri*, *Glyphalinia specus*). Several populations discovered may represent new species:

two aquatic hydrobiid snails, four millipedes, an annelid, a harvestman, and at least five pseudoscorpions.

Pseudoscorpions: In the eastern United States, the enigmatic genus Hesperochernes comprises two species, *H. holsingeri* (Muchmore, 1994) and *H. mirabilis* (Banks, 1895). Over 150 populations from caves located south of the Ohio River have been attributed to *H. mirabilis* or to the genus with no species-level identification. In contrast, *H. holsingeri* is known from two caves in Indiana. All of these were identified by William Muchmore, the only North American pseudoscorpion taxonomist active between 1960 and 2000. He was of the opinion that *H. mirabilis* is highly variable both within populations and across its geographic range (Muchmore, 1994). The genus is currently being revised using a combination of molecular and morphological methods; accordingly, identifications at present are limited to the generic level. Published records from 1967-1971 documented Hesperochernes from 19 caves in the AVR of TAG (11 Alabama, 7 Georgia, 1 Tennessee). We resampled populations from three caves (2 Alabama, 1 Georgia), and discovered 14 new populations from our other sampling efforts (6 Alabama, 3 Georgia, 5 Tennessee). Hesperochernes is now known from 49 caves in the AVR of TAG (29 Alabama, 14 Georgia, 6 Tennessee) (Stephen *et al*., 2016). Further sampling in the AVR is likely to uncover more populations, some of which may represent undescribed species of this widely distributed genus.

Other important pseudoscorpion discoveries include: (1) discovering new populations of a species thought to be extinct; (2) new populations of known species with restricted distributions; and (3) populations of species potentially not yet described. *Microcreagris nickajackensis* (Muchmore, 1966) is endemic to Nickajack Cave, Tennessee; it was thought to be extinct due to flooding of the cave system with the construction of Nickajack Dam in the 1960s (Lewis, 2009). Attempts to find the species in Nickajack Cave in accessible, unflooded areas of the cave were not successful. However, we discovered two populations of this presumed extinct species in nearby caves in Alabama and Tennessee. Discoveries of new populations of known species included three species in the genus Kleptochthonius. Two of these are endemic to the AVR: *K. affinis* (Muchmore, 1976), and *K. charon* (Muchmore, 1965). These species are now known from three and two caves, respectively. We also discovered *K. magnus* (Muchmore, 1966) for the first time in one cave of the AVR; previously it was known only from the ILP. Finally, populations of troglobiont pseudoscorpions in three families were discovered that may represent undescribed species. These include specimens identified as Neobisiidae from Limrock Blowing Cave, Alabama; Neobisiidae from Hooker Cave, Georgia; Olpiidae from Beech Spring Cave, Alabama; and two potentially new Tyrannochthonius (family Chthoniidae) from a cave in Georgia and a cave in Tennessee.

Millipedes: The millipede genus Scoterpes (Chordeumatida: Trichopetalidae) is comprised of 15 species that occur throughout much of the ILP and the southern AVR. In AVR, 6 species have been described, including *S. austrinus*, *S. blountensis*, *S. cf. copei*, *S. nudus*, *S. syntheticus*, and *S. willreevesi*. This project yielded several new distributional records of this genus in the AVR. New populations of *S. blountensis* were discovered in Knox and Sevier counties, Tennessee, while new populations of a likely undescribed species closely related to *S. copei* were discovered in Roane and Monroe counties, Tennessee. These populations are closely related to a population from Sensabaugh Cave in Meigs County, Tennessee, which was previously identified as *S. copei*. Over 250 specimens of other millipede taxa were collected and are currently being examined by Dr. Bill Shear. This material includes new records of the genera Pseudotremia, Oxidus, Polydesmus, Pseudopolydesmus, Cambala, and Tetracion, among others. Preliminary examinations suggest that at least four new species of Pseudotremia in east Tennessee and northeastern Alabama exist from these collections.

Beetles: Cave beetles in the genus Pseudanophthalmus (Carabidae: Trechini) constitute a large radiation of >140 taxa in the ILP and Appalachians karst regions. Previously, most species in the AVR were known from <5 caves. Bioinventories associated with this project documented eight species from 16 caves, including new distributional records for *P. assimilis* (DeKalb County, Alabama), *P. rotundatus* (Claiborne County, Tennessee), *P. tennesseensis* (Knox, Loudon, and Roane counties, Tennessee), and *P. unionis* (Campbell and Union counties, Tennessee). In addition, we also confirmed the continued existence of *P. paulus*, *P. pusillus*, and *P. wallacei*, all single cave endemics. *Pseudanophthalmus paulus* had not been observed in >50 years from Nobletts Cave in Monroe County, Tennessee. As such, all of these confirmations are significant for the IUCN Red List of Threatened Species and NatureServe conservation rank criteria for the different species. Additional material remains to be examined from Anderson and Hamilton counties, Tennessee, as well as material from northwestern Georgia.

Amphipods: At least eight species of troglobiotic crangonyctid amphipods (Amphipoda: Crangonyctidae) have been described from the AVR of TAG. We documented three species during our bioinventories: *Bactrurus angulus* (Taylor and Niemiller 2016), *Crangonyx antennatus*, and *Stygobromus mackini*. Several new distributional records of *C. antennatus* were documented. This species is one of the few troglobionts that has a wide distribution in the AVR. Additional material remains to be examined from northwestern Georgia and the southern AVR in East Tennessee, so other taxa may be documented. In addition, a possibly undescribed species may exist in Union County, Tennessee.

Snails: No previous records for aquatic cave snails existed in Tennessee prior to our investigations, and now aquatic snails have been found in four AVR caves in Tennessee (Keenan *et al*., 2016). A new population of aquatic hydrobiid snails was discovered in Knox County in 2013. The snails are thought to belong to an undescribed species of Fontigens. Another Fontigens, possibly the same species as observed in Knox County, was observed in two other AVR counties (Roane, 1 individual; Sevier, several individuals). An unidentified aquatic snail likely belonging to the genus Antrorbis was found in Roane County, Tennessee.

Annelids: Ectosymbiotic branchiobdellidans, *Bdellodrilus illuminatus*, *Cambarincola holostomus*, and an as of yet undescribed species likely belonging to the genus Cambarincola were found colonizing the dorsal and ventral surfaces of an ovigerous (egg-bearing) crayfish (*Cambarus bartonii cavatus*) in a Knox County AVR cave (Keenan *et al.* 2014). Branchiobdellidan worms are frequently observed on surface- and cave-dwelling crayfish, but several features stand out from this particular crayfish. *B. illuminatus*, when found, occurs in low density and is locally rare despite a wide range from southeastern Canada to Alabama. *C. holostomus* is endemic to Virginia, Tennessee, and North Carolina, but prior to our observations, this species was never observed on a cave-dwelling crayfish. The high density (200+ individuals) and physical location of the branchiobdellidans, in particular high densities on the rostrum, was also distinct from previous surface- or subsurface-based observations. The observation of an undescribed species of Cambarincola suggests that there is high potential for novel ectosymbiotic species within AVR caves.

3.2. Vertebrates

Several studies have resulted from this new research. For one study, an annotated list of 54 vertebrate taxa was generated from eight years of data for only vertebrates from 56 caves in 15 counties in the AVR of eastern Tennessee and adjacent Blue Ridge Mountains in Tennessee (Niemiller *et al.* 2016a). In total, the list included 8 fishes, 19 amphibian (8 anurans and 11 salamanders), 6 reptiles, 3 birds, and 18 mammals. Three species were associated with the IUCN Red List of Threatened Species and six species were identified at risk of extinction according to the NatureServe conservation rank criteria. Two new localities for the only cave-adapted vertebrate in the AVR of east Tennessee, the Berry Cave Salamander (*Gyrinophilus gulolineatus*), were reported. Five bat species were observed in 29 caves, and there were new records for the federally endangered Gray Bat (*Myotis grisescens*). New observations of White-Nose Syndrome were made in four caves in Blount, Roane, and Union counties in Tennessee.

Another study focused on the Southern Cavefish (*Typhlichthys subterraneus*), which has one of the largest distributions of any cavefish in the world, extending throughout the ILP of Kentucky, Tennessee, Alabama, and Georgia. A population of *T. subterraneus* was discovered in Crane Cave in the South Chickamauga Creek watershed. The cave formed in the Ordovician Newala Limestone in Catoosa County, northwestern Georgia, and is clearly within the AVR. This represents a significant range extension for this stygobiotic cavefish (Zigler *et al.* 2015; Niemiller *et al.* 2016b). Genetic analysis of the new fish was undertaken to compare it to other cavefish populations in the region. The new population is genetically related to other fish from the ILP on the western margins of Lookout and Fox mountains in Dade County, Georgia, where caves are formed in Mississippian limestones, as well as to populations in the Little Sequatchie River valley in southern Marion County, Tennessee, where the caves are also in Mississippian limestone. These findings suggest that the newly discovered population shares its evolutionary history with the Dade County, Georgia and Marion County, Tennessee populations. The common ancestor must pre-date the emergence of the modern drainage divide and subsequent isolation of the Crane Cave fish, which likely happened in the Late Pliocene. The timing of these events corresponds with the estimated divergence of the TAG *T. subterraneus* populations from other lineages in the ILP, about 2.2 million years ago (Niemiller *et al.* 2016b). The potential exists to discover additional cavefish populations in other AVR caves within the same limestone units in Georgia and Tennessee.

4. Conclusions

Rather than representing a true biological signal that caves in the AVR ecoregion of Tennessee, Georgia, and Alabama had lower biodiversity than caves in the ILP, we found that less than 5% of caves in the AVR were comprehensively bioinventoried prior to 2013. This paucity of biological surveys has resulted in significant gaps in our knowledge of subterranean biodiversity and distribution compared to the ILP. From 2013–2016, surveys of 95 unique caves in the AVR added observations of >221 troglobiont taxa. This effort has substantially increased the number of biosurveyed caves and our understanding of troglobiont distribution and diversity in the AVR. For some of the troglobionts, there appears to be high rates of endemism, with only a few species having wide distribution throughout the AVR. These surveys now also provide important information for the IUCN Red List of Threatened Species and NatureServe conservation rank criteria for several species. The potential for observations of additional novel taxa, new cave records for troglobionts, and continued range extensions is still high, and continued surveys will help to fill these gaps.

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Table 1. Number of known caves from the Valley and Ridge by state (as of 2016), caves with obligate cave species records, and the number of obligate cave species known. Note: the total number of species is not the sum of the values for the three states because some species are present in more than one state.

State	Number of caves in AVR	Number of caves with obligate cave fauna records	Number of obligate cave species	% caves withobligate cave fauna records
Tennessee	1459	75	50	5.1%
Georgia	213	8	16	3.8%
Alabama	317	16	25	5.0%
Total	1989	99	73	5.0%

nos. 1585 and 1605) (M.L.N.). This work was permitted by the Georgia Department of Natural Resources under scientific collection permit no. 8934 and approval by the University of the South IACUC committee (K.S.Z.). We thank Mr. Forrest Bailey of Alabama Department of Natural Resources for permission to collect in Alabama. We also are indebted to landowners for allowing us to study their caves, and appreciate the assistance of dozens of individuals during biosurveys, listed by name at http://www.speleobiology.com/projects/vrbio/contributors.html.

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Starving In The Dark: The Impact Of Ultra-Small Cells On The Microbial Community Of The Wind Cave Lakes

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Abstract

The lakes at Wind Cave National Park, South Dakota, provide a rare natural window into the Madison Aquifer, a major regional source of drinking water. At -200 m, the geologic isolation and long residence time of water *en route* to the lakes results in nutrient-limited conditions. Despite these conditions, a diverse microbial community is present in the lakes at low concentration (~2,300 cells/ml). Several recent studies on similarly oligotrophic groundwater have shown the presence of ultra-small cells – those smaller than the previous theoretical limits on cells size (0.2 µm diameter) – which may have an effect on community diversity studies performed in karst aquifer systems. To assess the effect of ultra-small cells on the lakes in Wind Cave, we compared lake microbial community profiles using 0.2 µm and 0.1 µm membrane filters. DNA was extracted for 16S rRNA community analysis from these filters and sequenced using Illumina MiSeq. The resulting assigned taxa in each sample appear to be similar; however, up to 30% of OTUs in the 0.1 µm sample remained unassigned to representative taxa, indicating that a large portion of the microbial community was previously excluded and remains unclassified. It is unclear as to why such a potentially high percentage of ultra-small bacteria would be found in the lakes, although the filtering effects of the rock/sediment matrix of groundwater travels en route to the lakes may play a role. Alternatively, the microbes in the lakes may have a small size through adaptation in such nutrient-limited conditions. We tested this alternative hypothesis by enriching filtered and unfiltered lake water and then filtering the resulting cultures again through 0.2 µm and 0.1 µm pore size. These data suggest that the small cell size is not a result of cell starvation and may be a specific adaptive trait. The processes that support survival in nutrient-limited cave environments remains virtually unexplored and community adaptations, including the role of ultra-small cells, is vital to understanding the cave microbial ecosystem as a whole.

Keywords: Karst aquifer, Wind Cave, Microbial community, 16S rRNA, Ultra-small microbes

Wind Cave, located in the Mississippian age Madison Limestone at the southeastern flank of the Black Hills of South Dakota, USA, and namesake to Wind Cave National Park, is an extensive network maze cave of hypogenic origin (Palmer and Palmer 2000). The lowest level of the cave intersects with the massive and ancient Madison Aquifer, a major source of water in the upper Midwestern United States as well as several provinces in Canada. At the cave-aquifer intersection, approximately 3 kilometers from the cave entrance and 200 meters below the surface, a series of cave lakes are formed that offer a rare natural window into an aquifer surface. In addition to being isolated from human contamination by both physically-difficult access and restriction of access by the National Park Service, the cave lakes are also separated from surface hydrogeological cycles (Ohms 2016). Water *en route* to the lakes has an estimated residence time 25 years, during which time many nutrients are stripped from the water (Back 2011).

Despite extremely nutrient-limited conditions (TOC < 0.30 mg/L), a diverse microbial community is present in the lakes, at a concentration of approximately 2,300 cells/mL, lower than any other oligotrophic lake examined (Barton 2011). As part of the ongoing study of the lakes, early measurements of microbial community diversity via 454-pyrosequencing estimated that up to 4,000 bacterial species were present, along with a small population of archaea and no detectable eukarya (Barton 2011).

Several recent studies, including one of similarly oligotrophic groundwater and another of Antarctic lake brine have revealed the presence of ultra-small microbial cells via enrichment of samples by passage through a filter pore size of 0.2 µm in diameter (Kuhn *et al.* 2014, Luef *et al.* 2015). Previously,

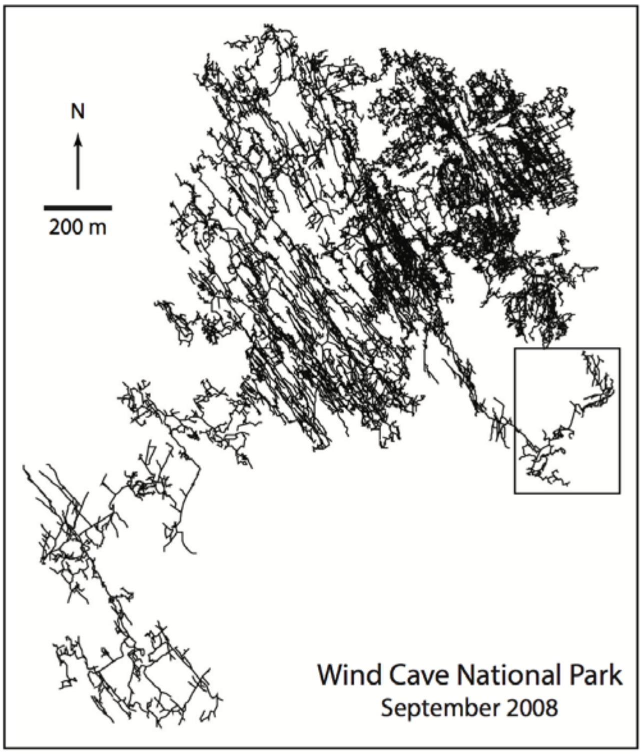

Figure 1. Lineplot of Wind Cave, Wind Cave National Park, South Dakota, USA. The lakes are located in the boxed area, in the lowest level of the cave (courtesy of Rod Horrocks, Wind Cave National Park).

minimum cells size was thought to be limited to no smaller than 0.2 µm in diameter due to the calculated space needed for genetic material, ribosomes proteins, cells membranes, etc., necessary for life (Luef *et al.* 2015). As a result of this perceived limitation, environmental microbial samples are often

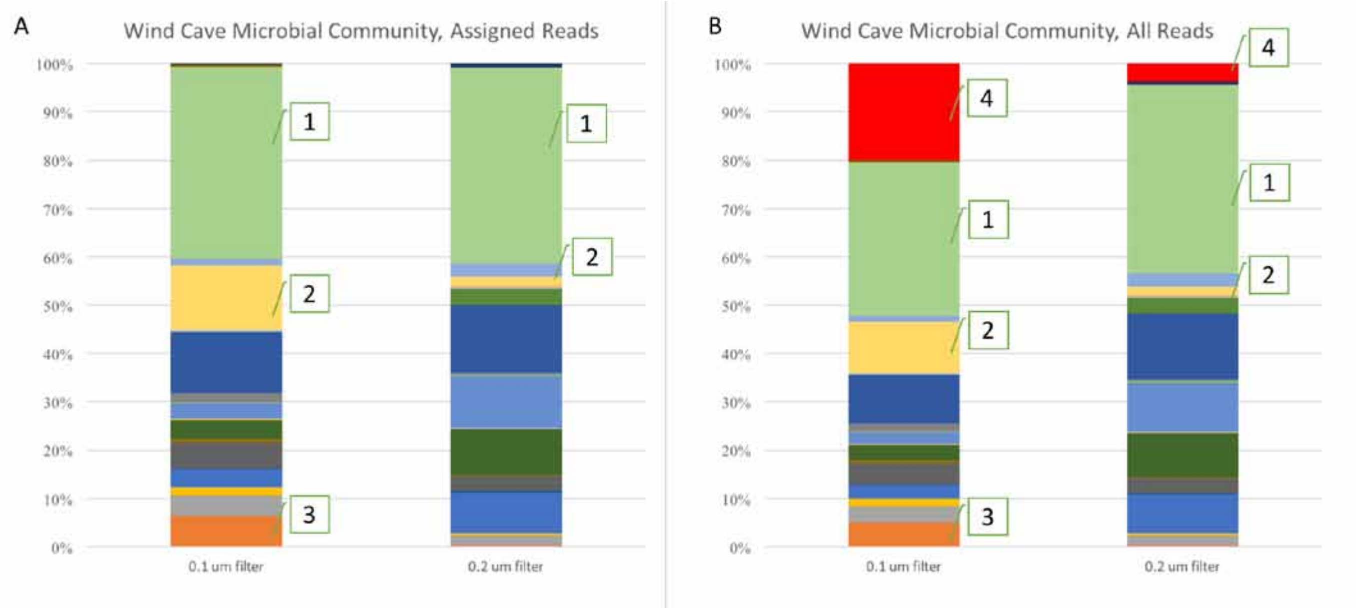

Figure 2. Taxa bar chart of microbial community at the phylum level, assigned reads only. [1] Proteobacteria*, [2]* Nitrospira*, [3]* Euryarchaeota. Nitrospira *and* Euryarchaeota *are known to have some species with small morphology and are are more highly represented in the 0.1 mm sample. B) Taxa bar chart of microbial community at the phylum level, including [4] unassigned reads. Only 3% of reads in the 0.2 mm sample were unassigned, whereas 20% were unassigned in the 0.1 mm sample.*

collected on the surface of 0.2 μm filters, as few cells would be expected to pass through the filter. This assumption may have had an effect on community diversity studies performed in karst aquifer systems by excluding an important part of the community by size exclusion.

To assess the effect of ultra-small cells on the lakes in Wind Cave, we compared the previous community analysis, collected on a 0.2 μm membrane filter (Barton 2011), to a new microbial community profile collected on a 0.1 μm membrane filter. Given the very low cell counts in the lakes, approximately 200 L of lake water was filtered over ~24 hours through the 0.1 μm membrane filter using a portable battery operated Global Water SP200 (Xylem, White Plains, New York, USA) variable speed peristaltic pump. The membrane was collected and preserved for transportation in 70% ethanol. DNA was extracted from the membrane filter via a phenol/chloroform/isoamyl alcohol extraction, then purified of inhibitors and concentrated using the Boreal Genomics Aurora System (Vancouver, BC, Canada). For microbial community analysis, 16S rRNA sequence was amplified using universal primers for bacterial and archaeal 16S rRNA (V3/V4 region) with Illumina iTag barcoded sequences. The DNA was sequenced on the Illumina MiSeq at the University of Kentucky Advanced Genetic Technology Center (Lexington, Kentucky, USA). Sequences were trimmed and demultiplexed by the sequencing facility. The resulting sequences were evaluated using the open source Quantitative Insights into Microbial Ecology (QIIME) software, using the recommended scripts for open reference OTU picking with the most recent Greengenes database (Caporaso *et al*. 2010).

The resulting assigned taxa in each sample appear to be similar; however, when including unassigned taxa, the community profiles become distinguishable. When using Greengenes, a widely-used database in many microbial community analyses, approximately 30% of the OTUs in the 0.1 μm sample remain unassigned to representative taxa. However, the latest Greengenes update (May 2013) lags behind in newly released taxa information, so the data was analyzed again using the more frequently updated and curated SILVA database, most recently updated in May 2016 (Quast *et al*. 2012). Using the SILVA database, 20% of sequences in the 0.1mm still remained unassigned to representative taxa. This indicates that a large portion of the microbial community was previously excluded in the 0.2 μm sample, and remains unclassified in the major databases due to size exclusion in database cultivation. In the 0.1mm sample, unclassified microbial sequences are second only to Proteobacteria in sequence dominance, which is represented by ~32% of sequences.

It is unclear as to why such a potentially high percentage of ultra-small bacteria would be found in the lakes, although the filtering effects of the rock/sediment matrix of groundwater travels en route to the lakes may play a role. If the pore size of the matrix restricts the passage of larger microbes, a higher proportion of small microbes would be represented. Alternatively, the oligotrophic conditions of the lakes may play a role in the size distribution of microbes in the lakes, either by producing an environment in which small size evolved as an adaptation to low nutrient availability.

We tested this alternative hypothesis by collecting and enriching filtered and unfiltered lake water with various liquid media. The cultures were allowed to grow for ~2 weeks, and subsequently filtered cultures through 0.2 and 0.1 μm pore size syringe filters, into fresh media. In several samples, growth was observed after filtration, indicating that cell size did not increase when extra nutrients were initially provided. These data suggest that the small cell size observed in both culture-dependent and culture-independent methods of observing the microbial community may not be a result of cell starvation and may be a specific adaptive trait to surviving in an oligotrophic environment.

As a whole, the processes that support microbial survival in nutrient-limited cave environments remain largely unexplored. The growing field of metagenomics has advanced our knowledge of the presence and potential role of microbes in a well studied groundwater system (Anantharaman *et al.* 2016) as well as the role of cave microbes in some specific nutrient cycles (Tetu *et al.* 2013; Ortiz *et al.* 2014). However, community adaptations to subterranean oligotrophic environments, such as the acquisition of small cell size for increased nutrient uptake efficiency, may greatly effect the accuracy of a community survey resulting in an incomplete genetic picture of the community. Understanding such adaptations is vital to understanding the cave microbial ecosystem as a whole.

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(Abstract) **Tropical karst as an island of biodiversity: Melody Rocks, Cape York Peninsula, Australia**

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Abstract

Greater Melody Rocks consists of two isolated karst areas about 30 km SW of Cooktown. These were were poorly known until late 2013 when detailed exploration commenced. They are the only karsts within the Cape York Bioregion and lie in close proximity to the Great Barrier Reef and Wet Tropics World Heritage Areas. The climate is heavily monsoonal. Due to the unique cave habitats and karst-dependent vegetation communities these karsts are areas of exceptionally high biodiversity. Erosion patterns on the exposed surface show impressive examples of tropical karst landform solution features: massive rillenkarren, dramatic spitzkarren pinnacles and kamenitza. The larger eastern karst has three extant towers and at least a further six in various stages of collapse. The karst towers are highly cavernous with rifts, pits and extensive phreatic passages. These have been only partially explored and mapped. To date nineteen species of bat have been recorded in the karst area. The only breeding site currently known in Australia for the nationally endangered large-eared horseshoe bat, *Rhinolophus philippinensis* was confirmed in the site's largest known cave complex. A second endangered species, Semon's leaf-nosed bat, *Hipposideros semoni* also uses this karst and there is strong indication that it too is breeding there. Records of other species of conservation significance in the eastern karst area include: bare-rumped sheathtail bat *Saccolaimus saccolaimus*, ghost bat *Macroderma gigas*, northern quoll *Dasyurus halucatus*, red goshawk *Erythrotriorchis radiatus* and the orchid *Dendrobium bigibbum*. There is a wide range of invertebrate species, many still to be collected and described. The smaller western karst (located 7 km away) consists of one extant and one collapsed tower. This karst has the largest breeding colony of *M. gigas* currently known in Queensland. The combination of soil chemistry and climate supports a unique rainforest assemblage on the karsts, making a sharp contrast to the monsoonal savanna woodland present on the surrounding metamorphic sediments. The rainforest here is variously wholly or partially deciduous and includes at least five plant species listed as threatened in Queensland. Five indigenous rock art sites have been located to date, one featuring engravings that elsewhere in the region are dated to 10,000 BP. One occupation site in a rugged and inaccessible part of the karst contains worked glass implying a post-contact site. There is a current application for a mining lease to quarry the eastern karst.

Observations of the first stygobiont snail (Hydrobiidae, *Fontigens* sp.) in Tennessee

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Abstract

The Appalachian Valley and Ridge (AVR) region of East Tennessee (USA) is one of the most cave-rich areas of the state, with approximately 1,470 caves in a 6,379 km^2 area. Despite decades of exploration, only 5.1% of caves in the area were biologically inventoried prior to 2013 and basic data on species distributions were lacking. This sampling gap prompted the start of ongoing biological surveys in the AVR. One of the first AVR bioinventories took place in 2013 in a small cave in Knox County (TKN24). A surface stream enters the cave from the northeast and flows down-dip through the lower wet passage. The cave receives a high anthropogenic load in the form of surface runoff, physical debris (i.e., trash), and raw sewage. In 2015, a large sewage release flushed through the cave, but prior estimates of total aerobic bacterial loads in 2014 indicated an unhealthy waterway.

Despite the obvious human impact, during the bioinventory we identified 14 invertebrate and five vertebrate taxa. Of particular interest were the small (1–3 mm), white to translucent, aquatic hydrobiid snails attached to the sides and bottom of rocks in the stream, which represent the first stygobiotic snail discovered in Tennessee. Detailed monthly surveys were conducted from March to August 2014 to gain insight into the snail's life history, abundance, physical distribution within the cave stream, and habitat preferences. Snail abundance and density were estimated from visual-encounter surveys in a single area of the stream passage. Surfaces of ten rocks were examined during each survey. Most (65 to 100%) of the snails were observed on the bottom of rocks completely submerged in the stream water. Snail density negatively correlated with increasing temperature ($R^2 = 0.61$) and was greatest in March (1.11 snails per m^2) in 9 ˚C water and lowest in August (0.39 snails per m^2) in 15 °C water.

This new Tennessee hydrobiid has been identified as a member of the genus *Fontigens* based on morphology. Previously described stygobiotic hydrobiid snails from karst regions in the eastern United States include *Antrorbis breweri* from northeastern Alabama, *Fontigens bottimeri, F. morrisoni, F. tartarea, F. turritella*, and *Holsingeria unthanksensis* from the Virginias, as well as *F. cryptica* from Indiana, *F. antroectes* from Illinois, and *Antroselates spiralis* from Indiana and Kentucky. This new population extends the distribution of the genus into Tennessee.

Keywords: Hydrobiid, cavesnail, Appalachian, aquatic, invertebrate, mollusc

1. Introduction

Biological surveys of subsurface invertebrate diversity continue to provide a wealth of new information about cave fauna, including the discovery of previously undescribed species. The Appalachian Valley and Ridge (AVR) region of East Tennessee is particularly promising for the discovery of new invertebrate taxa, and for extending ranges of known invertebrate and vertebrate taxa. This region has been undersampled compared to neighboring karst areas like the Interior Low Plateau (Niemiller and Zigler 2013; Niemiller *et al.* 2016). Recent efforts to fill this sampling gap highlight the need for continued research in and exploration of this region (e.g., Keenan *et al.* 2014; Niemiller *et al.* 2016). One of the reasons for a sampling gap may be because biodiversity in AVR caves has been assumed to be lower than in other karst regions, due in part to the caves being smaller in length and size, and because smaller caves could have limited habitat availability (e.g., terrestrial and/or aquatic habitats) to support a more specious fauna. Another reason why AVR caves may have been ignored in the past for biodiversity studies is because many of the known cave systems have the potential

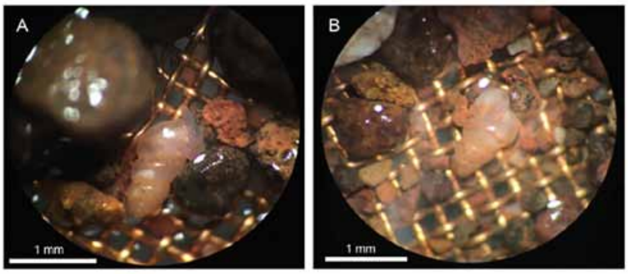

Figure 1. Photographs of snails recovered from Cruze Cave. (A) Lateral and (B) ventral views of two snails recovered from sieved cave sediment. The sieve mesh is 30 μm wide.

to be impacted by human activities, such as contamination from road waste, agricultural waste, or urbanization, as well as from visitation by people and enhanced foot-traffic due to their proximity to urban centers.

During a biosurvey of Cruze Cave, Knox County, Tennessee (TN24) in May 2013, tiny, white, aquatic snails were observed on several rocks within the cave stream, approximately 75

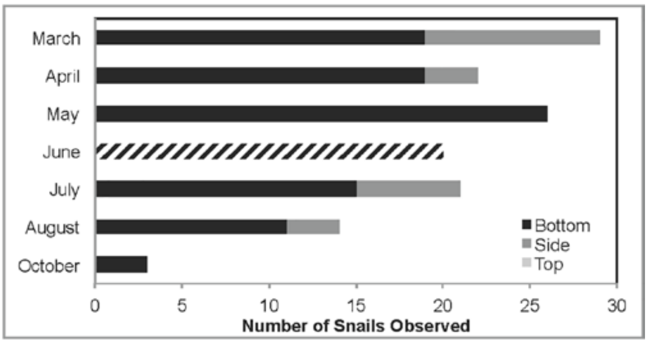

Figure 2. Physical distribution of snails on rocks during each monthly observation period. During the June observations, physical distribution data were not collected, but approximately 75% of snails were observed on the bottom of rocks and the remaining 25% were observed on sides of rocks. No snails were observed on the tops of rocks.

m from the cave entrance. There had been several previous accounts of terrestrial snails in cave systems in Tennessee, as well as aquatic snails likely transported by fluvial systems during high flow events (Hubricht 1940, 1964). However, to our knowledge, the presence of stygobiont snails in the state had not yet been reported. This absence in the literature has been surprising, especially considering the diversity of stygobiont snails known from adjacent states in the Appalachian region, including Virginia, Alabama, and Kentucky (Hershler 1989; Hershler and Thompson 1990; Hershler et al. 1990; Lewis 1994), as well as other bordering states, including Missouri (Peck 1998; Lewis et al. 1999) and Arkansas (Graening 2003).

Cruze Cave is developed along southeast-dipping bedding and fracture planes within the Holston Formation (Knox Group), which is comprised of Ordovician-aged carbonates and interbedded shales and sandstones. Cruze Cave is located within the city limits of Knoxville, and a dozen homes are within 500 m of the cave entrance. The cave is approximately 19 m in depth (total vertical extent), and the lower, main passage extends for a surveyed length of about 300 m. A surface stream enters the cave and flows through the length of navigable passage before ending in a narrow sump. Because of the direct connection to the surface, stream flow is subject to variable discharge during intense rainfall events. Anthropogenic debris (i.e., lawn chairs, bottles, trash, road waste) is wedged within passage fractures as high as 4 m above the base-flow streambed. During base-flow conditions, the stream is 12 cm deep or less. Sampling was only done during base-flow conditions. In addition to visible trash, the presence of pervasive brown- to- orange biofilms covering all underwater surfaces of the cave indicated a high organic load to the cave, such as from sewage. Such biofilms would provide a nutrient source for the snails and other macrofauna, even if the microbes were linked to sewage contamination. The aims of this study were to evaluate snail population densities over time, and to evaluate stream water quality, including confirming if there was continued sewage contamination into the cave.

2. Methods

Detailed monthly surveys occurred from March 2014 until August 2014. The purpose of the surveys was to gain insight into the life history, abundance, physical distribution, and habitat preference of snails within the cave stream. Snail abundance and densities were estimated from visual-encounter surveys in a single area of the stream passage, located approximately 150 m from the entrance. The surfaces of ten fully submerged rocks were examined during each survey for the presence of snails. Rock length, width, and height were measured to quantify surface area. When encountered, snail position on the rock was recorded as top, bottom, or side.

Stream physiochemistry, including water pH, conductivity, and temperature, was measured using standard field instruments. During one sampling event in October, total aerobic bacteria and total yeast and mold colony forming units (CFU) counts per mL were conducted using RIDA® COUNTs culture plates (R-Biopharm AG), according to manufacturer instructions.

3. Results

All of the observed snails were unpigmented and ranged in size from sub-mm to 3 mm in length (Figure 1). Their shells were turreted with 4-5 rounded whorls, and ranged in color from completely clear to orange/brown, and sometimes appeared spotted, which was likely due to variable colonization of microbial biofilms or food within the snail gut. The snails were identified as belonging to the genus Fontigens (Robert Hershler, personal communication), although the species is new and currently undescribed.

During the observation period, snails were restricted to the bottom (84%) and sides (16%) of rocks (Figure 2). Total snail density, presented as a function of rock surface area, ranged from 1.11 snails/m^2 in March to 0.39 snails/m^2 in August, the highest and lowest density time points, respectively (Table 1).

Snail density negatively correlated with increasing temperature (R^2 = 0.573), with the greatest number and highest density of snails observed in March (29 snails, 1.11 snails/m2) in 9 °C water, and the lowest in October (3 snails, 0.3 snails per rock) in almost 15 °C water (Figure 3). In addition, the snail density increased as the stream chemistry shifted from pH ~7.0 up to pH 7.7 (R^2 = 0.509). Snail density was not correlated with conductivity (Figure 3; R^2 = 0.001).

Total aerobic bacteria and total yeast and molds were quantified from water at three locations along the cave stream: upstream of the snails (approximately 50 m from the

Table 1. Number of observed snails, snail density, and stream physiochemistry at each observation point (2013).

	#of Snails	# of Rocks	Snail Density/ Surface Area (m2)	pH	Temp. (°C)	Conduc-tivity (µS/cm)
March	29	6	1.11	7.72	9.7	426
April	22	10	0.73	7.66	10.9	437
May	26	12	0.48	7.51	11.1	401
June	20	13	0.62	7.3	11.7	142.8
July	21	10	0.72	7.25	12.6	362
August	14	10	0.39	6.98	13.7	504
October	3	10		7.04	14.7	297.4

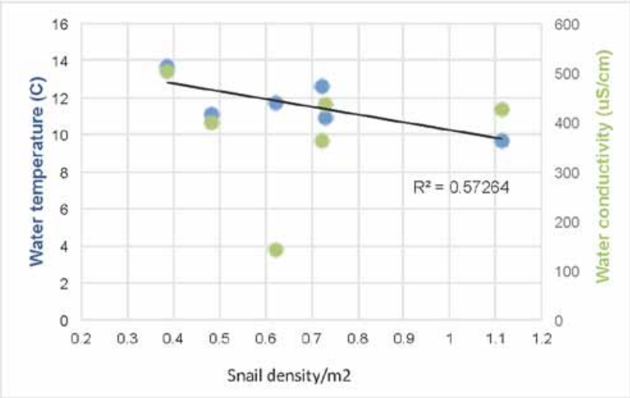

Figure 3. Snail density as a function of water conductivity (µS/cm) and water temperature (°C). The number of observed snails negatively correlated with temperature.

entrance), next to the snails, and downstream (approximately 250 m from the entrance). Aerobic bacterial CFU decreased along the length of the passage, as did the CFU per ml for yeast and molds (Table 2).

4. Discussion

The distribution, ecology, and systematics of hydrobiid snails within the genus *Fontigens*, particularly subterranean species, are largely understudied. In the years since the Cruze Cave discovery, several other individuals likely to be of the same species were discovered from two caves in nearby Roane and Sevier counties in Tennessee. As the first reported stygobiont snail from Tennessee, the Cruze Cave snails will help to fill a large gap in our understanding of hydrobiid distribution in the AVR because the current range of stygobiont hydrobiids includes the states that neighbor Tennessee: Virginia and Kentucky to the north and Alabama to the south (Hershler *et al.* 1990; Lewis 1994), as well as Missouri (Peck 1998; Lewis *et al.* 1999) and Arkansas (Graening 2003) to the west.

The Cruze Cave *Fontigens* sp. snails preferred to colonize the bottom and sides of rocks within the streambed rather than the top surfaces that could be exposed to flowing water and predators. The Enigmatic Cave snail (*Fontigens antroecetes*) from Illinois and Missouri has a similar niche preference for the bottom (~80%) and sides (~15%) of rocks in its cave stream (Taylor *et al.* 2013). It is likely that the snails graze the microbial biofilms on the rocks, and that the high load of microbial cells in the cave stream serve as a constant supply of microbes for biofilm growth. Additional research needs to be done to determine if the microbial load changes seasonally,

Table 2. Total aerobic bacteria and total yeast and mold counts from three locations along the Cruze Cave stream.

	Total aerobic bacteria (CFU per mL)	**Total yeast and mold (CFU per mL)**
Upstream	2600	181
Midstream (near snails)	1352.5	48
Downstream	1200	25.5

which may affect the snail population densities. It is clear that seasonal changes in population density do correlate to temperature and/or pH changes in the stream water. The current dataset did not indicate a relationship with conductivity.

5. Conclusions

The discovery of stygobiontic hydrobiids in three caves (at present) in the AVR region of East Tennessee supports recent suggestions that there is high potential to discover new species in the region, as well as high potential for species range extensions (Niemiller and Zigler 2013). As Cruze Cave demonstrates, even caves that are heavily impacted by human activity have the potential to host diverse invertebrate (and vertebrate) communities, and more caves within urban watersheds should not be dismissed for future biosurveys. Assumptions that cave faunal diversity may be lower because a cave is small or because of anthropogenic impacts should not be used as criteria to guide biosurveys in the AVR region.

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Active Surveillance of Coronaviruses and Paramyxoviruses in Korean bats in 2016

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Abstract

Bats play a critical role in several emerging infectious diseases. Coronavirus (CoV), paramyxovirus and lyssavirus have zoonotic potential continue to be discovered in bats around the world. This study was to investigate recent viruses from the bat samples in Korea. Consensus primers-based reverse transcriptase polymerase chain reactions (RT-PCRs) and virus isolation have been performed to detect viruses from 212 bat samples collected at around 48 sites of the bats' natural habitats since March, 2016. It was revealed that there are diverse coronaviruses in Korean bat faeces: alphacoronaviruses and betacoronaviruses including SARS CoV-like bat CoVs. In addition, unclassified bat paramyxoviruses which might be related to the genus henipavirus were detected. A novel paramyxovirus was also isolated from the bat sample and its characteristics studied. This study may provide recent information on the bat viruses circulating in Korea and their zoonotic potential. There should be continuous surveillance and research on viruses in bats.

Keywords: Bat, RNA virus, Coronavirus, paramyxovirus, lyssavirus, Korea, zoonotic potential, active surveillance

1. Introduction

Bats are considered reservoirs of several emerging pathogens. Recently emerging human viruses, such as severe acute respiratory syndrome coronavirus (SARS-CoV), Middle East respiratory syndrome coronavirus (MERS-CoV), Nipah virus, Hendra virus, and Ebola virus are all thought to be bat-borne viruses (Han *et al*., 2015). In addition, new species of influenza A viruses, lyssaviruses, paramyxoviruses, and coronaviruses continue to be discovered in bats around the world (Tong *et al*., 2013; Banyard *et al*., 2014; Mortlock *et al*., 2015; Yang *et al*., 2014). Therefore, viruses that originate in bats may be a source of additional spill over from wildlife into domestic animals and humans (Plowright *et al*., 2015).

In Korea, SARS-like, MERS-like coronaviruses were recently detected in the bat faeces (Kim *et al*., 2016). Several RNA viruses such as group H rotavirus were also found. Therefore, in this study, we continuously investigated RNA viruses in bat faeces at natural bat habitats as a follow-up study.

2. Materials and methods

Bat faecal samples were collected at the sites of natural bat habitats, such as caves, an abandoned mine, and under a bridge. Fresh bat faeces were placed into a transport medium in 10% suspension and were transported to the laboratory for further analysis. The major bat species at the collection sites were determined based on morphology and on previous data from bats' roosting sites (Han *et al*., 2012), and presented in table 1.

Table 1. Information on the major bat species found in the sampling sites

Province	Sampling sites	Major bat species
Kangwon	15	Hypsugo alaschanicus
		Eptesicus serotinus
		Myotis daubentonii
		Rhinolophus ferrumequinum
Kyungsang	7	Miniopterus schreibersi
		Hypsugo alaschanicus
		Rhinolophus ferrumequinum
		Murina leucogaster
Jeju	15	Miniopterus schreibersi
		Rhinolophus ferrumequinum
		Myotis bombinus
Jeonla	5	Rhinolophus ferrumequinum
		Myotis macrodactylus
Chungcheong	6	Eptesicus serotinus
		Rhinolophus ferrumequinum
		Miniopterus schreibersi
		Myotis daubentonii
		Murina leucogaster

RNA was extracted from the faecal samples using TRIzol LS (Invitrogen Corp., Carlsbad, CA), and cDNA was synthesized with a commercial M-MLV reverse transcriptase kit (Invitrogen Corp., Carlsbad, CA) following the manufacturer's protocol. Consensus primer-based reverse transcriptase polymerase chain reactions (RT-PCRs) were performed to detect influenza A viruses, coronaviruses, lyssaviruses, and

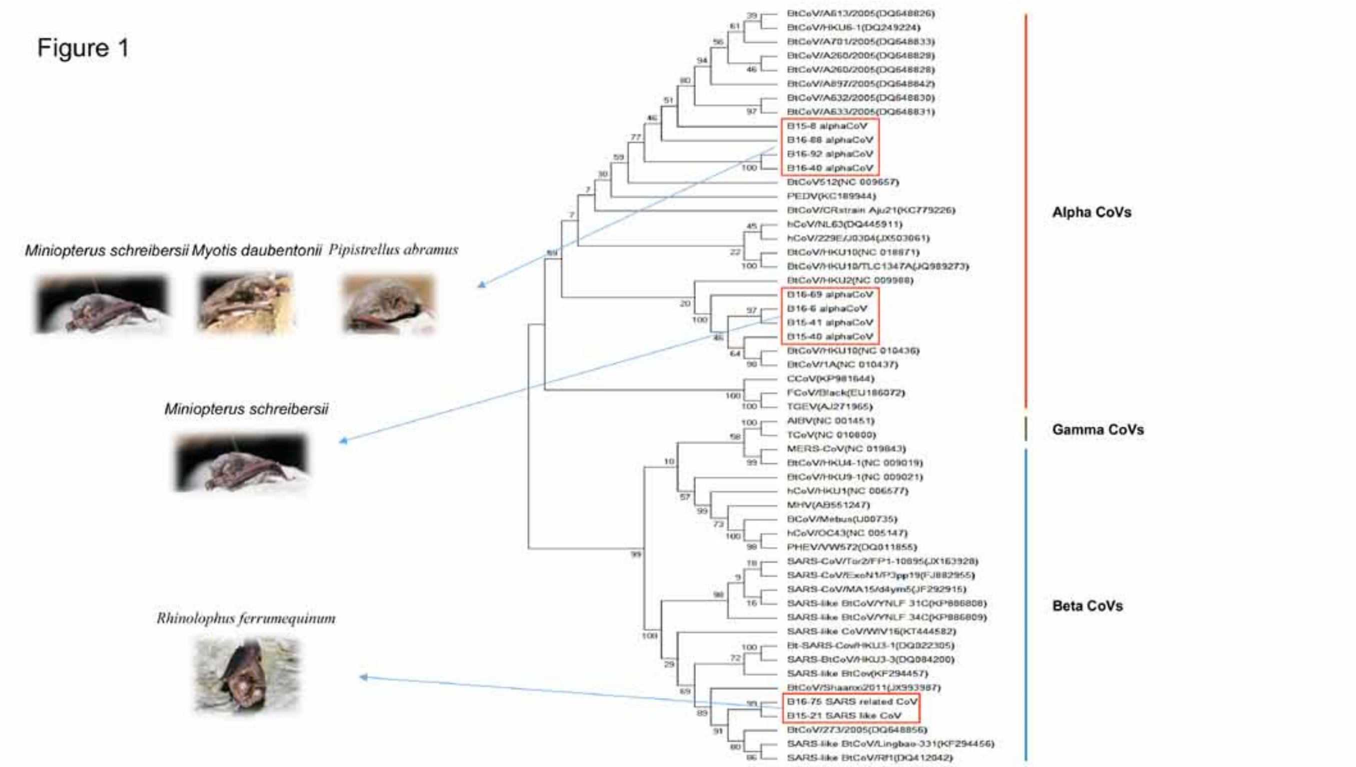

Figure 1. Phylogenetic analyses of nucleotide acid sequence of the 306bp fragment of RDRP gene of coronavirus were performed by the Maximum-like hood 1,000 replicates bootstrap method and Kimura 2-parameter model using MEGA 6.

paramyxoviruses (Fouchier *et al*., 2000; Poon *et al*., 2005; Vázquez-Morón *et al*., 2006; Tong *et al*., 2008).

Amplicons from positive RT-PCRs were sequenced using target-specific forward and reverse primers synthesized by Cosmogenetech Co. Ltd. Some samples were submitted to Macrogen (Seoul, Korea) for high-throughput sequencing in a HiSeq 2000 sequencing system based on the transcriptome de novo sequencing platform. The sequences were aligned with related reference sequences using ClustalW. The aligned sequences were trimmed using BioEdit. Phylogenetic analyses based on neighbor-joining, maximum likelihood and UPGMA methods were conducted using MEGA ver. 6.

3. Results

Alphacoronaviruses and SARS-like bat coronavirus were continuously detected in the bat samples collected in 2016. The phylogenetic analysis based on the RDRP sequences showed that the coronaviruses in Korean bats were divided into three major groups, two in alphacoronavirus group and one in betacoronavirus group (Fig. 1).

A bat paramyxovirus was also detected for the first time in Korea. Phylogenetic analysis showed that the bat paramyxovirus detected in this study closely related with genus Henipavirus which includes nipahvirus, but in a different clade. (Fig. 2)

4. Discussion

Although the alpha-coronavirus and SARS-like CoV detected in 2016 was not distinct from the one found in 2015, a bat paramyxovirus is detected for the first time in Korea. Phylogenetic analysis showed that the bat paramyxovirus detected in this study closely related with genus henipavirus which includes nipahvirus. The natural host of the nipah virus are bats and this virus is also capable of causing disease in human, pigs and other domestic animals. Therefore, there should be continual surveillance and research of viruses with zoonotic potential in domestic bats.

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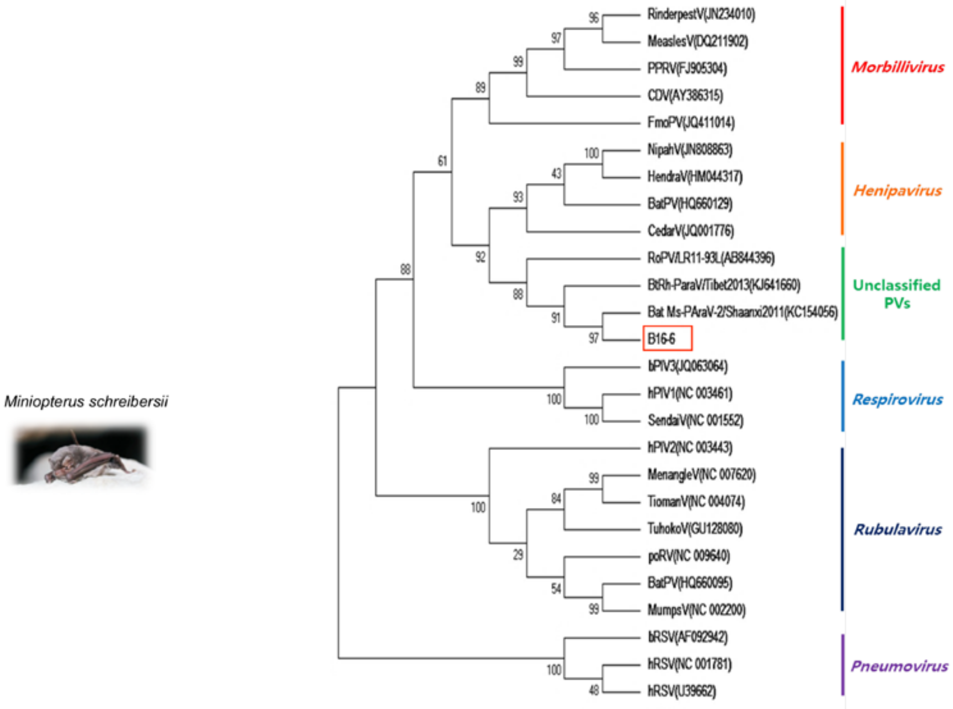
Figure 2



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First record of the Order Palpigradi Thorell, 1888 (Arachnida) from South Korea

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Abstract

The order *Palpigradi Thorell*, 1888, have studies initiated from early 1900 by Silvestri, and comprehesive studies conducted by Condé. Two families, 7 genera and 102 species of Palpigradi have been recorded in the world, and there has been only one species, *Koeneniodes madecassus* Rémy, 1950, described, from the East-Asia region (China) (Condé, B. 1993; Marvey 2003; Marvey 2013). Palpigradi inhabit soil, litter, and caves, and endogean ecosystems. Palpigrades have a small body size (less than 3mm) with leg-like pedipalps, an ovate abdomen, and a pair of three-segmented chelicerae with a long terminal flagellum(Marvey 2013). In this study, we discuss a newly record of cave-dwelling Palpigrade in Gossi-gul cave, Gangwon-do province, South Korea.

Keywords: first record, order, Palpigradi, South Korea

Figure 1. Gossi-gul cave

Figure 2. Live palpigradi in Gossi-gul cave habitat.

1. Introduction

Class arachnid includes five orders, pseudiscorpionida, araneae, opiliones, scorpiones, and acari. Palpigradi have very small body size, no eyes, three-segmented chelicerae with a long multi-segmented terminal flagellum. This is a new record for Korea.

2. Materials & Methods

The specimens were collected in Gossi-gul cave, Gangwon-do province, South Korea.

3. Result

We have had difficulty in studying palpigradi because only one specimen in Gossi-gul cave was collected. However this is still meaningful because this is the first record of this Order palpigradi in South Korea.

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Microhabitat Distribution Of Invertebrates In White Cave, Mammoth Cave National Park, Usa

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Keywords: Cave cricket, *Hadenoecus subterraneus*, *Meta* cave spiders, camel crickets, *Ceuthophilus stygius*, White Cave, Mammoth Cave National Park

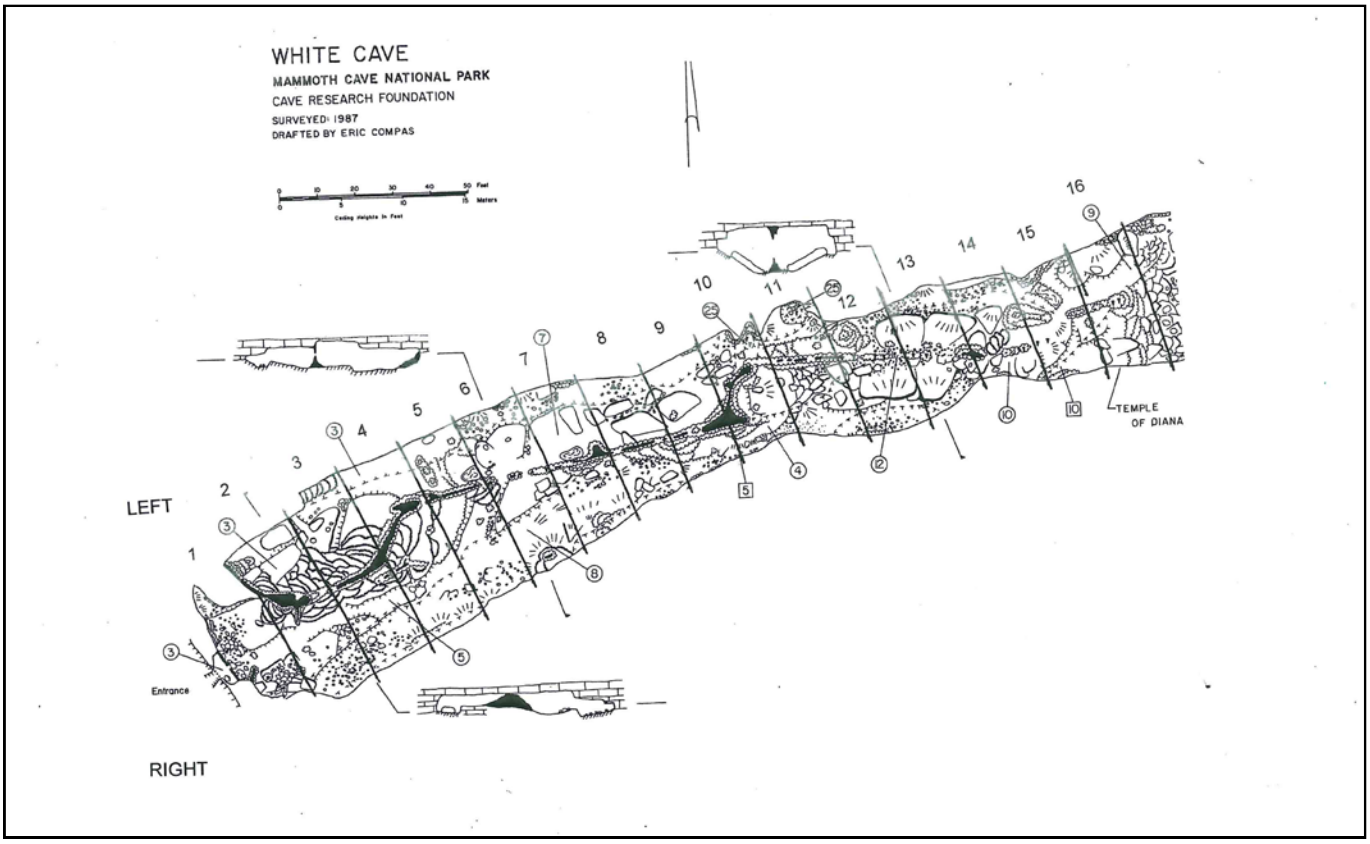

Figure 1. Map of The first 80 m of White Cave divided into sixteen 5 m transects that parallel the entrance gate. The curtain begins at the start of transect 2 and ends after transect 14. The cave is entered through a bat friendly gate to the Right of the curtain. The area behind the curtain is designated as Left.

White Cave is a remnant trunk passage on Mammoth Cave Ridge but separate from historic Mammoth Cave in Kentucky. White Cave is roughly bisected by a curtain of formations that divides the cave into a left side behind the curtain, and the right side, where the entrance is located (Fig 1). Although the curtain has numerous openings, we wanted to know if it affects the microclimate and the distribution of invertebrates.

In June 2016 we collected data on the distribution of animals on both sides of the curtain by 5 m transects through the first 80 m of the cave using a visual census (Fig 1). The dominant invertebrate, *Hadenoecus subterraneus* cave crickets (Lavoie *et al.* 2007), were subdivided during the census into four size classes (SC) (SC4 are adults with hind femur lengths ≥ 20 mm; SC3 adolescents with HFL of 15-20 mm; SC2 are juveniles with HFL 10-15 mm; and SC1 are young with HFL ~5-10 mm). We characterize White Cave as a sink cave, where the numbers of large (SC3 and4) crickets typically exceeds the number of small crickets (SC1 and 2) (Gilmore *et al.* 2016).

As expected, the numbers of invertebrates drops off with distance into the cave. Numbers of cave crickets of all size classes were significantly higher on the right side of the curtain than the left until 75 m (Transect 15) into the cave when numbers reached very low levels. *Ceuthophilus stygius*, a trogloxene, was only found on the right for the first 15 m. *Meta* cave spiders roughly showed the same pattern of distribution as the cave crickets. Total numbers were: *H. subterraneus* 8044 ; *C. stygius* 95; and *Meta* 68.

Although temperature and RH measurements are identical on both sides of the curtain, there may be subtle environmental clues that favor cricket distribution to the right of the curtain. Perhaps the curtain is not as freely penetrable as we expected, or there may be cues that signal the crickets when times to leave the cave to forage may be more opportune on the right where the entrance is visible.

Figure 2. The keystone cave cricket species, Hadenoeccus subterraneus.

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(Abstract) **Monitoring subterranean microbats in south-eastern mainland Australia**

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Abstract

Population monitoring has been conducted on two large maternity colonies of Eastern Bentwing Bat (*Miniopterus schreibersii*) in southern New South Wales, Australia, since 2008. This species is an obligate cave-dweller and only three large maternity colonies are known in New South Wales. Monitoring has also been undertaken at other (non-maternity) caves in southern NSW to determine frequency of use by this species. Thermal infra-red videography and missile tracking software has been used to count nightly fly-outs and fly-ins of bentwing bats at the two maternity caves. This technology has permitted, for the first time, multiple, accurate and rapid counts to be obtained of the bats as they fly in and out of cave roosts. Ultrasonic recorders have also been used to monitor bat activity at various cave sites and provide important information about the seasonal use of these habitat structures. The majority of the work has been conducted at Church Cave, near the town of Wee Jasper, approximately 80 kilometres west of Canberra. There, the maternity population over 8 years of monitoring has fluctuated from a low of 16,200 individuals in 2011 to a high of 23,600 in 2016. Year-to-year changes in population size are usually in the order of ± 5-10% and appear to be correlated with spring rainfall.

Seasonal Variations in Species Abundance and Impact of Large-Scale Visitation in Robber Baron Cave, Texas

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Abstract

Robber Baron Cave is located within an urban neighborhood in the city of San Antonio, Texas, and is home to two endangered species, the Robber Baron Cave Spider (*Cicurina baronia*) and the Robber Baron Cave Harvestman (*Texella cokendolpheri*). The cave is owned and managed by the Texas Cave Management Association and access is limited, but it experiences a significant amount of visitation every 18 months when the organization holds a fundraising open house for people in the surrounding neighborhoods. A two-year study was performed to assess the species present in the cave on a monthly basis. Two main species that bring nutrients into the cave and benefit the troglobite endangered species include cave crickets (*Ceuthophilus cunicularis*) and the Tri-colored bat (*Perimyotis subflavus).* As species abundance was studied, a more detailed look at the meteorological conditions related to these two troglofauna was also examined during the second year of data collection. While a connection to seasonal trends for some species was observed in the abundance measurements, no correlation could be made between changes in abundance and the large-scale visitation events.

Keywords: Robber Baron Cave Spider, Tri-colored bat, cave cricket

1. Introduction

Robber Baron Cave sits in the urban setting of Alamo Heights, Texas, an incorporated area within the greater city of San Antonio, Texas. The cave is owned and managed by the Texas Cave Management Association (TCMA), which is concerned about protecting not only the structure of the cave, but the biota that it houses. Many characteristics of the cave render it susceptible to ecological change such as the residences that exist over two-thirds of the cave passages, the nearby high traffic road within 30 feet of the sinkhole, and visitation by those that may litter.

Studies from cave systems around the world have also documented the impact of human activities within and around caves, and how endemic species are of particular concern in cave ecosystems (Vermeulen and Whitten 1999; Whitten 2009; Biswas 2010; Baker *et al.* 2015).

As with any environment, many abiotic and biotic factors have an interdependent relationship upon which the cave biodiversity thrives. In Robber Baron Cave, a gate at the entrance to the cave cut off many of these resources starting in 1980, keeping natural water flow and leaf litter to a minimum, and constricting the exchange of air with the surface. In December 2000, two endemic species that were identified in Robber Baron Cave became federally listed endangered species (US Fish and Wildlife 2000). An exemplary troglobite found in Robber Baron is known as the Cicurina baronia, or the Robber Baron Cave spider (TCMA 2016), and its survival was of concern because the entrance limited the ability of cave crickets to move into and out of the cave. The dynamics of this routine of the cricket renders it largely responsible for bringing nutrients into an otherwise closed cave ecosystem (Weckerly 2012). Crickets often leave the cave to forage but use the cave as a habitat for laying eggs and shelter (Baker *et al.* 2015), which in turn allows the crickets to bring nutrients into this otherwise closed ecosystem in forms of carcasses, eggs, and fecal matter (Taylor *et al.* 2008). In 2002, the TCMA worked with the US Fish and Wildlife Service to change the entrance gate, and restore the sinkhole to a more natural setting to allow not only the cave crickets to enter and exit the cave, but also to allow other species, water flow, and more air exchange to occur.

After the cave entrance was changed, the TCMA hosted an open house to invite the neighbors into the property and learn about the species being protected. The event was highly popular with the community and TCMA started holding the events every 18 months as a community relations and fundraising activity. The change in entrance gate also allowed for more species egress, and a wintering population of Tri-colored bats was found to grow in the cave in the following years. While there was one biological survey performed in 2013, identifying species of millipedes, beetles, snails, ants, mosquitos, gnats, wasps, cockroaches, and isopods (Texas Department of Transportation 2015), this survey was a one-time visit that did not document how the populations of the species in the cave changed throughout the seasons.

The purpose of this project was to examine species seasonal population trends within the cave, the effects of meteorological factors in the cave environment, and to determine whether the open house events had an impact on the biodiversity of the cave.

2. Study Area Description

Robber Baron Cave is a maze cave located in an upthrown fault block within the Austin Chalk Formation (Veni 1988). The sinkhole contains two entrances: the smaller entrance, or Historic Entrance, is permanently gated with a wildlife- friendly gate, and the larger, or Main Entrance, has been designed to allow limited human access through a lockable wildlife-friendly gate. The most recent theory of cave formation for Robber Barron Cave is demonstrated through the morphologic suite of rising flow possibly due to nearby springs and rising flow from the presently confined Edwards (Klimchouk 2007). With this theory, the passages are presumed to have formed along existing fracture lines where dissolution could take place through hypogene processes.

Although there is more than a mile of mapped passage in Robber Baron Cave, the limitation of two entrances provides

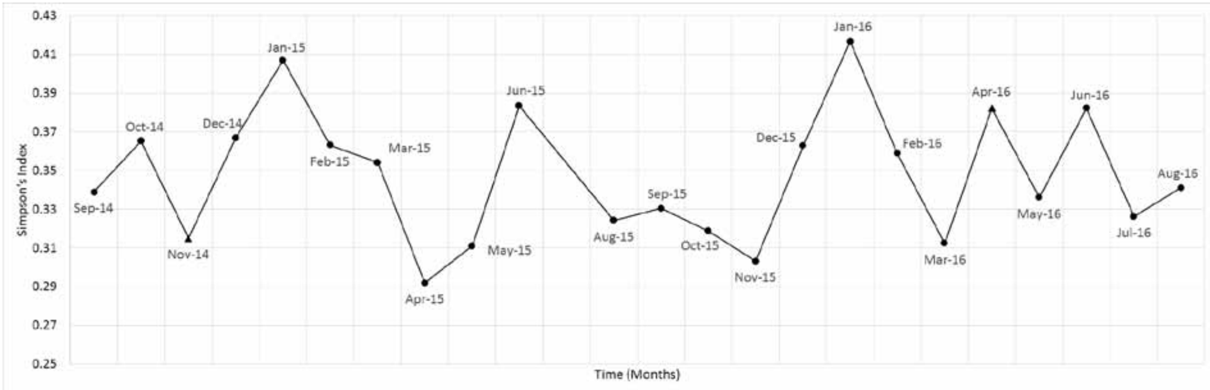

Figure 1. Monthly Simpson's Diversity Index for species documented in Robber Baron Cave, San Antonio, Texas. The solid black triangles indicate when the open house events took place.

limited access for species that utilize both the cave and other locations as habitats. Vermuelen and Whitten (1999) identified four distinct zones for fauna in a cave: the twilight zone, which is the region near the entrance where light, temperature and humidity are highly variable; the transition zone, which remains mostly in darkness, but has variable humidity and temperature; the deep zone, which is in complete darkness, near 100% humidity and has a constant temperature; and the stagnant zone, which is in complete darkness, 100% humidity and has high carbon dioxide levels due to little air exchange.

The species monitored in this study are located within the twilight and transition zones.

3. Methods

The data collected for this project lasted 24 months, starting in September 2014. Two open house events have passed since the beginning of this survey; one in November of 2014 and the other in April of 2016. Due to the complicated nature of the passages within Robber Baron Cave, not all passages were surveyed, but the main passages that connected directly to the two entrances were chosen to sample the life present in the cave. A transect style survey method was utilized to document position of the species found within the cave. To do this, a tape measure was positioned with the zero point at each entrance of the cave and spread out to the end of each surveyed corridor. In this study, the Main Entrance corridor was surveyed from entrance to end with a total length of about 50 meters. The Historical Entrance was surveyed in two different directions: one passage which forked off the Historical Entrance towards the Graffiti Room, a room on the eastern edge of the cave, and the other which forked towards the Lunch Room, a main connecting passage in the middle of the cave. The Graffiti Room survey was 30 meters long and the Lunch Room survey was 25 meters long. After the tape measure was arranged, a small team carefully examined the corridors for organisms of any kind. Each organism found was documented by species or genus and location as determined by the tape measure. The main entrance was documented first on each visit, followed by the two corridors stemming from the Historical Entrance. During the second year of the study, the team also took data for weather conditions using a PASCO GLX Datalogger with a weather/anemometer sensor. Four measurements were recorded every five meters along the tape measure: relative humidity (+/- 2%), absolute humidity (g/m^3), temperature in Celsius (+/- 0.5 °C), and barometric pressure (+/- 1 hPa).

The five species and genera included cave crickets (*Ceuthophilus cunicularis*), Tri-colored bats (*Perimyotis subflavus*), millipedes (*Oxidus gracilis*), spiders (*Eidmannella sp.*), and snails (*Helicodiscus sp).* These abundance datasets were divided into two groups: group one consisted of the month of an open house event and one month after; group two consisted of the two months before the open house event. Data taken during the month of the open house was taken approximately a week after the event. As previously stated, open houses took place in November of 2014 and April of 2016. These two groups were compared using a Chi-Square test to determine if there was a difference in the most populous species and genera analyzed in the two groups.

The Simpson's Diversity Index was used to gauge overall diversity of the cave. This equation, $D = \Sigma(n/N)^2$, where the n represents the total number of a certain species and N is the entire count of all species, was chosen due to the way that the majority of the weight is given to the most populous species. In this case, each species was calculated for each month and then the individual species were totaled per month to give the overall Simpson's Diversity Index, D. Values closest to one indicated higher biodiversity within the cave.

In addition to measuring general diversity, we were most interested in analyzing the abundance and location of the two species that are most likely to deliver nutrients to the cave, cave crickets and Tri-colored bats. We analyzed the temperature and humidity factors preferred by these species to determine their preferred locations in the cave.

Understanding habitat requirements for these species can also help to TCMA with management plans to ensure that these species will continue to provide nutrients for the Robber Baron Cave Spider.

4. Results

We analyzed several factors to look at how open house events at Robber Baron Cave affected biodiversity. The Simpson's Diversity Index showed changes in relative diversity throughout the year. As seen in Figure 1, the biodiversity after the November open house increased whereas it decreased after the April open house. The population abundances during the months revolving around the events were significantly different (November: df = 5, X^2 =0.000, n = 219, April: df = 5, X^2 = 0.000, n = 121). However, the changes in abundance were not consistent. After the November open house, bat abundance increased and snail abundance decreased, while after the April open house, species abundance decreased markedly.

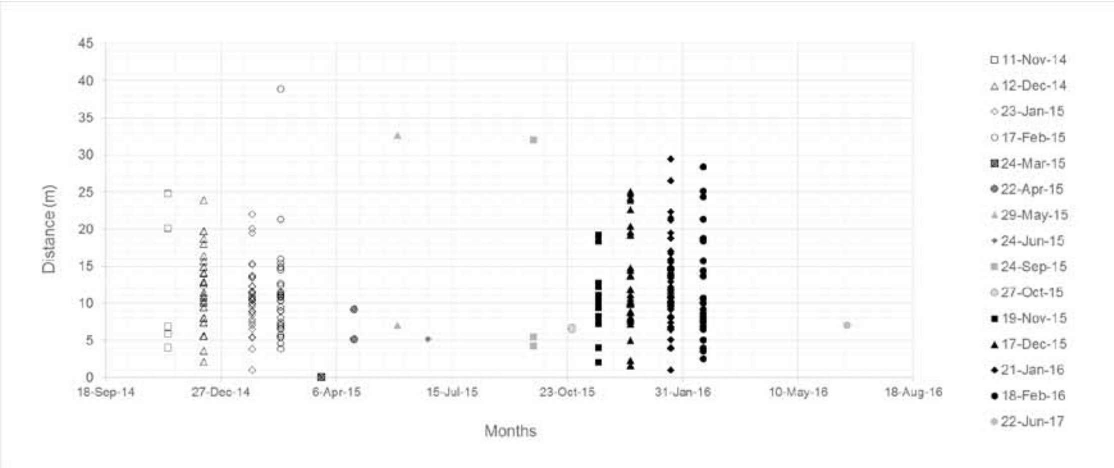

Figure 2. Monthly position data for Tri-colored bats (Perimyotis subflavus) located in Robber Baron Cave, San Antonio, Texas.

4.1. Tri-colored Bats

Robber Baron has become a winter home for a sizeable population of Tri-colored bats, and the population has been observed to increase each successive year since the entrance gate was changed. The bats were observed in this survey to be in residence in the largest concentrations during the November, December, January, and February surveys during both years, and most of the population was in the main entrance passage, which stems off the larger of the two cave entrances. While in general the main populations tended to stay within 30 meters of the main cave entrance, there were a few outliers that were found further back in the cave, as shown in Figure 2. The temperature in the cave varied along the main passage route, as shown in Figure 3, but remained between 20 °C and 32 °C in most of the survey points during the winter months, except for December of 2015 where the outside morning temperatures ranged from 8.3 – 16.7 °C and influenced temperature at the gate. Humidity in the same corridor varied from 53% to 100% during the fall and winter months. In Robber Baron Cave, most of the bats were located within the first 35 meters of the entrance passage, where humidity was documented to be between 53% and 100% during all fall and winter months (Figure 4). An interesting observation was also made that in December of 2015, all but three of the 48 bats chose to roost between 5 and 25 meters from the entrance, where the relative humidity was measured to be at 100%.

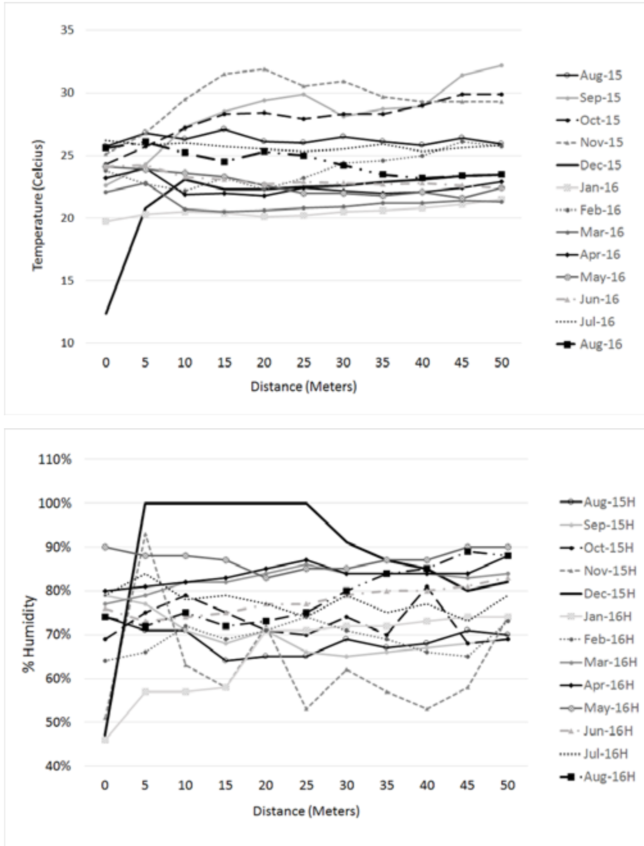

Figure 3. Monthly temperature (a) and humidity (b) profiles for the Main Entrance Passage in Robber Baron Cave, San Antonio, Texas with zero being located at the gate.

4.2. Cave Crickets

To better understand the dynamics of the life cycle of the cave crickets, they were analyzed as adults, juveniles, and as a total population.

Looking at Figure 4, the cricket population was present for most of the year, with significant increases in April through June of 2015 and for August of 2015, followed by a decrease in September through November of 2015. Another increase was seen in December 2015, and the population stayed fairly steady into 2016 until there was another decrease in August of 2016.

As seen in Figure 5a, most of the crickets in Robber Baron Cave were found 15 meters from the main entrances, with 10 and 20 m being the second most; about 72% of all crickets surveyed were found in the first 20 m of the cave. There was a negative correlation according to the trend line. Based on this information, we can conclude cricket count decreases in correlation with increasing distance. Figure 5b displays cricket counts in relation to the temperature. According to this Figure, the majority of crickets were found between 21 and 29 °C, with a slight increase with increasing temperature as seen with the positive trend line; however, this positive correlation was not statistically significant (r=0.103, p=0.75).

About 35% of all crickets were found in the highest count range between 25 and 27.1 °C, and about 77% of all crickets can be found between 21 and 29 °C. Figure 5c shows a large group of crickets between 62 and 83 % relative humidity. About 34% of crickets were found in the highest humidity group at 73-79% humidity and about 78% can be found in the range of 66 to 86%.

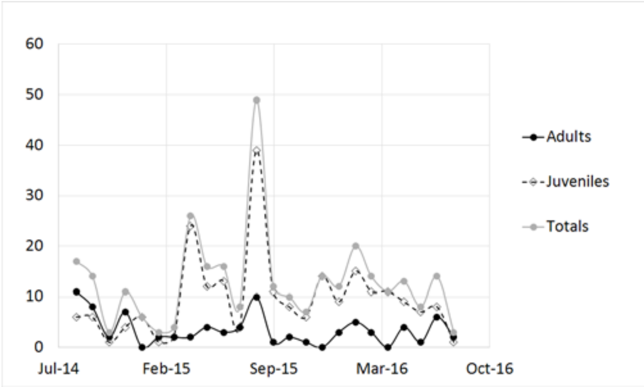

Figure 4. Monthly cricket count shown as Adults, Juveniles, and Total population counts for the Robber Baron Cave, San Antonio, Texas from September 2014 – August 2016.

There was a negative correlation between cricket abundance and humidity, but this was not statistically significant (r=-0.61, p=0.292).

5. Discussion

As mentioned previously, open house events are held at Robber Baron Cave every eighteen months for fundraising purposes. In this study, we looked at whether these events had a detrimental impact on the species biodiversity of the cave.

The post-open house events had conflicting results: the first open house in November of 2014 saw a rise in biodiversity afterwards whereas the second open house in April of 2016 saw a drop in biodiversity afterwards, both based on the Simpson's Diversity Index. Similarly, the Chi-square results confirmed that there was a significant change to the abundance before and after the open house events, however the changes were not a consistent decrease in abundance across species and genera in response to the open house events. Therefore, the fluctuations in abundance were likely due to seasonal trends.

The Simpson's Index was dynamic in change with the highest peaks in January of 2015 and 2016. Some of the lowest months on the Simpson's Index were April of 2015, November of 2015, and November of 2016. As mentioned before, the biodiversity increased after the first open house event in November while it decreased after the second open house event in April. The January peaks seemed to coincide with the increase in the bat population, as the species was in largest numbers during this month in both years. By April, most of the bats have left the cave which could explain the low points measured in the spring of both 2015 and 2016, but it was interesting to note that the changes in the cricket population did not seem to coincide with changes in diversity. The changes that were observed in relation to the open house seemed to be more driven by seasonal trends related to changes in individual populations. However, it is interesting to note that the diversity within the cave varied continually throughout the year, and showed that to determine a full picture of the biology of the cave, a one-time visit does not give a full representation of what species are found within the habitat, and how those populations vary over time.

The two species that bring nutrients into the cave, the Tri-colored bats and cave crickets, showed a preference for specific temperature and humidity conditions throughout

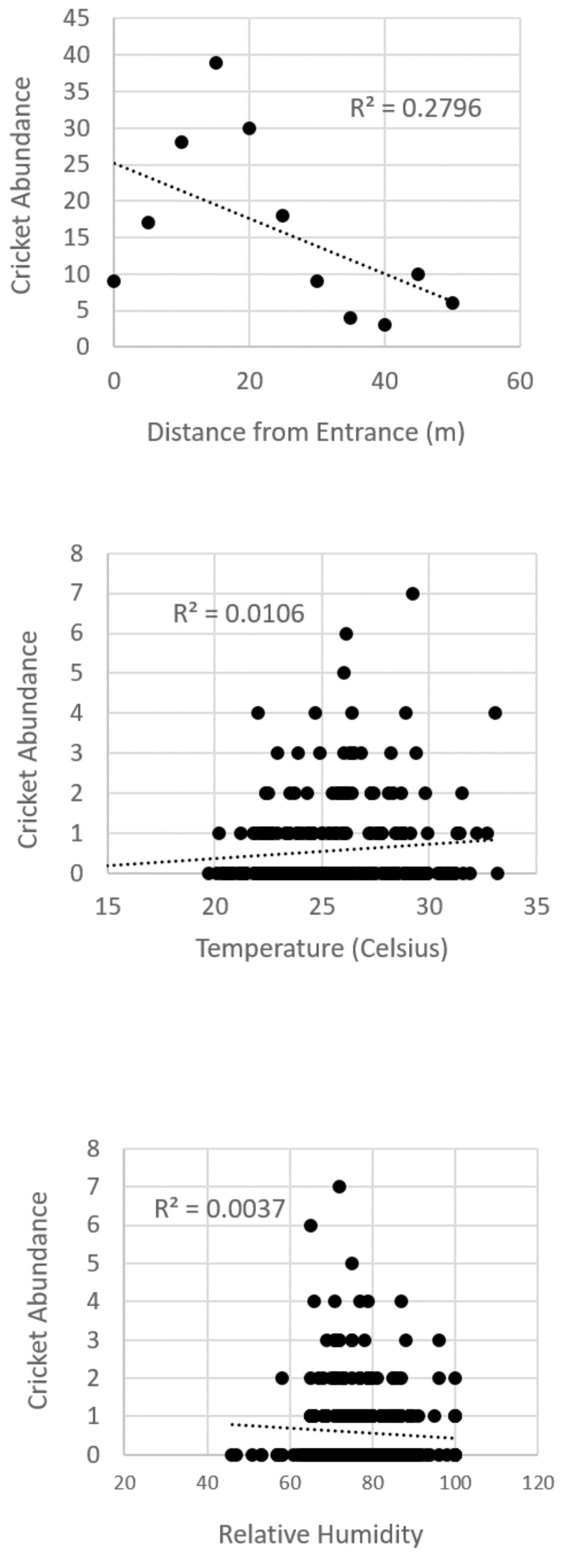

Figure 5. Abundance of cricket compared to (a) distance from the entrance, (b) temperature and (c) relative humidity measurements in Robber Baron Cave, San Antonio, Texas from September 2014 – August 2016.

the year. The cave corridors utilized by the bats maintained a temperature between 20 and 32 °C for most of the year and a humidity level of 53 to 100%. These conditions correlated well with other studies performed on this species (Sandel and Benatar 2001; Perry 2013). The population of Tri-colored bats was largest between November and February. Over 75% of the crickets were found to be in locations that ranged from 21 to 29 °C and 66 to 86% humidity. Cricket counts were highest from February through September, when more juveniles were present in the population.

According to Lavoie *et al.* (2007), cave crickets see an increase in population during July and August in juveniles because of their natural birthing cycles and that measurable ova were found in the late summer months such as August, September, and October. This would support the increase in population seen in August 2015, and may account for a small increase in population in July 2016. The overlap in climate conditions needed to sustain both species seemed to be beneficial for the Robber Baron Cave Spider, as it allowed nutrients to be available in the habitat year-round: when the bat population is present, guano deposits add to the nutrients present in the cave, and when the cricket population is at its peak, fecal matter and ova can become a nutritional source.

6. Conclusions

The study found no relationship between changes in biodiversity and open house events. While the study was based on data from the population changes on only two open house events and could benefit from continued analysis, the trends in biodiversity change appeared to align with seasonal trends related to the populations of cave crickets and Tri-colored bats. However, at this point, management plans for the cave seem to be sufficient in protecting the species within the cave and providing enough nutrients for the Robber Baron Cave Spider.

The Tri-colored bat and cave cricket populations are most frequently located within ranges for temperature and humidity that were consistent with previous studies. While only two passages were surveyed in this study, a full map of temperature and humidity parameters within the cave could help researchers determine which zones might be most likely to find additional individuals for each species. Future work could include monitoring different passages within the cave to obtain similar species counts, and then utilizing the temperature and humidity data to build a model to estimate the total count of each species in the cave.

Also, while a few individuals of the Robber Baron Cave Spider were observed during the study, in order to protect the species, areas of the cave that they are known to inhabit in higher numbers are off limits to most individuals. A future study, with permission of the Texas Cave Management Association and the U.S. Fish and Wildlife Department, could compare counts of the Robber Baron Cave Spider with cricket and bat counts during the year, and potentially even do genetic studies to correlate the spiders with their food sources.

Acknowledgements

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(Abstract) Subterranean and surface cryptopid centipede diversity in Western Australia.

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Abstract

Cryptops is the most speciose genus of the scolopendrid centipede family Cryptopidae, with 181 valid species worldwide from both surface and subterranean habitats. All species are blind and often lacking in pigmentation. The genus Cryptops currently has seven recognised species in Australia; C. australis, C. (Trigonocryptops) camoowealensis, C. haasei, C. hortensis, C. megalopora, C. (Trigonocryptops) roeplainsensis and C. spinipes. There two members of the subgenus Trigonocryptops are troglomorphic from caves on the Nullarbor Plain and far western Queensland. An undescribed species, Cryptops sp. A, possibly conspecific with C. inermipes Pocock is recognised from Christmas Island. This study has used a multigene approach of COI, 12S and 28S for 140 specimens to determine the diversity of Cryptops in Western Australia, focussing on the Pilbara region in the north of the state. Specimens from South Africa, Papua New Guinea, New Caledonia and the Canary Islands have also been sequenced to place the Australian fauna in a global framework. We plan to investigate biogeographic and phylogenetic patterns of subterranean and epigean Cryptopid species.

(Abstract) Environmental metagenomics of the chemolitho-autotrophically based ecosystem of Ayalon Cave, Israel

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Abstract

Ayalon Cave near Ramla, Israel, received worldwide attention in 2006, soon after its discovery, because of its eight previously undescribed, obligate, cave-adapted invertebrate species. The discovery added Ayalon Cave to a growing list of known chemolithoautotrophically-based cave ecosystems worldwide, including Movile Cave (Romania), the Frasassi Caves (Italy), Cueva de Villa Luz (Mexico), and Lower Kane Cave (USA). The cave formed from hypogenic speleogenesis in Turonian limestone, and is part of the regional Yarqon-Tanninim karst freshwater aquifer that is also influenced by the local Ayalon Saline Anomaly of warm, sulfidic water. Most of the biological diversity in the Ayalon system is found near a large pool of anaerobic and sulfidic water (up to 4.7 mg/L dissolved sulfide, 1371 ± 395 mg/L total dissolved solids, ~29 °C). In the past decade, descriptions of the new invertebrates have included the aquatic *Metacyclops longimaxillis* Defaye & Por (Crustacea: Copepoda), *Metacyclops subdolus* Kiefe (Crustacea: Copepoda), *Tethysbaena ophelicola* Wagner (Crustacea: Thermosbaenacea), and *Typhlocaris ayyaloni* Tsurnamal (Crustacea:Decopoda), and the terrestrial *Akrav israchanani* Levy (Arachnida: Scorpiones), *Ayyalonia dimentmani* Čurčič (Arachnida: Pseudoscorpiones), *Lepidospora ayyalonica* (Insecta: Zygentoma), and *Troglopedetes* sp. (Collembola: Paronellidae). Over the past decade, hydrogeological monitoring and study of the cave system revealed that regional aquifer levels have declined precipitously, which has resulted in significant habitat loss. However, almost nothing is known about the ecosystem microbiology. We undertook a field campaign in late 2016 to collect water and microbiological samples from the cave to investigate the cave's aquatic and terrestrial microbial diversity, as well as to examine the potential functional diversity of the microbial communities using shotgun metagenomics. Previous research indicates the microbial community is dominated by sulfur-oxidizing bacteria belonging to the genus Beggiatoa spp., but other sulfidic karst systems have a range of microbes, including uncultured Epsilonproteobacteria and Thiothrix spp., among others. From the environmental DNA (eDNA), we also evaluated the potential to detect the aquifer, and even terrestrial, invertebrate fauna from the cave and aquifer system. The results from this study have important implications for protecting the Ayalon Cave and its ecosystem into the future, and will provide potential eDNA-based approaches that can be used to investigate the distribution of fauna beyond the accessible cave passages.

(Abstract) Iron-rich rocks: A little recognized habitat for troglofauna colonization

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Abstract

Knowledge on troglomorphic fauna in iron-rich rocks is still limited. In Brazil, biological studies performed for mining projects have revealed the diversity of cave adapted fauna in iron-rich rocks. The highly porous nature of the surficial canga (a breccia composed of iron-rich fragments cemented by a ferruginous matrix) and the abundance of caves and small voids allow for the existence of a shallow subterranean habitats (up to 5 metres) – SSH. This habitat is characterized for being aphotic and able to harbor specialized species for subterranean life. The present study aims to present the results of subterranean fauna present in canga, as well as the results on the troglomorphic fauna. Three methods were applied: Leaf Litter Trap; Drip Pools and MSS-Trap. Although the proportion of registered troglomorphic is low, its presence in these spaces has been regularly verified. The MSS-trap proved to be the most efficient method for collecting these organisms, among which have been recorded the Collembola genera Pararrhopalites, Pseudosinella and Trogolaphysa, and organisms with greater body size, such as the Pseudoscorpiones genus Pseudochthonius and the Aranae family Caponidae. All these taxa were already described as present in the macro caves of the studied areas. These results presented confirm the existence of troglomorphic species in canga, and the potential of this environment for sustaining subterranean populations.

Life in Darkness – a Biospeleological Project in the Bavarian Alps

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Abstract

At the end of 2014, the project "Life in Darkness" started with biospeleological monitoring of 7 caves in the Bavarian Alps. The monitoring took place during all seasons and in several regions inside the caves to get a wider view of the different populations. The outcome of the project was breathtaking. By the end of 2015, in total more than 13.000 animals had been captured and their data integrated in the biospelological register of the Hesse Federation for Cave and Karst Research. The identification process of the different species is still ongoing in some special cases. However, 3 species which have to this date never been found in Germany before were confirmed. 2 species were found for the second time, more than 40 years after the first report. Over 200 different species could be verified. As there was a lack of knowledge about cave animals in the Bavarian Alps, this project can be seen as a turning point for awareness as well as scientific knowledge. The project was sponsored by the Bavarian Ministry of Environment with 40.000 € .

Keywords: biospeleology, Alps, Bavaria, Germany,

1. Introduction

The European Union Habitats Directive pushed biospeleology in Germany. Nevertheless there are large blind spots on the landscape. One is the Bavarian part of the Alps. To get an overview of existing species inside caves, the project "Life in Darkness" was embedded in the Ecoplan Alps Strategy of the Bavarian Stateministery of Environment and Consumer Protection. 7 caves along the German part of the Alps were monitored during all seasons. The project started in December 2014 and ended in October 2016.

2. German Cave Animals

Most of the known findings in Germany are listed in the biospeleological register of the Hesse Federation for Cave and Karst Research. Over 2300 are eutrogloxene species and cannot survive underground, they just end up there accidentally. 149 subtroglophile species use the caves seasonally. 428 eutroglophile species are building populations and 165 eutroglogionte species are completely dependent on caves. In total, there are 742 known species living in caves in Germany.

3. Project Caves

1. Gamsbockloch, Allgäuer Alpen: entrance 1349 m above sealevel, 150 m long, 60 m deep, Schrattenkalk formation, special: large hall

2. Angerlloch, Estergebirge: entrance 940 m above sealevel, 700 m long, 40 m deep, platy limestone, special: outdoor tourism

3. Wendelsteinhöhle, Mangfallgebirge: entrance 1711 m above sealevel, 573 m long, 106 m deep, Wetterstein limestone, special: show cave with non-touristic parts

4. Große und Kleine Spielberghöhle, Laubensteingebirge: entrance 1302 m above sealevel, 1500 m long, 200 m deep, Wetterstein limestone, special: 1966 only finding of *Neobisium hermanni* in Germany

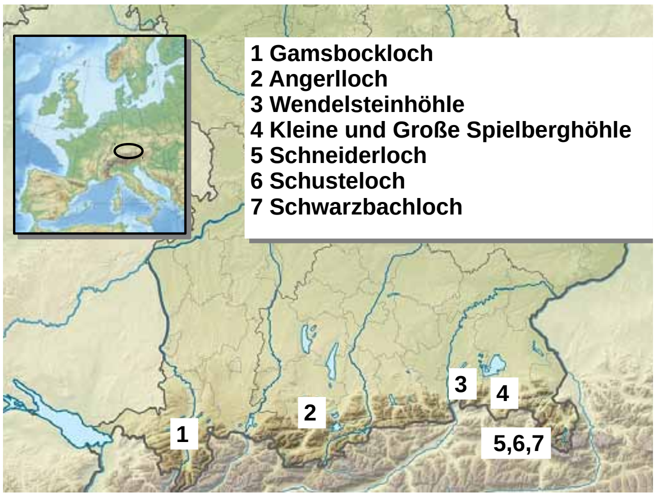

Figure 1.

5. Schusterloch, Lattengebirge, Berchtesgadener Alpen: 660 m above sealevel, 70 m long, 20 m deep, Ramsau dolomite Dachstein limestone, special: temporarily flooded

6. Schneiderloch, Lattengebirge, Berchtesgadener Alpen: 670 m above sealevel, 46 m long, 40 m deep, Ramsau dolomite Dachstein limestone, special: parts temporarily flooded

7. Schwarzbachloch, Reiter Alm, Berchtesgadener Alpen: entrance 776 m above sealevel, 3030 m long, 72 m deep, Ramsau dolomite Dachstein limestone, special: entrance large spring with unflodded parts, dry second entrance, the spring drains 90% of the mountain area

An important selection criteria was the easy access in winter. VdHK tried to cover different types of alpine caves, regions and status.

Figure 2. Crenobia alpina, *Photo: Klaus Bogon*

Figure 3. Crenobia alpina, *Photo: Andreas Wolf*

4. Results

Beside many visual observations, over 13.000 invertebrates were captured in small barber pitfall traps. More then 200 different species were identified, including 3 first findings for Germany: *Gymnomus soosi*, *Schaefferia sexoculata* and *Chionea austriaca*. *Neobisium hermanni* was found for the second time after more than 50 years, both in the same cave.

From the Wendelsteinhöhle, *Chionea araneaoides* was a first finding in the German Alps as well as *Deuteraphorura variabilis* whose next confirmed find, in Germany, is in Helgoland, a North Sea island.

Mughiphantes variabilis, the 11th finding in Germany and first finding in the German Alps after 15 years.

In the Gamsbockloch, *Chionea alpina* was captured. It is the second finding in Germany.

Out of Schusterloch, the endemic *Troglohyphantes subalpinus* was the 5th finding in Germany. It only exists near Berchtesgaden. The alpine endemic species *Bythinella austriaca* was detected in both Schusterloch and Schneiderloch.

The existence of *Crenobia alpina* which survived in the groundwater of the northern parts of the Alps since the last ice age was confirmed in Schwarzbachloch.

Overall, the spectrum of species is composed of 50.5% insects, 25.6% arachnids, 9.8% gastropods, 6.0% crustatians, 4.4% myriapods, 3.9% others like annelids and nematodes.

The Minister of State of the Environment and Consumer Protection, Ms Ulrike Scharf, honoured us with her presence when the outcome of the project was presented on the 20th of October 2016 at Wendelstein. The media were involved as well. 130 articles in newspapers and magazins reported on the event and the project, as did Bavarian radio and television broadcasts.

Prof. Dr. Haszprunar from the Bavarian State Collection of Zoology, plans to continue the work by DNA analysing the project's captured cave animals.

5. Conclusion

The invention of the VdHK cave animal of the year campaign since 2009 has been a great success until now in raising public awareness of underground protection. The nation-wide assessment procedure for the Natura 2000 habitat type "caves not open to public" in 2016 is another big step forward and shall be supported by providing a web app to simplyfy the monitoring process.

Nevertheless biospeleological projects of this size cannot be accomplished on an honorary basis only, without financial support. With a relatively small amount of money, extraordinary results are more than possible. This project can be seen as a first step. The amount of volunteer work was far more then expected and had to be spread among the experts. Further pecuniary aid, engagement and education is needed to get an overall view about Germany's life in darkness and how to protect it.

Institutions involved

- Verband der deutschen Höhlen – und Karstforscher e.V. (German Speleological Federation), www.vdhk.de
- 1 project coordinator
- 5 coordinators for the different caves,
- along with 23 cavers to install and empty the barber pitfall traps
- Identification of species by 10 experts

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Cave Animal Of The Year – From National To International?

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Abstract

For 8 years, the Verband der deutschen Höhlen- und Karstforscher e.V., VdHK (German Speleological Federation) has declared a “Cave Animal of the Year”. It is part of the public campaign “Nature of the Year” of German nature conservation NGOs and has been a great success for speleology and partners like Eurobats or the European Society of Arachnology. In 2017, the VdHK declared Diphyus quadripunctorius (Ichneumonidae, Hymenoptera) the German Cave Animal of the Year.

Being a cheap and easy way to highlight cave protection with a focus on biospeleology, it is simple for other organisations to join the campaign. The idea is, each year, to fix a new world-wide cave animal family, order, or class depending on chosen taxa. Participating countries can choose their cave animal from that. Information from participating countries could be linked using the internet to present a broad perspective of the world’s underground life. This can be useful for schools as well as experts. General information about the species will be given as well as contact with specialists. It can provide a platform of networking and knowledge sharing about cave and karst ecosystems.

Keywords: cave animal of the year, cave protection, campaign, biospeleology

1. Introduction

From its inception in 2009, the German Cave Animal of the Year campaign has been very successful. It raises awareness about protection of caves as a habitat in various ways. The intention is to provide information for cavers as well as scientists and at the same time for the general public about underground habitats and species. By supplying the VdHK homepage www.hoehlentier.de it reaches anyone interested worldwide, flyer and posters are sent to VdHK members and showcaves.

The selection criteria for the Cave Animal of the Year is easy to describe: easy to find, a story to tell, knowledge available and photogenic.

Figure 1. German Cave Animal of the Year 2014 Proasellus cavaticus, *Photo: Klaus Bogon*

2. German cave animals of the year

2009, genus Niphargus: eutroglobiont, a real cave animal and groundwater species started the campaign

2010 *Scoliopteryx libatrix* Herald Moth: subtroglophil, hibernates in caves

2011 *Myotis myotis*: Greater Mouse-eared Bat, for the international Year of Bats

2012 *Meta menardi*: European cave spider, eutroglobiont, easy to identify with its cocoon

2013 *Speolepta leptogaster*: fungus gnat, eutroglobiont proofen for genetic studies in 2012

Figure 2. German Cave Animal of the Year 2015 Oxychilus cellarius*, Photo: Klaus Bogon*

Figure 3. German Cave Animal of the Year 2016 Amilenus aurantiacus*, Photo: Klaus Bogon*

2014 *Proasellus cavaticus:* class of Crustacea, eutroglobiont, groundwater animal

2015 *Oxychilus cellarius:* Cellar Glass-snail, eutroglophil, lives in other cold and dark habitats as well

2016 *Amilenus aurantiacus:* species of harvestmen, subtroglophil, hibernates in caves

2017 *Diphyus quadripunctorius:* species of Ichneumonidae, subtroglophil, female species survive winter in large groups inside caves

3. Success

Due to the national annual "Nature of the Year" campaign, the cave animal of the year information circulates very easily. It is linked to authorities like the Federal Environment Agency or cities as well as all sorts of clubs including speleology, alpine clubs, gardening societies, kids programs and of course calendars, print media, radio and television.

The homepage had 5550 clicks during the last 6 months. The top 10 countries with hits were Germany 80%, USA 5.1%, Austria 4.7%, Switzerland, UK, Italy, France, New Zealand, Spain and Poland. During 2016, about 50 articles were published in print media. In 2012, the first European cave animal was announced: *Meta menardi* became the European spider of the year in cooperation with the European Society of Arachnology. In 2014, the German Cave Animal of the Year campaign was honoured by the Department of Karst and Cave Protection of the International Union of Speleology awarding the France Habe Prize to promote the protection of karst and caves for generations to come.

Cave Animal of the Year was one strong pillar reaching long term aims such as caves being added to nature protection legislation in Germany. VdHK received its first funded biospeleology project: Life in Darkness, about animals in alpine caves. A member of the European Union groundwater working group did research in the Netherlands about the impact of pollution on groundwater species. The cooperation was triggered by a campaign flyer.

4. From National to International?

As it is an easy concept and can easily be transferred to other countries. Biospeleologists all over the world could present their cave animal of the year campaign together with national speleological federations. It should be chosen out of a given family/order/class depending on the chosen taxa. Cooperation with the UIS Biology Commission is recommendable. A website could summarize the information to give a wide perspective of species around the globe. VdHK has provided campaign flyers since 2013, also in English.

5. Conclusion

The potential of the cave animal of the year campaign to support cave protection is very high. As these animals are more or less unknown to the general public, they can serve as a

Figure 4. German Cave Animal of the Year 2017 Diphyus quadripunctorius*, Photo: Klaus Bogon*

door opener to cave protection. If many federations join the campaign, offering a stronger unity in speleology, the transboundary habitat can be highlighted. This is an inexpensive way of creating awareness, so the outcome is great and affordable, but there is also a need for time to conduct research on the species. An exchange of information between experts will lead to a win-win situation. Let's start!

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German Cave Animal of the Year Team: Project Coordinator: Stefan Zaenker (Fulda), Web layout: Tobias Busch (Bad Hersfeld) Photographic work: Klaus Bogon (Sontra), Heiko Bellmann (Ulm), Rolf Palm (Schwarzenfels), Max Wisshak (Erlangen) and Stefan Zaenker (Fulda), Flyer and poster layout and print:Tobias Busch (Bad Hersfeld) and Torsten Kohn (Berlin), Translation: Dr.Helmut Steiner (Hanau am Main), Astrid Vogel (Malmö) and all other colleagues for their cooperation and help.

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White-Nose Syndrome And Australian Bats – What Is The Risk And What Can We Do?

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Abstract

White-nose syndrome (WNS) is a fungal disease that has caused significant declines in insectivorous bat populations in North America, with mortality estimates over 6 million. The fungus causing WNS has also been found in Europe and China, but without mass mortalities of bats. WNS has not been identified in Australia. This project was established to improve Australia's preparedness for a potential introduction of white-nose syndrome. A risk assessment found the most likely method of entry of WNS into Australia is via infected objects such as clothing, footwear or equipment used in affected caves overseas. Cave-dwelling insectivorous bats in the colder southern parts of Australia are considered likely to be at risk of WNS if introduced, in particular the Critically Endangered southern bent-winged bat (*M. orianae bassanii*) and the eastern bent-winged bat (*Miniopterus orianae oceanensis*). A range of response options have been considered for a possible incursion of WNS, and response guidelines have been developed. Cavers are recognised for their vital role in protecting Australian bats from WNS, and advice is provided on how to keep WNS out of Australia.

Keywords: White-nose syndrome, bats, biosecurity, conservation

1. Introduction

White-nose syndrome (WNS) is a fungal disease caused by *Pseudogymnoascus destructans*, which has caused significant mortalities of insectivorous bats in North America (Turner *et al.* 2011). Mortality estimates are over 6 million animals, reaching as high as 90-100% in some roosts, and causing the collapse of numerous bat populations with regional species extinctions expected (Frick *et al.* 2010; Alves *et al.* 2014; Turner *et al.* 2011; U.S. Fish & Wildlife Service 2016). Since WNS was first recognised in New York State in 2006, it has spread through eastern USA and Canada (White-Nose Syndrome.org 2016). In March 2016 the fungus was detected in Washington State, more than 2,000 km from prior detections in the eastern states (U.S. Geological Survey 2016). The *P. destructans* fungus has also been found across Europe and in north-east China, but without the mass mortalities observed in North America (Puechmaille *et al.* 2011; Hoyt *et al.* 2016). *P. destructans* has not been identified in Australia (Wildlife Health Australia 2015). A recent surveillance project tested 148 southern bent-wing bats (*Miniopterus orianae bassanii*), 100 eastern bent-wing bats (*Miniopterus orianae oceanensis*) and 25 environmental samples from Victoria and South Australia, and all were negative for *P. destructans* (P. Holz 2016, pers. comm.)

White-nose syndrome is a disease of hibernating insectivorous bats, as the fungus requires low body temperature in order to grow on the skin (Lorch *et al.* 2011). *Pseudogymnoascus destructans* thrives at cold temperatures (less than 15 °C) and can persist in the environment for long periods (up to two years), even in the absence of bats (Verant *et al.* 2012; Lorch *et al.* 2013; Reynolds *et al.* 2015). Fungal spores can be inadvertently spread from one site to another by humans, for example on boots, clothing and equipment (Reynolds *et al.* 2015).

Australia is home to many species of insectivorous bats, or microbats, and a number of species live in caves ranging from small splits or crevices through to extensive caverns. We set out to answer the question: "Are Australian bats at risk from WNS? And if there is a risk, what can we do?"

2. Project outline

The Australian Government Department of Agriculture and Water Resources funded a project through Wildlife Health Australia (WHA) to improve Australia's preparedness for a possible introduction of white-nose syndrome. The project was to firstly assess the potential risk of introduction of *P. destructans* to Australian bats, and then to develop guidelines to assist response agencies should the disease appear in Australia.

3. Risk assessment

A risk assessment for introduction of WNS into Australia was conducted by a team of Australian experts (Holz *et al.* 2016). The potential entry routes for *P. destructans* were identified. The possible consequences were then assessed, taking into consideration the differences in Australian climate, bat ecology and immunity that could impact on the epidemiology of the disease. Potential host species and geographic areas of risk were identified.

The most likely method of entry is considered to be infected fomites (objects) such as clothing, footwear or equipment used in affected caves in other countries, for example by a caver, researcher or tourist. While the susceptibility of Australian bat species to WNS is not known, the assessment found that cave-dwelling insectivorous bats in the colder southern parts of Australia are likely to be at risk of WNS if the fungus is introduced.

The species at highest risk from WNS in Australia are the Critically Endangered southern bent-winged bat and the eastern bent-winged bat. While the large scale mortalities seen in North America are considered less likely in Australia due to the different climate, lower mortality rates due to WNS could still be significant for the survival of the southern bent-winged bat due to the presence of other threatening processes, and the fact that the entire population lives within the preferred temperature zone of *P. destructans*.

4. Response guidelines

A facilitated workshop was held by Wildlife Health Australia and Animal Health Australia in October 2016 to discuss response options for a possible incursion of *P. destructans* and the appearance of WNS in bats in Australia. The workshop brought together key stakeholders and response agencies to consider the options for responding to WNS and test these in a range of scenarios. Participants included representatives from Commonwealth and State government agencies for agriculture and environment, Animal Health Australia, Wildlife Health Australia, biosecurity emergency management experts, bat ecology experts from the Australasian Bat Society, and university wildlife disease experts and epidemiologists.

A range of response options were considered appropriate for different situations, including activities to prevent further *P. destructans* transmission by humans and bats, surveillance to detect the extent of the disease, communication and education to assist with early detection and prevention of spread, and support for infected bats through conservation activities and environmental modification. A number of knowledge gaps were identified, where further research could assist the decision making process.

WHA then prepared response guidelines based on the outcomes of the workshop, the findings of the risk assessment, and a review of overseas management responses. The guidelines describe a range of management activities and considerations to assist response agencies during a possible outbreak. The guidelines are currently being considered by stakeholders, and will then be published.

5. Advice for cavers

Cavers play a vital role in protecting Australian bats from WNS. By following the advice of the Australian Government,[1] they can help prevent the introduction of this disease. Cavers visiting Australia are asked not to bring clothing, footwear or caving gear that has been used in other countries. This includes countries outside of North America, as the fungus that causes WNS has been found in Europe and China. Congress delegates are additionally asked to comply with the cleaning protocols imposed by the congress organisers to decontaminate gear before and after field trips. Australian cavers visiting caves overseas should avoid taking their own gear, particularly if visiting caves in areas where WNS is known to be present.

Guidelines on decontamination after visiting caves are available from the USA.[2] However decontamination may not completely remove or destroy the fungus, and the protocol recommends that gear used in an affected cave is not used in 'clean' caves.

1 http://agriculture.gov.au/pests-diseases-weeds/animal/white-nose-syndrome

2 https://www.whitenosesyndrome.org/topics/decontamination

6. How to report a suspect case of WNS in Australia

Clinical signs of WNS in insectivorous bats include white or grey powdery fungus on the face, fur, skin or wings; wing damage; mass mortality (multiple deaths); and abnormal behaviour such as flying during the day.

If WNS is suspected in Australia, contact: the State/Territory WHA Coordinator,[3] the 24 hour Emergency Animal Disease Watch Hotline (freecall 1800 675 888),[4] a local veterinarian, or Wildlife Health Australia. Cave managers or park rangers should also be notified. For more information, see WHA's *How to report a suspect case of white-nose syndrome*.[5]

Note: Members of the public should not handle bats. Contact with bats such as bites and scratches carry a risk of infection with Australian bat lyssavirus and require urgent first aid and medical attention.

7. Conclusion

Australia has general measures in place at the border as part of a risk-based approach to prevent introduction of a broad range of diseases, however WNS may be spread by people through transfer of fungal spores on boots, clothing or equipment. As a result of this project, Australia is better prepared for a possible introduction of WNS, and the project also provides a useful model for Australia's approach to the assessment of the potential introduction, establishment and impact of an exotic wildlife disease. Cavers are recognised for their vital role in protecting Australian bats from WNS, and advice is now available on how to keep WNS out of Australia.

Acknowledgements

Australian Government Department of Agriculture and Water Resources, Animal Health Australia, WHA Bat Health Focus Group, Nicholas White, participants at the WNS Response Guidelines Workshop, The University of Melbourne, South Australian Museum, Department of Environment, Land, Water and Planning Victoria (Arthur Rylah Institute), and The University of Adelaide.

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3 http://www.wildlifehealthaustralia.com.au/AboutUs/ContactDetails.aspx

4 http://www.outbreak.gov.au/report-outbreak

5 http://www.wildlifehealthaustralia.com.au/ProgramsProjects/BatHealthFocusGroup.aspx#WNS

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Monitoring a Bat Maternity Cave in South-eastern Australia Using Remote Technology

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Introduction

The Critically Endangered Southern Bent-wing Bat (SBWB) *Miniopterus orianae bassanii* is restricted to southwest Victoria and southeast South Australia. It is an obligate cave dwelling bat with two key maternity caves, one in each state. Little is known about what makes these caves suitable as maternity sites or how microclimate, seasonal conditions and environmental triggers influence the SBWB breeding cycle. This information is critical to effectively manage the caves and the SBWB population, but is often difficult to obtain. The key Victorian maternity cave has several entrances allowing air to circulate. One birthing chamber is within a bell hole approximately 2 m above the cave floor. Remote monitoring technology enables the lifecycle of the bats and pups to be followed at this critical stage, with minimal disturbance.

Aims

- To determine the efficacy of remote cameras and dataloggers to monitor the numbers of bats and environmental conditions in one birthing chamber.
- To investigate how the bats modify their cave environment.

Methods

Two Reconyx XR6 Ultrafire Covert cameras were set within the birthing chamber to take a time-lapse photo every hour, for 3 months (Sept to Dec 2015). The covert infrared night vision illuminators provide clear night time images, ideal for the cave environment. This model has a dedicated camera lense for infrared photography with no moving parts. Thus the camera produces no sound or light. Bat coverage was assessed by placing a grid over each photo and estimating the percentage cover of bats within the photo.

Two Hydrochron ibuttons dataloggers were located within the birthing chamber (where the bats roost and on the chamber wall ~ 2 m away). Other ibuttons were set elsewhere within the maternity cave. All took hourly temperature and humidity readings.

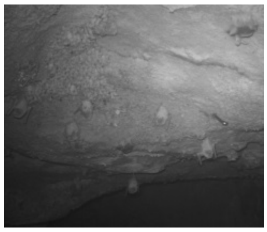
Results

The cameras revealed precise, highly synchronised birthing dates. The first pups were born 2nd December, the main birthing commencing in the early hours of the 3rd with the majority born by the 4th. The females then transferred their pups to a higher (40 m), more open chamber by the 8th December 2015.

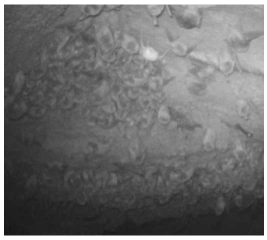
The dataloggers revealed how and when the bats modified their environment, while the cameras provided detailed corresponding information on the numbers of bats. When bats were present the temperature in the roosting area increased compared to the adjacent chamber wall.

Adult bats clustering in the birthing chamber:

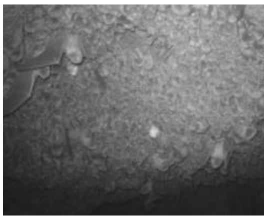
- increased temperature by up to 17.5^{o}C above ambient cave temperature, to a maximum of 33.1^{o}C around the pups
- decreased relative humidity from 99.6% within the cave to a minimum of 72.8% around the pups



The pups are located in the top left corner of the photo, the ibutton is located to the mid right side of photo.



Pups are completely covered by the clustering adult bats, the ibutton is still exposed.



Adult bats completely cover the wall of the chamber where the pups are, including the ibutton. This provides indicative humidity and temperature levels experienced by the pups.

Conclusion

The remote cameras and dataloggers show great promise in enabling detailed hourly monitoring with minimal disturbance to the bats.

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Cave and Karst Management and Education

(Abstract) The Journey to Preserve Puerto Rico's Santa Rosa Cave System

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Abstract

The purpose of this study is to report on the speleological surveying and research conducted in the Santa Rosa Buro of Utuado, PR. Utuado is in the Karst North Central section of Puerto Rico. Puerto Rico is the smallest Island of the West Antilles of the Caribbean. The Santa Rosa region is unique since it was densily populated when coffee and agriculture in general was the most important production of the Island but with industrialization was abandomed by the residents and has now return to its forestal state. It is also important due to the number of caves and subterranean rivers and streams, 200 caves have been identified so far, most of which are connected by subterraneous rivers and caves. These rivers are a major source of waters to a larger river, the Tanama river. Six rivers that cross the Karst region, mostly the north of Puerto Rico, are the sources that give water to the north aquifer's.

For 20 years, the Foundation for Speleological Investigations (FIEKP) has surveyed and conducted research in the area. So far FIEKP has surveyed the largest caves, 27 caves and mapped 17 of them, most of which have underground streams. In our study FIEKP presents the results of the surveying initiatives and the maps including topographical overlays. The study also presents results and excerpts of the research complete at the site by FIEKP and by other affiliated organizations. FIEKP's main objective is to preserve the site as a natural reserve and to annex it to the "Bosque of Rio Abajo", a Puerto Rico regional forest.

Management of karst environments within NSW parks and reserves

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Abstract

There are more than 400 separate outcrops of carbonate rock (predominately limestone) in NSW, approximately 90 of which contain caves large enough for a person to enter. These cavernous environments range in size and significance from small outcrops, with a few small caves, to extensive areas with well-developed surface features, hydrological systems, hundreds of caves, dolines and other karst features.

NSW karst environments contain a diverse range of geological and geomorphological features, systems and processes. They also provide important habitat for biodiversity; their surfaces host rare and endemic flora and fauna, whilst belowground caves shelter cave-dependant bats and invertebrates. Many karst environments have rich cultural associations that include special meaning to Aboriginal people and historic heritage linked with Australian folklore and early cave tourism.

Caves are important for their recreation and tourism. They also contain valuable scientific information such as insight into land-forming process, past climates and species distribution and linage.

Karst environments are highly sensitive to disturbance and unlike many other environments, may lack the resilience to endure even the slightest of human impacts. On the surface, their thin layers of soil render them susceptible to weed infestation and erosion and allow pollutants such as herbicides to be easily absorbed into the groundwater. Belowground, caves and conduits can quickly spread pollutants, with little scope for contaminants to be removed through natural filtration or remediation.

The continuation of a natural, healthy karst environment typically requires careful management. Approximately half of the cavernous karst environments in NSW are protected within parks and reserves managed by the NSW 'National Parks and Wildlife Service (NPWS)'. These include well known systems such as Abercrombie, Bungonia, Jenolan, Wombeyan and Yarrangobilly, as well remote areas that are less frequently visited such as those in the 'Macleay Karst Arc'.

This presentation provides an overview of key management strategies, guidelines and policies developed and utilised by the NSW NPWS to ensure best practice management of its karst environments. Current monitoring and collaborative research are also discussed.

Keywords: Management, NSW, National Parks

1. Introduction

The NSW 'National Parks and Wildlife Service (NPWS)' manages approximately half of the karst environments in New South Wales (NSW), which extend from Ashford Caves (Kwiambal National Park) in northern NSW to Indi Caves near the NSW-Victorian border in Kosciuszko National Park. Karst environments managed by 'NPWS' range significantly in their size and extent of karst development, and contain values of local, state, national and/or international significance.

In recognition of the unique management requirements of karst environments within parks and reserves managed by the 'NPWS', the former 'Karst and Geodiversity Unit' (now part of 'Landforms and Rehabilitation Team') was established in 2006 to ensure karst and geodiversity issues were prominent in strategic and operational planning. An overview of the Unit and its preliminary initiatives is provided in Meehan (2009a, b).

The 'NPWS' manages its parks and reserves in the context of a legislative and policy framework, primarily the National Parks and Wildlife Act and Regulation, the Threatened Species Conservation Act and numerous 'NPWS' policies. Other legislation, international agreements and charters may also apply such as the Environmental Planning and Assessment Act, 1979 and the International Union for the Conservation of Nature and Natural Resources (IUCN) Guidelines for Cave and Karst Protection, 1997.

2. Key Management Initiatives

Consultation with 'NPWS' field staff, karst managers and stakeholders identified a number of issues and knowledge gaps concerning the management of karst environments in 'NPWS' parks and reserves. These shortfalls were addressed through the following documents:

Cave Access Policy – developed in response to concerns raised by staff and members of the caving and scientific communities regarding the need for a consistent approach to regulating cave access. The policy (DECCW, 2010a) also acknowledges the on-going role of 'NPWS' in protecting the sensitive and often irreplaceable features found in many of NSW caves and was developed in consultation with a range of stakeholders including the Karst Management Advisory Committee and Australian Speleological Federation.

Cave Access Protocols – developed in response to concerns raised by 'NPWS' rangers, field officers, technical specialists and other members of staff regarding a lack of formal procedures to guide their safe passage through caves. The protocols specify the requirement for:

- A job safety analysis to be prepared, which outlines the specific measures to be taken to control the risks posed by caves to Office of Environment and Heritage staff; and

- Members of staff who regularly access caves to be formally trained in basic caving techniques.

Guidelines for Controlling Weeds on Karst – developed to help ensure that weed control activities undertaken by staff are environmentally sustainable. Specifically these guidelines:

- Outline the issues to be considered when planning and undertaking weed control activities in karst environments;
- Identify the appropriate methods for undertaking weed control in karst environments; and
- Summarise the weeds which are commonly found in NSW karst environments and the herbicides used in their control.

Guidelines for Managing Fire on Karst – developed to respond to the concern that karst values may be compromised by fire and associated management activities, these guidelines provide consistent and best practice approach to managing fire on karst. The implementation of the guidelines ensures that the planning and management of prescribed burns and fire suppression activities by 'NPWS' staff does not adversely impact on karst values.

Guidelines for Undertaking Development on Karst – developed for use by reserve managers (and potentially relevant lessees/licensees) when planning for, and undertaking, development (e.g. utilities, services, trails and walking tracks) in 'NPWS' karst environments. These guidelines help to ensure that development on karst is environmentally sustainable and support existing 'NPWS' environmental impact assessment procedures.

Karst Significance Assessments – developed to assist the 'NPWS' Reserve Establishment Team with the identification of karst acquisition priorities 'off park'. The methodology used in the assessments was based on the outcomes of a workshop attended by external specialists and was endorsed by the Karst Management Advisory Committee. This methodology was subsequently applied 'on park' to provide detailed documentation of the values of every karst environment within the 'NPWS' reserve system.

Karst Area Management Plans – developed with the primary objective of providing on-going protection of karst at a local level through the identification of site-specific issues and actions to provide sustainable use and management. Karst area management plans compliment park/reserve plans of management and to date have been developed for Deua National Park, the Macleay Area and Kosciuszko National Park.

3. Raising Public Awareness

To promote karst and geodiversity values more broadly across NSW, two posters 'Karst Environments NSW' and 'Geodiversity NSW' were produced (refer Meehan 2009a). Following the success of these posters, a more detailed 'Guide to NSW Karst and Caves' (DECCW, 2010) was produced. The guide has a geotourism focus and highlights the values, features and locations of 15 of the state's more prominent karst environments, both within and outside 'NPWS' managed parks and reserves. It also contains a strong educative component and is of potential benefit to schools, tertiary institutions and special interest groups.

4. Monitoring and Research

In addition to initiatives that directly assist the conservation and promotion of NSW karst environments, monitoring and research programs provide valuable baseline data, which can be used to guide and affirm local management decisions and inform broader strategic programs. Two prominent examples are:

Jenolan Environmental Monitoring Program – Jenolan Caves are arguably Australia's best known show caves, attracting more than 200,000 visitors each year. Monitoring measures air and water quality parameters that are of relevance to karst conservation and the conservation of biological diversity. Furthermore, the measurement and reporting of such parameters enables an objective evaluation of the environmental performance of Jenolan Caves Reserve Trust (or any future successor), with regards to air and water quality in the show caves. A more detailed overview of the program and preliminary results are provided in Baker (2014).

Research into the impacts of fire on karst – The natural fire regimes for karst environments in NSW are generally unknown. In 2012, the former Karst and Geodiversity Unit initiated a collaborative research project to support the development of fire management strategies for conserving karst environments.

The project received funding from the Australian Research Council and is led by the 'University of NSW (UNSW)', with the Office of Environment and Heritage, Australian Nuclear Science and Technology Organisation (ANSTO), University of Birmingham, and Optimal Karst Management collaborating as partner investigators. The UNSW work is examining the impacts of fire on karst, while extension work in 'OEH' is looking at the impacts on the aboveground flora associated with karst. The project will have important benefits for the management of 'NPWS' reserves containing karst and provide input into improved management guidelines.

5. Conclusion

The 'NPWS' utilises a range of initiatives including policies, guidelines, strategic reports and management plans to help ensure best-practice management of its karst environments. These initiatives are vital in assisting the NSW Government in meeting its conservation and sustainable visitation objectives, and safeguard the states karst and caves for future generations.

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Conveying the importance of stromatolites to self-guided tourists in Nettle Cave, Jenolan, NSW.

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Abstract

Stromatolites span all of geological time; they are the oldest evidence of life on Earth and are important in understanding how life began and first started to diversify. They also played a critical role in shaping the atmosphere as we know it today, causing an irreversible increase in atmospheric oxygen at ~2.4 Ga. Significantly, stromatolitic speleothems in Nettle Cave, Jenolan, resemble these truly ancient forms. Cyanobacteria growing on the surface of these stromatolites use hydrogen carbonate from roof seepage drip-waters as a source of carbon, and light from four entrances allows for photosynthesis and liberation of oxygen. Calcium from the limestone drip-water is deposited as calcium carbonate. The overall shape of these stromatolite structures is most influenced by wind, which causes drip-water to fall at an oblique angle, forming the asymmetric, segmented shapes. Wind also blows-in insects and sediment which become trapped on the surface of the stromatolites by biofilm produced by the microbes. One sample analysed previously shows growth over a period of 20,000 years, capturing an excellent source of information about recent past climates and could reveal environmental fluctuations over this time span.

In order to ensure their continued protection, it is important to promote an understanding of the scientific value of the stromatolitic speleothems in Nettle Cave to both visitors and guides at Jenolan. Linking these speleothems with information about the earliest life on Earth and the persistence of stromatolites through time plays a key part in engaging and educating the public about these interesting structures. Currently, tourists can take a self-guided tour of Nettle Cave using the Jenolan mobile application; however, there is minimal information available on the scientific value of stromatolites to our understanding of past climate and the early Earth. The proposed new visitor information project would involve: updating the stromatolite section of the current mobile application; placing a concise and attractive display board in front of the most prominent stromatolites; creating a pamphlet with more explanation, including pictures and diagrams, available from the guides office; and, updating the Jenolan Caves website to give further detail, including examples of other key stromatolites through time and links to scientific literature, for those wanting up-to-date and more in-depth information.

Keywords: *Stromatolites, Nettle Cave, Early life, Science Communication, Cave Management.*

1. Introduction

Nettle Cave, part of the greater Jenolan Caves system, has been open on and off as a show cave for the best part of 200 years, since 1838 (Cox 1984). It contains large, blue-green stromatolitic speleothems, which are able to grow and flourish in this particular cave due to the balance of microbial activity with sunlight, wind and the rate of cave drip-waters. These relatively rare speleothems were first described, although not directly by name, by Cook (1889): "One prominent stalagmite is like the back of a newly-shorn sheep, with shear-marks in the wool." However, it was not until a century later that these structures, more commonly known as 'lobsters' or 'craybacks' due to their asymmetric mound-shape and overall segmented appearance (Fig. 1A, B), were studied in more detail (Cox et al. 1989a). Cox et al. (1989a) looked at the morphology and mode of formation of the blue-green speleothems and concluded that they fit the definition of cryptalgal stromatolites after Aitken (1967): "(those structures which) originate through the sediment-binding and/or carbonate-precipitating activities of nonskeletal algae."

2. Formation and Morphology of Stromatolites

Stromatolites are most commonly found submerged in shallow-water environments, including; marine (e.g. the hypersaline lagoon of Shark Bay, Western Australia), fresh-water (e.g. Lake Pavilion, Canada), and hot spring environments (e.g. Rotorua, New Zealand). Stromatolites also occasionally occur in subaerial evaporitic settings, such as those from Nettle Cave, and also Wombeyan Caves (James et al. 1982). However, there are relatively few examples of stromatolites of this type worldwide. Cox et al. (1989a) proposed a model of formation of the stromatolitic speleothems in Nettle Cave, which involved a complex interplay between the photosynthetic cyanobacteria, rate of drip-waters, wind speed and direction, humidity and level of evaporation (Fig. 1C). These stromatolites primarily grow from "biologically driven inorganic calcite precipitation" (Cox et al. 1989b), enhanced by evaporation, on the surfaces where water falls from above. Depending on which stage a stromatolite is at in this cycle, its colour can change dramatically from deep blue-green (Fig. 2A), to dusty blue (Fig. 2B), to cream, as new calcite precipitates covering the cyanobacteria (Fig. 1A).

There are a number of differences between the Nettle Cave stromatolitic speleothems and other forms of stromatolites (Table 1). The evaporitic cave stromatolites are unique in that they are subaerial, gaining moisture and a source of carbon from the cave drip-waters (Cox et al. 1989b), whereas typical stromatolites are submerged in water and are only periodically, if ever, exposed. The morphology of stromatolites, whether exposed in air or submerged in water, is controlled by both the microbes and the prevailing environmental conditions. In the case of the Nettle Cave stromatolites, the cave environment is the primary control of overall morphology. The asymmetric, elongated shape of the stromatolitic speleothems is caused by the wind, which blows between the

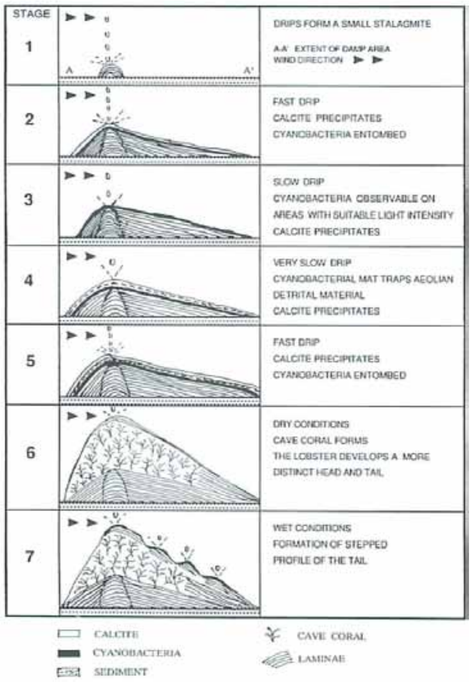


Figure 1. (A), (B) Sub-aerial stromatolitic speleothems in Nettle Cave were known as 'lobsters' or 'craybacks' due to their asymmetric and segmented appearance. (B) Shows blue-green cyanobacteria visible on opposite side of same stromatolite as in (A). (C) Mode of stromatolitic speleothem formation in Nettle Cave, from Cox et al. (1989a).

southern entrance to Nettle Cave and the large void opening into the Devils Coach House to the north (Fig. 3). In cross section, the tallest point (i.e. left hand side of Fig. 1C) is where the drips fall straight down, whilst the tapering 'tail' is caused by the wind blowing the drips sideways to varying degrees. This effect is nicely displayed on the concrete walkway of the Devils Coach House (Fig. 4A). A similar phenomenon is observed with the modern stromatolites in Hamelin Pool (Shark Bay, Western Australia), where the stromatolites are elongated in the direction of the tides (Fig. 4B). However, unlike the submerged stromatolites in Shark Bay which are subject to erosion and sediment deposition from rough waves and storms, the stromatolitic speleothems are comparatively protected from the outside environment. This results in a relatively uninterrupted record of the environmental and climatic conditions being preserved in these cave examples.

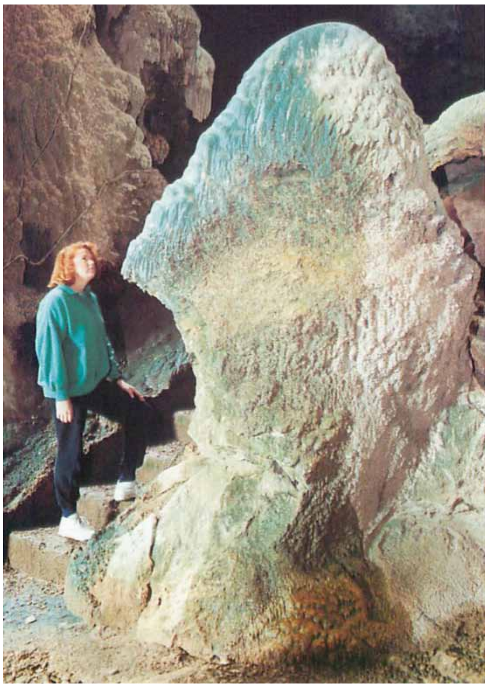
3. Value of Stromatolites

Fossilised stromatolites are important clues in understanding how life began and first started evolving on Earth. They are the oldest evidence of life, with good examples preserved from the c. 3.5 Ga Dresser Formation in Western Australia (Walter et al. 1980), and new, controversial stromatolites reported from c. 3.7 Ga in Isua, Greenland (Nutman et al. 2016). Stromatolites are known from throughout the global geological record, persisting through to the present day. Interestingly, it is not until c. 1.8 Ga that individual fossilised microorganisms are large enough to be visible with the naked eye (Grypania, see: Walcott 1899; Han 1992; Sharma & Shukla 2009, among others); microbial life apparently persevered alone for over 1.7 billion years.

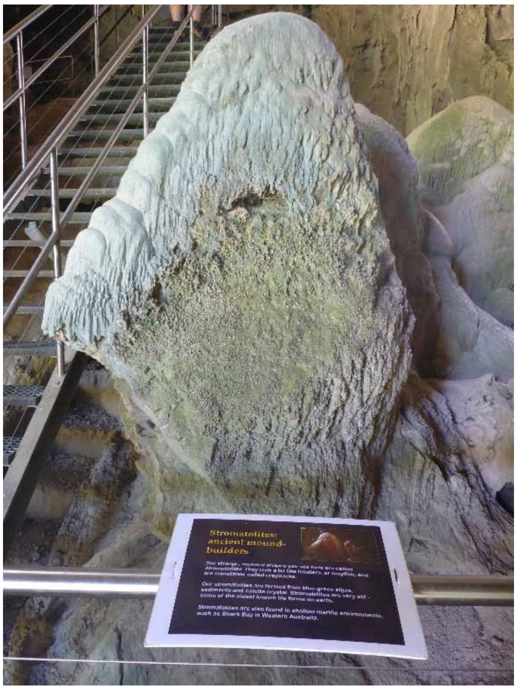
Microbes also played a huge role in shaping the Earth as we know it today. The Archean atmosphere was very oxygen poor, with <10-5 of the present atmospheric level (PAL) (Pavlov & Kasting 2002). It was not until the Great Oxidation

Table 1. Comparison between shallow-water stromatolites and stromatolitic speleothems:

Shallow-water stromatolites	**Stromatolitic speleothems**
Fully or partially submerged in water	Completely subaerial
Source of carbon from surrounding sea/fresh water	Source of carbon from cave drip waters (freshwater)
Water-borne sediment is trapped by microbial biofilm	Wind-blown sediment, along with dust and small insects are trapped by microbial biofilm
Primary influence on shape is sunlight, and tide strength and direction	Primary influence on shape is wind (Cox *et al.* 1989a) and sunlight from cave entrances
Range of morphologies present with increasing water depth	One broad morphology present, just different sizes
Growth of stromatolite primarily controlled by sediment input, as well as carbonate precipitation by microbes	Growth of stromatolite primarily controlled by inorganic calcite precipitation driven by microbes, as well as evaporation
Affected by erosion from wind and wave action, as well as potential to be partly or wholly smothered by sediment, and damaged by storms	Primarily affected by erosion from rate of drip water, but very protected from storms, wind erosion and potential to be completely smothered by sediment
Most common form of stromatolite at present day and throughout geological record	No known fossilised examples from geological record, and only rare examples exist today



(A)



(B)

Figure 2. Then and now:
(A) Stromatolitic speleothem from Cox et al. (1989a), wet with drip waters, highlighting vibrant blue-green colour of cyanobacteria.
(B) Same stromatolite in 2017 with cyanobacteria still present, but much less colour due to cessation of drips. In foreground is current, temporary A3-sized poster board on display to public.

Event (GOE) at c. 2.4 Ga that there was a significant rise in levels of atmospheric oxygen (Farquhar 2000; Holland 2002; Bekker et al. 2004). This irreversible rise is regularly attributed to oxygenic photosynthesis by stromatolites (Schopf 2014). Thus, through research into – and comparison with – modern analogues, fossilised stromatolites provide key information in understanding and reconstructing the original environment of deposition (Table 2). For example, Barlow et al. (2016) determined the relative water depth of different fossilised stromatolites from 2.4 Ga and was able to reconstruct the position of these different morphologies within the carbonate reef system, which allowed analysis of transgression and regression cycles. In a similar way, stromatolitic speleothems preserve a neat record of the paleoclimatic conditions during formation. Cox et al. (1989b) dated a piece of cyanobacterially-covered flowstone from Nettle Cave at over 20,000 years old, and estimated some of the larger structures to be at least 100,000 years old. Studying layer thickness and variability, as well as carbon and oxygen isotope data of stromatolitic speleothems such as these can reveal terrestrial paleoclimate information such as temperature, pH, rainfall and changes in overlying vegetation (Blyth et al. 2016; Wong & Breecker 2015).

4. Promoting Education

Since first use of the term stromatolite more than a century ago (Kalkowsky 1908), much research has gone into the different environments stromatolites inhibit and the array of microbes associated with each, resulting in an understanding of their importance in being able to unravel information about the past. In order to manage and protect the stromatolites at Nettle Cave, this needs to be communicated effectively to both the guides and visitors to the cave. The aim is to communicate scientific knowledge in an engaging way through a mutli-layered approach, using different media. This would include:

Table 2. Environmental and depositional information available from studying stromatolites:

Type of environment (lagoon, carbonate reef, lake, etc.)
Tide direction and subsequent shoreline
Approximate water depth
Location within the carbonate platform system (intertidal, subtidal, etc.)
Compositional information of water
Relative stability of environment (thickness of units)
Other environmental influences on stromatolite shape: relative tide/current strength, presence of storms, changes in amount of sediment input, changes in water depth.
By compiling information about stromatolites, inferences can be made about the changing and potentially increasing diversity over time, both in the form of morphology and microbial make-up.

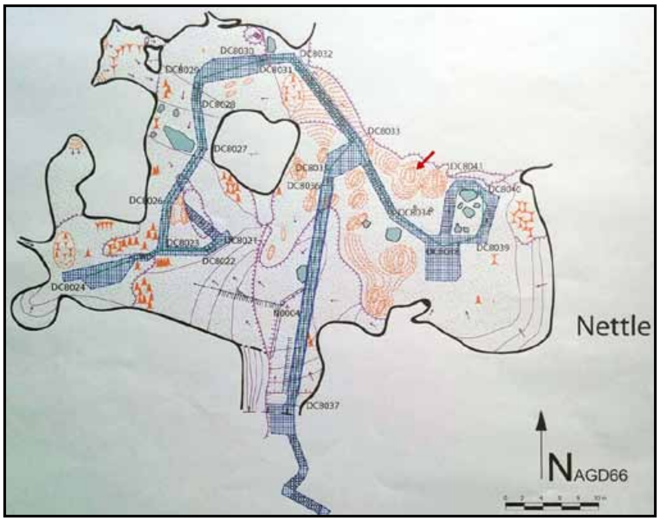


Figure 3. Nettle Cave map (© Jenolan Survey project, 2014), with stromatolitic speleothems shown by the elongated, segmented ovals in the central right hand side of the cave (e.g. arrow).

1. Updating some of the content of the mobile application, linking stromatolites with evidence of early life in the Archean, whilst keeping it easy to understand.

2. A poster board displayed in front of the most prominent stromatolite, where the current temporary sign is now (Fig. 2B), with more detailed information than is currently there. Proposed size would be A2 and it would cover: how stromatolites grow; that these particular stromatolites are at least 20,000 years old and by studying the layers, scientists can get information on past climates; stromatolites more commonly grow in shallow marine environments (e.g. Shark Bay, WA), which is why these cave examples are so special; the oldest evidence of life on Earth are fossilised stromatolites (from at least 3.5 Ga). The board would refer visitors who want more information to a pamphlet available at the Guides' Office.

3. A pamphlet, with further details on the above information including more diagrams and pictures, would be made available at the Guides' Office. This could be in the form of a folded, double-sided A4 sheet of paper, for ease of reproducibility. The pamphlet would direct those seeking even more information to the Jenolan Caves website.

4. Updating the stromatolitic speleothem page on the Jenolan Caves website, with extra information made available through links to articles and journal papers on stromatolites, both modern and fossilised. Using this method means it would be easy to update and add to the page as new research is reported, keeping the information current.

Using this multi-layered approach, where each of these media would contain slightly more information than the last, means visitors to Nettle Cave can gain as much, or as little, information as they would like about the stromatolites, allowing them to easily investigate further if they wish. Furthermore, the pamphlet and website would be a good resource for the guides to use, and to direct people towards more information. Most importantly, the proposed approach will have minimal impact on Nettle Cave and the stromatolites.

(A)

(B)

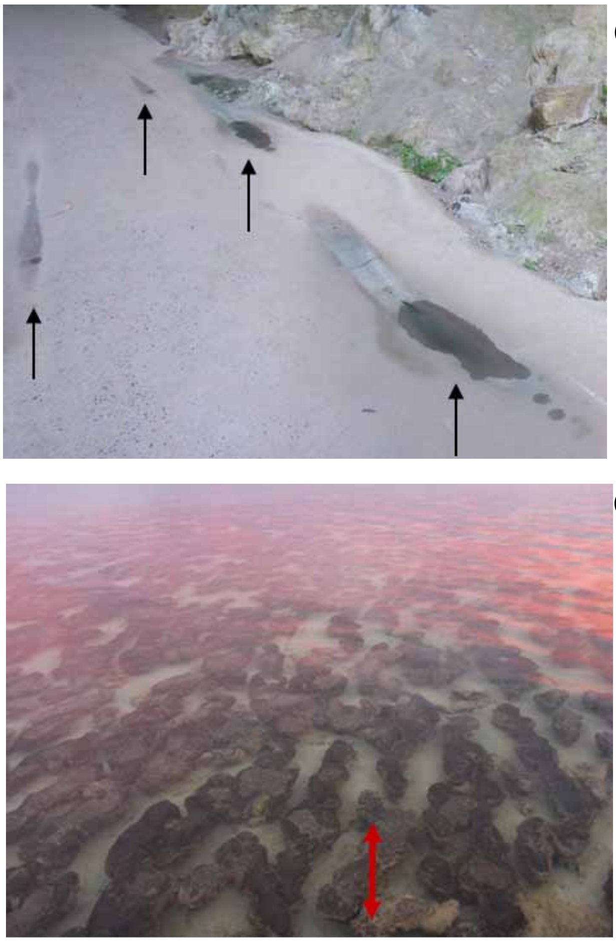


Figure 4. (A) New stromatolitic speleothems growing on the concrete walkway in Devils Coach House, Jenolan, highlighting the effect of wind on stromatolite form (arrows).
(B) Submerged, shallow-water stromatolites in Shark Bay, Western Australia, showing elongation with tide direction (arrow).

5. Summary

It is extraordinary that the stromatolite form has persisted for at least the last 3,500 million years, across a range of different environments. To accurately encompass this range, and include both modern and fossilised stromatolite examples, an updated and more widely accepted definition is now used: "Stromatolites are... layered, early lithified, authigenic microbial structures… that develop at the sediment water interface in freshwater, marine and evaporitic environments" Riding (2011). The stromatolitic speleothems in Nettle Cave are an uncommon but important example, as they preserve a consistent paleoclimatic record from the last 20,000, and possibly up to 100,000 years (Cox et al. 1989b). The introduction of the self-guided tour and installation of floating walkways has allowed visitors to view the stromatolites and surrounding cave with minimal impact, whereas previously, they could walk right up to and around the speleothems. It is proposed the value and importance of stromatolites be further conveyed in a series of engaging and multi-layered media for the public, including a poster board, pamphlet and updated webpage, to go alongside the existing mobile application.

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New Materials, Techniques And Technologies For Best Practices In Show Caves Management

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Abstract

The numerous pictures of concrete examples of good and bad situations taken around the world make this presentation an illustrated reading of the Recommended International Guidelines For The Development And Management Of Show Caves. Developed by the International Union of Speleology (U.I.S.), the International Show Caves Association (I.S.C.A.) and the International Union for the Conservation of Nature (I.U.C.N.), they were approved on November 3rd, 2014.

With particular attention to new materials, new techniques and technologies, it approaches among other topics were visitor safety, from wild cave to show cave, the above ground level works, access into a show cave, pathways in a cave, visitor capacity, lighting, lampenflora, bats, materials and new age materials, monitoring, cave managers, cave maintenance, visual pollution, cave guides and the public awareness.

It gives some tips and tricks to make the management of show caves easier for the sake of sustainable protection.

RÉSUMÉ

Les nombreuses photos d'exemples concrets de bonnes et de mauvaises situations prises de par le monde font de cette présentation une lecture illustrée des lignes de conduite internationales recommandées pour le développement et la gestion des grottes touristiques (Recommended International Guidelines).

Keywords: recommended guidelines, show cave management, cave protection, lighting, materials.

1. Introduction

The transmission of information for the best practices for the management of show caves are one of the main missions of the UIS Karst and Cave Protection Department.

The first mission of a tourist cave manager is, at a minimum, to keep the cave in excellent condition.

He/She must therefore make an environmental assessment of the cave and put in place a whole range of possible actions to maintain intact its fragile and very sensitive ecosystem or even improve it by sustainable development and management.

The main lines of action are outlined below.

2. A brief return to the past

The first protection commission: the Commission Nationale de Protection des Sites Spéléologiques was founded in Belgium in 1970. In 1975, Bernard Gèze wrote:

> *« Les grottes correctement aménagées pour le tourisme constituent donc non seulement des centres culturels de première importance, mais aussi des modèles pour la protection de la nature souterraine, telle que nous désirons tous la voir survivre. » (Gèze, 1975, p. 20).*

(Properly equipped show caves are not only cultural centers of primary importance, but also models for the protection of the underground nature as we all want to see survive).

3. Show cave management best practices

Show cave management best practices are about showing the cave in the most aesthetic way. It takes into account the protection of the cave environment and the socio-economic constraints but also doing this sustainably to ensure the cave resources will be available to future generations.

It is not simple… but possible.

For that we have a very helpful tool: the Recommended International Guidelines For The Development And Management Of Show Caves. These guidelines are the result of a wide cooperation between the International Union of Speleology (U.I.S.), the International Show Caves Association (I.S.C.A.) and the International Union for the Conservation of Nature (I.U.C.N.). They were developed and approved by these three international organization on November 3rd, 2014. The intention was to create recommended international guidelines, commonly accepted that all show cave managers and operators can work towards, taking into account both the protection of the environment and socio-economic constraints.

Many recommendations and suggestions have been received over the course of nearly twenty-five years, and therefore this document can be considered as the result of an active cooperation among specialists.

4. Keys of information

The guidelines provide key information about, among others: contingent and limiting conditions, visitor safety, above ground level works, access into a show cave, pathways in a cave, visitor capacity, lighting, lampenflora, radon, bats, new age materials, monitoring, cave managers, materials that usually do not belong in a show cave, cave guides and public awareness.

Figure 1. Gruta de Bustamante - Nuevo Leon – Mexico.

5. From wild cave to show cave

The conversion of a wild cave into a show cave can have a positive financial success for the cave itself but also for the surroundings of the cave. It may also be a way to protect the cave from crime and vandalism.

A detailed feasibility study should always be carried out to evaluate the impact of such conversion and to look at issues such as: commercial and financial aspects, impact on the broader area surrounding the above ground area, impact on the cave biotope, transport facilities to the region, external support facilities, access to the caves, signalling, inputs and artificial paths, internal pathways and internal transport, lighting, structural safety and security, communication systems, etc.

6. Visitor capacity

The visitor capacity is the maximum number of visitors allowed over a given period of time. It is defined in such a way that the visits will not in any way permanently change the environment parameters beyond their natural fluctuation range. It depends on the volume available, the ventilation, the lighting regulation and so on. This maximum capacity must be based on thorough monitoring, studies and advice of cave experts.

7. Monitoring

A show cave needs to be continually monitored. It's a necessity in a commercial and administrative sense but also environmentally. The cave climate depends on the number of visitors, the quantity of CO2, the air temperature, the air flow, the humidity and sometimes, in some places, radon levels. The interpretation of this data by scientists specialized in cave environments will help managers to determine the visitor capacity in order to maintain the cave integrity. Furthermore, the presence of lampenflora and of trash and dirt must be monitored.

8. Visitor safety

Both outside and inside, the visitor safety is a fundamental objective of any show cave. It includes:

- the access roads, parking, outside trails and all reception infrastructures;
- sufficiently high pathways or clear warning signs, solid handrails and railings (fig. 1);
- the possibility of access to people with reduced mobility;
- safety lighting along all paths;
- use of unsinkable electric boats; which must have two engines and a transverse engine for manoeuvring of the bow.

9. Safety

Communication between guides in the same group or between guides and the visitor centre is crucial in the context of a show cave. For large tourist groups, more than one guide may be necessary for leading, for the queue size control and especially for keeping people together during the visit. In such situations, communication is usually performed by radio. Communication between the guide and the visitor centre is critical to for the first call for external help in case of accidents or health problems of visitors. In this case usually the communication is done by phone or by an alarm system that can be activated. The number of participants of a group should be smaller if any sport activities are planned in a show cave. Two guides is a minimum for 10 participants. Even if the proposed activity is a great success and many people want to take part, the participant safety number should not be exceeded. It takes time to build a good reputation but it takes just one accident to ruin both your reputation and your business!

10. Entrances and air lock

The use of a double set of doors with an air curtain in between is the most efficient method to ensure an effective air lock system at artificial entrances (tunnels) and to avoid any disruption of the air circulation in the cave. It could be a pair of close and airtight doors or distant pairs of doors and sealed.

11. Materials

All materials used above or within a cave must be durable and should not adversely affect the cave environment and biota.

Avoid these if possible:

- concrete; alternately, spread it on a geofabric or plastic film;
- wood, which has a short life, it decomposes and supports fungal and bacterial growth;
- composite materials with fibre wood which also supports bacterial growth.

Don't use:

- galvanized metals which easily oxidise;
- dissimilar metals which are subject to corrosion problems;
- non-ferrous metals as copper with their green stains;

Figure 2. Grotte de Han – Belgique - Cave Lighting.

- iron and steel which rust;
- bitumen (asphalt) which leaches toxic product for biota.

Use as soon as possible modern materials which are more suitable in such environment such as fiberglass inside a plastic cover (Fibergrate ®):

- is up to 70% lighter than steel with an exceptional strength-to-weight-ratio when compared to materials like metal, concrete or wood;
- is corrosion and UV resistant. It requires less maintenance than traditional products;
- gives you the freedom and flexibility to create compelling new designs and to make your vision a reality;
- it is as easy to assemble as wood.

Technical information about this new material can be found here: http://www.fibergrate.com

12. Pathways needs

Pathways need a good walking surface. They are mostly in concrete but are also more often now in stainless steel which is however expensive and not easy to install. This long term investment requires no maintenance but the use of grids allows dust and small rubbish to fall through! New material as fiberglass inside a plastic cover is suitable. It is much less expensive, easy to install and durable but their grids also allow dust!

Pathways must be wide enough for 2 people walking by side and keep in mind people with reduced mobility and thus avoid stairs. Strong handrails are necessary. The stainless steel brightness is aesthetically unpleasant. Prefer thus to use new plastic with fiberglass. One can benefit from the use of discreet and aesthetic side kerbings to contain feet and washing water. They are also useful to include water pipes and cables. Concrete should not be laid from wall to opposite wall, so that the resulting impression looks like a carpet. The edge of path prevents drain water from path-washing to flow through cave sediments or speleothems. Curves are preferable to acute angles when designing paths. Structures elevated above the cave floor are best. If a mesh or a grating is used, make sure that the cave floor can be cleaned; or place a tray or similar to catch dirt.

Never lay concrete directly on the cave floor; if needed, use a geofabric or plastic film.

Figure 3. Borut Lozej, archive of the Skocjan Caves Park – Slovenia.

13. The lighting, the most important of the changes

The lighting should highlight the scenery of the underground's natural beauties (fig. 2).

The ongoing evolution of LED lights has revolutionized cave lighting making all others redundant.

In order to succeed with this important goal, lights should be well positioned, directed and shielded for the best effect. It is important that the lighting does not trouble the visitors due to the brightness or placement. It is important to avoid illuminating cave fittings.

The placement of spot lights is critical. This must be experimented with to determine the best options: i.e. shield the lights, or just move them a little and see the difference it makes! Experiment! When modernizing, do not forget to remove the old lights and cabling completely. Except perhaps for some vintage ones as examples to remember the past.

For safety reasons, track lighting of the pathways requires a lot of attention. It must be sufficient and discrete but at the same time avoid interfering with the atmosphere and natural design of the cave (fig. 3).

14. Lampenflora

Lampenflora is the persistent scourge of many show caves. To control lamenflora:

- Lights should not be closer than one meter from any surface.
- Lights must not shine on soft surfaces such as clay or amorphous calcite.
- Lights must be connected on separate circuits to be switched off when there is no visitor.

Chemical, mechanical and technical measures exist to control lampenflora but all have problems and will not eliminate lampenflora.

The methodology of lampenflora removal is excellently described in a paper written by the Show Cave Administration in Czeck Republic (Hebelka, 2014). Three methods are explained. The one with Sodium hypochlorite (5%) is nasty and produces dangerous fumes but it is cheap and needs only one-off applications. Hydrogen Peroxide (15%) must be buffered with calcite immediately before use. It is cheap but a nasty chemical without fumes. Two applications are at least required. A totally different method is the use of Ultra-violet light. This technique is cumbersome, slow and requires special safety measures but it is quite effective in the short term.

15. Respect the bats!

If a show cave hosts bats, make sure that visits are not organized in the sections used for hibernation and breeding. To facilitate their coming in and out, keep in mind that the top section of the gate entrances are to be equipped with horizontal bars with an air gap 15 cm high and 45-75 cm wide (minimum).

16. Cave managers

Cave managers should be competent both in managing the show cave business as well as the environmental protection of the cave. The cave must be preserved with great care and in a sustainable way. It's crucial that anyone involved in the management of a show cave has experience in the following fields: financial management, staff management, sustainable environmental management, communication, technical equipment, or must surround themselves with people knowledgeable in these areas.

17. Cave guides

Their role is extremely important. They are the link between visitors and the cave. They must have and use a guide manual specifically written about guiding in their cave. They must be properly trained.

18. Public awareness

To inform, sensitize and educate the visitors, place a short sign in an area everyone passes through before the entrance of the cave to explain them how to conduct themselves in the cave, and about the formation of the cave and the speleothems. To use more than one language is a plus but pictograms may be the best way. If there is one, take advantage of the mascot of the cave.

19. Maintenance

Maintenance is unfortunately often neglected until major works are needed. A formal time-based maintenance schedule should be developed for each cave regarding: the pathway and handrail state, the cleaning of the path floor, the lighting and other electrical fittings, the removing of graffiti, rubbish, coins and similar visitor-related issues.

20. Visual pollution

Excess equipment, infrastructure and inadequate lighting, railings and other elements often pollute and distort the visual beauty of the cave. 'Inadequate' and excess light pollute the visual amenity and distort the beauty of the cave which is the main reason why people visit these caves. Keep pathways and infrastructure as discreet as possible; don't illuminate them unnecessarily.

Protection installations are sometimes the only possible way to maintain speleothems near the path in pristine condition by preventing tourists from touching them. Choosing more discreet protection, is often the best!

21. What else can we do?

Promote these practices whenever you can! Never sell speleothems in show cave shops even if it is written that they were taken from quarries. It gives bad ideas to the ignoramuses.

22. Conclusion

Make an effort to protect these beauties and try to reflect on these points.

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Student and Public Engagement through Cave Microbiology Research at Thompson Rivers University, Canada

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Abstract

In Cheeptham's laboratory, we endeavor to discover **new drugs that could be derived from rare/less studied microorganisms isolated from caves.** While our work on cave microbiology has been published in scientific peer-reviewed journals, its significance has not been fully understood by the general public. Thus, to bring our science "to the streets", we have organized public and student engagement activities. One chief example is our art and science project exhibition entitled "Cave Microorganisms and Drug Discovery Expressed Through Visual Arts: A Collaboration of Artists and Scientists", later named "Microbes aRt us". We first produced strikingly beautiful SEM images of cave microorganisms, which were then used as the basis of artwork by Aboriginal and non-Aboriginal students to promote an understanding of bacteria in treating diseases. We wanted to draw interest from a wider audiences and raise public awareness in order to disabuse the misconception that all bacteria are bad. Also, the creative perspective of artistic expression provides a new way of visualizing microbiology and may help advance scientific discovery. This presentation aims to engage the public in the excitement of the exploration of cave microorganisms and their potential for new drug development, while developing new perspectives in the popular and scientific view of microorganisms through Aboriginal and non-Aboriginal students' art exhibitions. Moreover, this innovative project has also contributed to enhancing student engagement and learning. The project was funded through the Society of Applied Microbiology (SfAM) Public Engagement Fund, SfAM President's Fund and TRU Internal Research Fund for Scholarship and Scholarly Teaching.

Keywords: art and science, student and public engagement, community outreach, cave microbiology, drug discovery

1. Introduction

During the renaissance, a symbiosis existed between the fine arts and the sciences: artists were scientists and scientists were artists (Jones 2012). This natural alliance led to innovative solutions for problems ranging from municipal sewage systems to aviation. Today, the traditional system of higher education segregates the arts and sciences into separate streams so it is likely for students of the arts to graduate with no understanding of microbiology or how to communicate this part of the human experience to the world. We have sacrificed the whole-brained thinker for the specialist (Abbott and Rutherford 2005). Communication through the fine arts is an appealing way of bringing the general public closer to understanding and appreciating the importance of science, in particular, microbiology in everyday life (Lohmann 2015; Maloy 2016). Not surprisingly, the creative perspective of artistic expression provides a new way of visualizing microbiology and may help advance scientific discovery. This study aims to excite the public regarding the exploration of cave microorganisms, their identification and potential for new drug development as well as to develop new perspectives in the popular and scientific view of microorganisms. According to Van Wagoner (2012), a professor of geology and ceramic artist, "By communicating through the visual arts, the most complex of ideas can become tangible, accessible, and understood. Art is sensitive and intimate communication. It is personal. It touches the soul, imprinting a picture on the mind that can be recalled, and recalled and recalled but not forgotten."

My research team has been working on the discovery and identification of novel bacteria from the less-studied habitats of caves, particularly the volcanic and karstic caves of western British Columbia (BC). An objective of this scientific work is to study the microbial community and its diversity in these unique habitats while also investigating whether these microorganisms can produce new scaffolds of bioactive compounds. We believe such compounds can be employed in the development of drugs to treat existing and emerging resistant infectious diseases. Our preliminary findings demonstrated that actinomycetes (Gram-positive filamentous bacteria) isolated from the Helmcken Falls Cave in Wells Gray Provincial Park, BC showed antimicrobial activities against a number of multi-drug resistance pathogenic bacteria used in the study (Rule *et al.* 2011; Sadoway and Cheeptham 2011; Sadoway *et al.* 2013; Requelme *et al.* 2015; Riquelme *et al.* 2017). As part of this research, my team has produced a number of strikingly beautiful SEM images of these microorganisms, which we thought had potential for use in an artistic framework to explain the scientific role of these and other bacteria in treating diseases. Our work on cave microbiology has been published in scientific peer-reviewed journals, but has remained largely unknown to the general public, as is the case for most emerging scientific discoveries. In addition, most students of the arts are unaware of their potential to contribute their creativity to the development, understanding, and communication of such scientific work.

As a mother, a microbiologist, and an educator, I try to correlate the relevancy of what I do in the laboratory to everyday life. Also, I want to demystify common and unfair misconceptions that our society has about bacteria/microorganisms. Bacteria are often seen as "germs" or "superbugs," and a great number of people strongly believe that "all" bacteria are bad and deserved to be rid of. The perception of the general public is that bacteria do nothing but cause diseases, and are thus always dangerous and harmful to human health. Evidence of this perception is demonstrated by the popularity of such products as antibacterial soaps, detergents, other

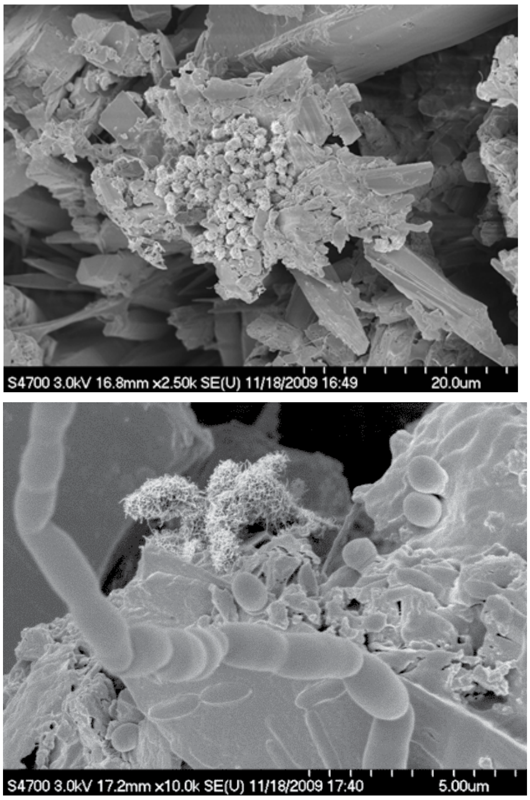

Figure 1. Some of SEM images of not-yet-identified microorganisms and their biofilms found in volcanic cave speleothem samples (Helmcken Falls Cave, BC, Canada); these images were used to inspire artists to create artworks.

household cleaners and personal toiletries. There is little general understanding of the symbiotic relationships between microorganisms and the actual well-being of people and their environment. As it turns out, we cannot live without microorganisms, as these diverse groups of bacteria and fungi are critical to our health in many ways: antibiotic production, fermented foods, bioremediation and plant disease control agents (Frey-Klett et al. 2011; Clemente et al. 2012).

To bridge this gap of knowledge and understanding, I spearheaded a student- and public-engagement project that resulted in art exhibitions entitled "*Cave Microorganisms and Drug Discovery: A Collaboration Between TRU Microbiology Researchers and Artists*", which later was renamed "*Microbes aRt us*". The objectives of this project were: 1) to increase the general public's understanding of the importance of applied microbiology in treating diseases by (a) creating and displaying artwork that communicates this message in tangible, accessible and interactive manners, (b) touring the art exhibit throughout BC, and (c) making it accessible online; 2) to provide an opportunity for Aboriginal students of fine art to explore applied microbiology through art; and 3) to encourage creative thinking among science students and scientists by engaging them in the artistic expression of applied microbiology of cave organisms. For this project, Aboriginal and non-Aboriginal students were fully engaged in the process, and their art exhibitions helped to promote an understanding of the potential role of bacteria in the treatment rather than the cause of disease as well as in our everyday life. Moreover, this innovative project contributed pedagogically to enhance student engagement and learning.

We would like the audience attending the art shows to appreciate the art work inspired by microorganisms dwelling in the Helmcken Falls Cave where the research had initially been conducted. The artistic expression of this work can be used to convey the connection between hard-core scientific research findings and the beauty/wonder of the world of microbes. Because my research and discoveries take place in an inherently interesting environment that stokes the public imagination—volcanic caves—it is hoped the art resulting from these evocative sites can provide a new creative perspective on novel bacteria and their potential in drug discovery, and illustrate the fact that "not all bacteria are bad". The cave environments I study are part of the Wells Gray-Clearwater volcanic field of central British Columbia formed during Pleistocene and Holocene time, with the most recent eruptions occurring 400 years ago (Hickson and Souther 1984; Hickson and Edwards 2001). These caves are low nutrient recycling environments, and the community relationships among organisms and their potential utility are poorly understood. I presented the first study of this volcanic cave microbiology and suggested that this particular habitat has great potential for the isolation of novel bioactive substances. To date, we have discovered over 400 isolates of actinomycetes from this very cave. SEM images showed the presence of microscopic life forms in all three rock and wall samples (Figure 1). 16S rRNA gene sequences revealed that 90% of the 43 isolates sequenced belong to the *Streptomyces* genus and the remaining 10% were *Bacillus*, *Pseudomonas*, *Nocardia*, and *Erwinia* genera (Rule *et al.* 2011; Sadoway and Cheeptham 2011; Sadoway *et al.* 2013). Some isolates showed a similarity to unidentified ribosomal RNA sequences.

Because Helmcken Falls Cave is located in the traditional Aboriginal territories of the Secwepemc Nation, we invited some Aboriginal artists (TRU students in Faculty of Fine Arts and Science) to contribute to this project and honor the land the caves are on. Additionally, as most of Aboriginal traditional medicine has a scientific foundation, it is appropriate to acknowledge and honor such wisdom. Despite a long history of applied microbiology, there is an underrepresentation of Aboriginals in this field, even though there are a number of successful Aboriginal artists and scientists elsewhere.

To tie together the art and scientific work, a short animated video titled "The Search for New Antibiotics" was created and shown at all the art exhibitions. To ensure accessibility and a wider dissemination of our scientific work, this animated video narrated by the author was also posted on YouTube on 26 September 2013. As of 19 January 2017 the video has received 70,766 views and the viewer number has continued to grow. The link to the video is: https://www.youtube.com/watch?v=B3_ujD53aL8

A number of students, local artists, and a TRU faculty member created artworks for this project: Julianne Peters, Erik Prytula, Louanne Mah, Ariga Avanessian, Tina Nguyen, Elizabeth Cummer, Wynona Edwards, Adah Gruver and Professor Nancy Van Wagoner. The exhibited artworks varied in styles, techniques and stories; they ranged from paintings, texture and paper work, tapestries, Photoshop, to 3D carving and potteries (Figure 2). Darlene Kalynka, an Associate Professor in the Visual and Performing Arts Department, has been our liaison and support providing experience and knowledge in

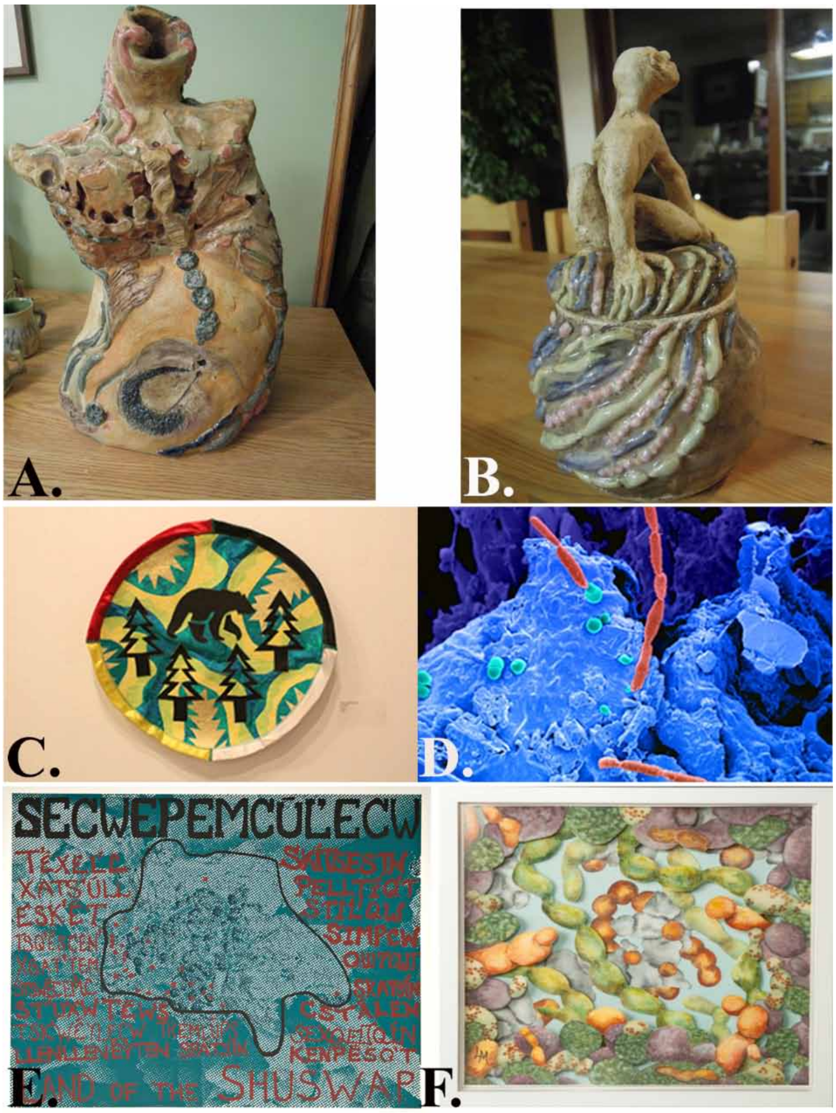

*Figure 2. Some of the artworks: A) Nancy Van Wagoner (Personal bacteria revealed: Torso); B) Nancy Van Wagoner (From simple to complex life: Evolution on a jar); C) Wynona Edwards (No title); D) Tina Nguyen (Cave Bacterial Graffito); E) Julianne Peters (***Secwepemcúl'ecw: Land of the Shuswap***); F) Louanne Mah (Bacteria Achomata).*

logistics related to exhibitions starting from framing to layout of exhibitions.

To date, we had five successful art exhibitions locally and provincially (please see information on artists and venues shown below). Some of our artwork was sold as well. Our art exhibition also captured the local media's attention and was featured in an article entitled "When art meets science, beautiful things happen" published in the Kamloops This Week on 17 January 2014 (pA21-A22). We were also interviewed in an article entitled "Science can be beautiful" in the TRU's Independent Student Newspaper "The Omega" in the volume 3, issue 15 which was published on 15 January 2014 (p4). Furthermore, this project was the subject of a keynote speech on "Collaboration Across Boundaries: Perspectives and Reflections from a Microbiologist" that was given for the University of Fraser Valley's campus wide professional development day with the main theme of interdisciplinary collaborations (Abbotsford, B.C. on 27 April 2015).

2. Art exhibitions

- Peters J, Mah L, Avanessian A, Nguyen T, Cummer E, Edwards W, Kalynka D, Cheeptham N, 2016. "Microbes aRt us" 1 May to 1 November 2016. Northern Lights College, Fort St. John Campus, Fort St. John, BC.
- Peters J, Mah L, Avanessian A, Nguyen T, Cummer E, Edwards W, Kalynka D, Cheeptham N, 2016. "Microbes aRt us" 23 March to 22 April 2016. The Pop Up Gallery at the Calvin Kruk Centre for the Performing Arts. Dawson Creek, BC.
- Peters J, Prytula E, Mah L, Avanessian A, Nguyen T, Cummer E, Edwards W, Van Wagoner N, Kalynka D, Cheeptham N, 2015. "Microbes aRt us" 20 September 2015 to 10 January 2016. Science World, Vancouver, BC.
- Peters J, Edwards W, Prytula E, Mah L, Avanessian A, Nguyen T, Gruver A, Van Wagoner N, Kalynka D, Cheeptham N, 2014. "Microbes aRt us". 2 to 17 October 2014 (Opening Reception: 3 October 2014 at 4:30 PM) TRU Art Gallery, Old Main Building, TRU campus, Kamloops.

- Peters J, Prytula E, Mah L, Avanessian A, Nguyen T, Van Wagoner N, Kalynka D, Cheeptham N, 2014. Cave Microorganisms and Drug Discovery: A Collaboration Between TRU Microbiology Researchers and Artists. 17 January to 22 March 22 2014 (Opening Reception: 17 January 2014 at 6:30 PM) Kamloops Art Gallery (BMO Open Gallery), Kamloops, BC.

3. An example of artist statements

Julianne Peters of Canim Lake Band, one of our Aboriginal artists, created 4 pieces of silk-screen printings entitled: 1) **Secwepemcúl'ecw - Land of the Shuswap shown in Figure 2-E;** 2) Sek'lep - ellcw - Coyote's; 3) SǓmec - Life Spirt; and 4) Píxem - Hunting trails. Below is an explanation about the piece in her own words:

"*My interest in this project was to share the history about Secwépemc people. My people traditionally used the Helmcken Falls and Wells Gray Park area as hunting grounds. The microorganisms were found in a cave where pictographs were found; this is the footprint of the Secwépemc. I wanted to share this history through a modern interpretation, and have used silk-screen as my medium. I believe that by sharing my people's history and language through art, that I could also preserve its beauty and revitalize the culture within myself. I thank Ann (Naowarat) for giving me this opportunity to share something so important to my self-identity.*

This artwork, titled "Secwepemcúl'ecw" (Land of the Shuswap), is a silk-screen print created by Julianne Peters of the Canim Lake Band (Tsq'éscen'). The two first layers are of the same bacteria image seen in Figure 1 (right). This image was obtained from a cave rock floor sample, chosen by the artist as they have a similar shape to the Traditional Secwépemc Territory. The first layer (dark blue) of the screen print is an inverted image to the left, which highlights the darker areas; the second layer (lighter blue-green) is the original image. The third layer, the red-brown text, contains the names of the existing Secwépemc bands in Shuswap Territory. The title, outline of the map, and also the 'X' marking the Helmcken Falls are all in black. The Helmcken Falls and Mahood area are a very important place to the Tsq'escenemc (Canim Lake People). As a semi-nomadic people, they would travel to these areas for hunting, fishing and trapping; there were many pictographs in this area that demonstrated the use of the land".

4. Summary

We succeeded in achieving the project objectives: 1) to increase the general public's understanding of the importance of applied microbiology in treating diseases by (a) creating and displaying artwork that communicates this message in tangible, accessible and interactive manners, (b) touring the art exhibit throughout BC, and (c) making it accessible online; 2) to provide an opportunity for Aboriginal students of fine art to explore applied microbiology through art; and 3) to encourage creative thinking among science students and scientists by engaging them in the artistic expression of applied microbiology of cave organisms.

This project bridged the gap between the arts and sciences in higher education, and in doing so created artwork that increases public awareness about the importance of applied microbiology and the human reliance on microscopic organisms. This project also has inspired our talented students of Aboriginal heritage through the exploration of their traditional Secwepemc lands with both modern science technology and art. By communicating these concepts through the artistic voice of Aboriginal art students we hope to inspire the participation in science of this under represented group. Overall, this work in applied microbiology is beautifully visual. The caves themselves are unique and scenic, and the SEM images of the microorganisms displays a natural artistry. Therefore, the idea using the fine arts as a means of enhancing the dissemination of concepts of applied microbiology and the importance of bacteria in treating diseases in our daily life was successfully achieved. Now, the messages that "not all bacteria are bad" and that these cave bacteria may one day help us to produce new antibiotics to fight the infectious diseases are spreading one cave and one exhibition at a time.

Acknowledgements

I wish to express my sincere appreciation to many people involved in this project directly and indirectly, without whom this project could have never materialized and succeeded: Julianne Peters, Erik Prytula, Louanne Mah, Ariga Avanessian, Tina Nguyen, Elizabeth Cummer, Wynona Edwards, Adah Gruver, Dr. Nancy Van Wagoner, Steve Van Wagoner, Darlene Kalynka, Donald Lawrence, Derrick Horne, Kent Watson, Ken Wagner, Jorge Cham, Colin Lyons, John Jacques, May Al-Fouadi, Joanna Urban, Jon Fulton, Joanne Brown, Dory La Boucane, Vernie Clement, Paul Michel, Dr. Tom Dickinson, Christine Petersen, Dr. Soumya Ghosh, Dr. Cynthia Ross Friedman, Dr. Mairi Mackay, Karen Ross, Ingebjorg Jean Hansen, Jo-Ann Coggan, Dr. Friderike Moon, Brian Anderson, and many students who kindly volunteered to help with exhibitions.

There are a number of funds and organizations that we are indebted to: Society for Applied Microbiology (S*f*AM) Public Engagement Fund (2012), S*f*AM President's Fund (2013) and TRU Internal Research Fund for Scholarship and Scholarly Teaching (TRU IRFSST 2014), and TRU Biological Sciences SPAF Fund (2016). We thank TRU Faculty of Science, TRU Faculty of Arts (Visual Arts) and TRU Aboriginal Education Resources for their continued support. Thanks also to University of British Columbia Bioimaging Facility, Piled Higherand Deeper (PHD Comics), Kamloops Art Gallery, Northern BC Speaking STEM series, Faculty of Science Northern Lights College (Fort St. John), Calvin Kruk Centre of the Performing Arts (Dawson Creek), Science World (Vancouver), and TRU Art Gallery.

Microbes aRt Us

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*Sadoway T,Cheeptham N,2011. Susceptibility of Three Drug–Resistant, Gram–Negative Pathogens to Antimicrobial Compounds Produced by Cave Actinomycetes. The 111th American Society for Microbiology General Meeting, New Orleans, LA from May 21 to 24, 2011. *Selected as one of the Student Poster Presentation Section.

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One Of Earth's Special Places

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Abstract

Naracoorte Caves, located in the southeast South Australia, along with Riversleigh in Queensland, were listed as UNESCO World Heritage Sites in 1994 as 'Australian Fossil Mammal Site (AFMS) - Naracoorte and Riversleigh'. The two sites were listed for their extensive fossil record as representing major stages of earth's history, record of life and geological processes and representing ecological and biological processes in evolution of Australian communities of plants and animals. Naracoorte's fossil record spans the last 500,000 years - a time period characterised by global ice ages. The fossil record is one of the world's most diverse, well preserved and rich for this time period. These two sites have significant fossils that reveal how Australian fauna developed over time and importantly - responses to climate change and arrival of Indigenous and later, Europeans to Australia. Many fossil deposits in one geographic area provide a near continuous record through the last ½ million years. AFMS - Naracoorte is a relatively small but complex site. In part due to increased visitation and advances in scientific research over the past four decades, it has become increasingly important to protect not only the caves and karst systems but also the fossil collection held on site at Naracoorte Caves WHA (NCWHA). Decision makers at Naracoorte now think three-dimensionally – how could above ground activities affect cave environments and fossil sites? Protections associated with the site over time changed with access more controlled than in past eras. In general local community, visitors and key stakeholder groups understand and recognise the need for protection. This paper describes two projects implemented with input from stakeholders in the planning and management of the NCWHA. The first project – a cave zoning review began in 2015 with goal of defining the access protocols for all caves within the park. Following close stakeholder consultations, there was agreement about reasons for protection of caves and World Heritage values. A second project focused on fossil collection and management at the WHA. Over a 45-year history of fossil excavation the curation of fossils has been largely directed by researchers with some oversight by South Australian Museum (SAM) or the agency responsible for managing Naracoorte Caves. This resulted in a very large fossil collection, split between South Australian museum and the onsite facility. Each has different record-keeping mechanisms. A six-month audit in 2015 of the fossil laboratory resulted in all specimens in the laboratory being listed in the publicly available Biodiversity Database South Australia (BDBSA) which will make them more easily available for research where appropriate, ensure they can be tracked when and if they are taken on loan. Accessibility to resources enables research and facilitates education.

Keywords:

1. Introduction

The Australian Fossil Mammal Site is a serial listing including sites at Naracoorte in South Australia and Riversleigh in Queensland. It is among the world's 10 most significant fossil sites and is an excellent illustration of the key stages in the evolution of the unique fauna of Australia. Naracoorte and Riversleigh are outstanding for the extreme diversity and the quality of preservation of their fossils and help us to understand the history of mammal lineages in modern Australia. The Naracoorte Caves contain one of the richest and most diverse fossil faunal assemblages on the Australian continent (Grün *et al.*, 2001; Macken *et al.*, 2012; Prideaux *et al.*, 2007). The Naracoorte Caves World Heritage Area (NCWHA) is located 11 km southeast of Naracoorte in South Australia. The area contains 26 known caves with over 100 fossil sites among them (Reed and Bourne, 2000). It was proclaimed a Conservation Park in 1972 when management was transferred to the National Parks and Wildlife Service. In 2001 the park was reclassified as a National Park and is currently managed under the Naracoorte Caves National Park Management Plan (2001).

The significance of the Naracoorte dates back to January 1984 when Blanche and Victoria Fossil Caves were entered into the Register of State Heritage Items (now known as the South Australian Heritage Register). At the time, both caves were regarded as being of State heritage significance because their use by man reflected changing perceptions and appreciation of aesthetic features of the cave environment. There is evidence of early white use and alteration to the interior of some caves especially in Blanche Cave, but little is known of the significance of the caves to the Aboriginal inhabitants of the area. While human influence can be observed within

Figure 1. Blanche Cave, walking by the historic garden

Blanche Cave, Victoria Fossil Cave remained largely inaccessible until the discovery of fossil beds in 1969. Subsequently, palaeontological excavations from this and other caves within the Naracoorte Caves National Park and World Heritage Area have contributed a large fossil collection of scientific, heritage and educational significance. The palaeontological significance of this site is most prominent with the presence of Miocene marine species (40-15Ma) throughout the limestone cave walls and roofs; oldest confirmed fossils to date (500 ka) in the Inner Chamber of Cathedral Cave (Prideaux *et al.*, 2007); presence of highly diverse Pleistocene fauna deposits, including Megafauna, type locality for three megafauna species (500-220 ka) in Victoria Fossil Cave Tourist Chamber (Grün *et al.*, 2001; Prideaux and Wells, 1998; Smith, 1976; Wells *et al.*, 1984; Wells and Murray, 1979); vast untouched Megafauna reference deposits in Victoria Fossil Cave Inner

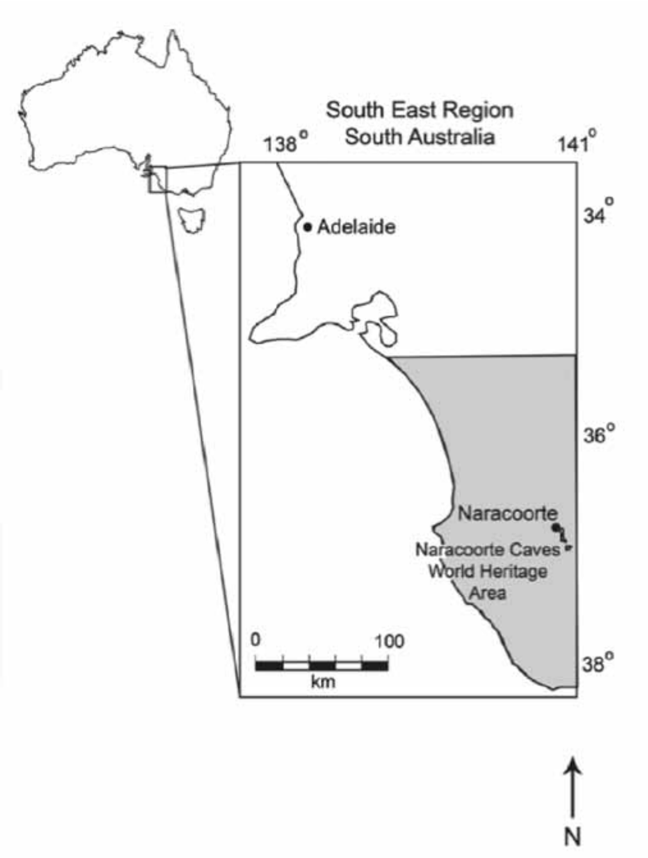

Figure 2. Location of Naracoorte Caves WHA

Figure 3. Paleontological excavation Blanche Cave. (Photo Liz Reed)

Ossuary Chamber (Reed, 2006); pre-Last Glacial Maxima faunal sequence in Grant Hall, Victoria Fossil Cave (Fraser and Wells, 2006; Macken *et al.*, 2011; Macken *et al.*, 2012); late Pleistocene faunal and vegetation sequence spanning the last glacial cycle in Blanche Cave – Third Entrance Chamber (Darrenougue *et al.*, 2009; Macken and Reed, 2013, 2014; Macken *et al.*, 2013b); late Pleistocene and Holocene faunal sequence spanning the Last Glacial Cycle in Wet Cave Entrance Chamber (Macken *et al.*, 2013a; Macken and Reed, 2014) and late Pleistocene and Holocene faunal and vegetation sequence spanning the Last Glacial Cycle in Robertson Cave Entrance Chamber (Grealy *et al.*, 2016; Macken and Reed, 2013).

2. Location of Naracoorte Caves

For more than 50 years, scientific investigations conducted at NCWHA have expanded our palaeological knowledge and contributed to the development of tourism interpretation materials at the site. Much of this research has contributed knowledge on late Quaternary faunal communities of southern Australia (Reed and Bourne, 2009); the taxonomy and systematics of extinct and living faunas (Prideaux and Wells, 1998); vertebrate taphonomy of cave deposits (Reed, 2006, 2009) and environmental change over the Quaternary (Darrenougue *et al.*, 2009; Forbes and Bestland, 2007).The scientific and natural history values of the cave deposits are reflected in not only the publications associated with this research but their World Heritage Listing and extensive on-site interpretation materials that have been developed over the past years. The Naracoorte Caves could be regarded as one of the earth's special places because of the presence of megafauna finds that help to explain past extinction patterns, the influence of man on ecosystems and past climate. However, with increasing scientific research and access by cavers, karst experts, recreational groups and tourists on guided tours, the need to adopt sustainable management strategies for the caves has become apparent. Extensive scientific investigations over the past decades have also resulted in a vast collection of fossil materials, some held onsite at Naracoorte and some held with SAM, with no common framework to manage such collection. This paper specifically focuses on stakeholder consultation leading to the cave access zone system and the development of fossil collections guidelines for the Naracoorte Caves World Heritage Area.

3. Cave Access Zone System

There are several criteria used to classify caves including how they are formed, presence of vertebrate and invertebrate fauna, and general access protocols for their protection and management, among other factors (Davey *et al.*, 1982; Engel, 2011; Gunn, 2004; Northup and Lavoie, 2001). Davey *et al.* (1982) proposed a cave classification system to guide protection and management of karst features, particularly caves. This classification system was adopted for most caves in Australia as a valuable tool to help managers, cavers and members of the karst community to adopt sustainable practices when accessing caves. At its basic level, a cave classification scheme defines management objectives and practices for specific caves whilst allowing for variations at a local level in response to specific conditions, land tenure and management authority. Davey *et al.* (1982) outline the following five principles for the implementation of cave classifications:

1. Consideration of the national significance of specific karst area and features.

2. Integration of cave classification in management planning.

3. Active consultation with stakeholders when classifying caves within a karst area.

4. Classifications should be regularly reviewed, and

5. Classifications should be based on stated criteria.

The classification system by Davey *et al.* (1982) has been applied at Naracoorte Caves with only minor modifications because of its flexibility to fit different karst environments. Despite its flexibility, this classification system has been criticised for its emphasis on users rather than conservation needs or values of caves (Larkin, 1993). Larkin (1993) argues that cave management classifications should be based on the

Figure 4. Thylacoleo & bed.

sensitivity of a cave to human disturbance and protecting the values of the cave. Other weaknesses noted by Larkin (1993) include the limited reference to the limits and controls to access under each classification, the ambiguous purpose of the 'reference' and 'dangerous' classifications and the emergence of multiple classifications applied to a single cave as observed at Naracoorte Caves and Jenolan in New South Wales. These shortcomings have been addressed by adopting specific cave classes and zones, where cave class specifies the broad management intent for whole caves and cave zones specify the objectives, users, prescriptions and conditions for managing specific areas within caves or in some cases whole caves. As caves and cave systems come in a wide range of shapes and sizes, from micro-fissures to caverns several thousands of metres deep and high, and hundreds of kilometres in length, there is considerable variation within and between sites on the access protocols put in place.

Here the evolution of the Cave Zone Access System at Naracoorte WHA is outlined. In an effort to promote cave awareness among different users and encourage responsible caving and develop robust management strategies for different caves and cave sections, a new cave access zoning review was initiated in 2015 to classify all caves on site. The process involved consultation with stakeholders including cavers, karst experts and recreation groups. The objective of the consultation was to identify all unclassified caves at the Naracoorte Caves World Heritage Area and specify access protocols for different caves and/or specific sections of a cave system. A Cave Zoning Workshop was held on site after initial consultation through an online survey and direct feedback from different user groups. This workshop brought together stakeholders from different backgrounds to share their views, ideas and concerns on the Naracoorte Caves – Cave Access Zone System. In addition, this workshop facilitated discussion about the implementation of the System and the re-zoning of selected caves within the Naracoorte Caves National Park, taking into account knowledge of the threats and values of the site. A range of recommendations was forwarded to improve the Cave Access Zone System. The insights, experience and knowledge of researchers and members of the caving and karst management communities made a significant contribution to the Cave Access Zone System, ensuring that it is appropriate and robust. The workshops enhanced stakeholders' understanding of the scope and role that Cave Access Zone System played in the management of access to caves. Participants at the workshop came up with a list of caves and cave sections recommended for a zoning review. Another positive outcome of this was the establishment of a working party to develop recommendations for the zoning of unclassified caves within the Park and other caves; the identification of knowledge and resource gaps (e.g., up-to-date cave maps) to be filled to support cave management and options for the implementation of Cave Zone Access System.

As emerged at the workshop an important requirement for the Cave Access Zone System from the perspective of stakeholders is for it to be flexible and values based. Flexibility in the cave access protocols may be warranted especially in the case of more routine special situations such as community events in Blanche Cave. Management determines access protocols for less predictable situations. In exceptional cases, management may modify access protocols in response to a special situation. Generally several factors will be considered including the nature and purpose of the special access situation, the nature of the cave sites to be visited, work health and safety risks and potential risks to cave values and environment posed by the activity and altered access protocol. Consistent with the World Heritage Management principles, primary consideration for on-site management of caves is the protection of the outstanding universal value of the site. This means any management action for non-World Heritage listed values and use of the site must be consistent with the management of World Heritage values. The Cave Access Zone System provides for the protection of World Heritage values as the highest management priority followed by protection of other cave values (e.g., geology, biology, cultural) whilst allowing for a hierarchy of appropriate access to enable the realisation of 'use' derived values (e.g., science, recreation, education, commercial). It is based on the premise that all caves within the Naracoorte Caves National Park and World Heritage Area contain values of significance at a State, National and International level. Protocols for managing each cave or specific sections within caves consider that features of the caves have intrinsic value. Other factors influencing the types of activities and levels of access permitted for the site's caves/cave sections, include how cave is classified under the current Management Plan, the level and type of infrastructure available to protect the cave environment and values from inadvertent degradation and damage, minimum leadership to manage groups and ensure the health, safety and welfare of visitors, the quality of experience for visitors and carrying capacity of the cave/cave sections, potential for cumulative damage from visitation and how can this be avoided through access protocols as well as work health and safety risks to staff and visitors posed by activities within the site's caves.

3.1. Implementation of Cave Zone Access System

The Cave Zone Access System is being trialled. Recommendations from this trial will be formally adopted in the revised Naracoorte Caves National Park Management Plan currently being developed. During this trial, there are no major changes expected to how access to the caves is managed. What the Cave Zone Access System does, however, is to document the protocols of access for specific caves and cave sections. While there are no major changes on how recreational cave groups and researchers will to access caves stakeholders recommended all tours into specific caves such Fox Cave are to be accompanied by two experienced leaders. DEWNR staff

BDBSA Project Metadata Detail

Survey/Project Number: 1052 ***Total No. of Sites:*** 0
Survey/Project Name: Taphonomy of large mammal bone deposits - Victoria Fossil Cave
Abstract: Study of the taphonomy of Main Fossil Chamber, Victoria Fossil Cave (5U1) by Dr Liz Reed. Project involved excavation and in situ interpretation of fossils from Pit E. PROJECT SPECIFIC PUBLICATIONS Reed, E.H. 2008. Pinning down the pitfall: entry points for Pleistocene vertebrate remains and sediments in the Fossil Chamber, Victoria Fossil Cave, Naracoorte, South Australia. Quaternary Australasia 25, 2?8. Reed, E.H. 2003. Taphonomy of large mammal bone deposits, Naracoorte Caves. PhD Thesis. Flinders University, South Australia. COLLECTION SUMMARY Pit E fossil collection is stored in the Naracoorte Caves Fossil Laboratory, organised by the positional reference system. Trays containing this material are labelled ?Pit E? in addition to the coordinate system labels. While the coordinates on the labels and in the database for this material are in decimal feet (in accordance with the established system), they were converted to metric measurements for the analysis for this project. About 65% of the collection is identified to genus or species level. As the taphonomic emphasis of this study required analysis of the wear and fragmentation on all bone material, the collection contains more well cleaned and preserved fragmented non-diagnostic items than a typical taxonomic collection. Bulk rock from this dig is stored in the Naracoorte Caves Fossil Shed, and has been approved for potential future disposal by Dr Reed.

Start Date: 01/01/1998 ***End Date:*** 31/01/2003
Survey Type: Vertebrates only

Study Area Description: Fossil Chamber, Victoria Fossil Cave (entrance 5U1), Naracoorte Caves National Park: Zone 54, Easting 482499, Northing 5899871.

Objectives
Vegetation: *** No vegetation survey objectives recorded
Fauna: *** No fauna survey objectives recorded
Methodology
Vegetation: *** No vegetation methodology recorded
Fauna: SAMPLE COLLECTION Excavation of Pit E in Main Fossil Chamber of Victoria Fossil Cave, following established positional reference system in the site ? see ?Fossil fauna of Fossil Chamber, Victoria Fossil Cave? for a description of the system. Pit E measured 3 X 3 m and was divided into nine 1 m2 grid squares (numbered 1 to 9). Diagram in associated publication. VERTEBRATE FOSSIL PREPARATION Excavated fossils were cleaned by washing, dried and were hardened by dipping in polyvinyl butyrate in acetone solution. VERTEBRATE FOSSIL REGISTRATION Majority of items were registered to the Flinders University palaeontology collection (FU 10,000 ? 13,640). SEDIMENTARY ANALYSES 500 g sediment coring samples were taken at 10 cm intervals along each section from each layer of Pits B, C and E for comparison and analysis. Auger sampling of the land surface sediment directly above the fossil chamber was also undertaken. Details in associated publication.

Data Distribution Rules: CODE 1:DISTRIBUTE ACCORDING TO DENR POLICY -need to confirm
Project Basis: Fauna : Fossil excavation
Data Custodian/s: Department for Environment and Heritage (BDBSA:South East)
Flinders University of SA

Figure 5. Example of project entered in BDBSA

and stakeholders will be familiar with the terminology of the Cave Access Zone System during this trial period before it can be formally adopted. Researchers will continue to access the caves through the existing permit system while recreational groups will submit applications for visit caves for recreational purposes. As recommended by stakeholder's recommendations, Wild Caves such as Appledore, Peppertree Hole, Pavy's Plunge, Little Cathedral, Little Victoria and Frog Hole will be managed as Limited Access Zones. Under this zoning, there are some changes to the access protocols for research and recreational caving. The most significant of these changes is that recreational caving will not be permitted during the trial period in accordance with the protocols for Limited Access Zone. The trial does not involve the zoning of sites to facilitate activities that restricted under the current Management Plan. These changes will only be implemented through the management planning process to ensure appropriate decision making, risk management and accountability.

A Cave Access Zone System working group was also established to review the outcomes of this trial and recommend value-based recommendations for all caves as well as classifying caves in Victoria Fossil Chamber. It will identify any identify challenges, concerns and opportunities for improvement prior to formal adoption in the Management Plan. A participatory approach will result in robust management strategies for different cave systems and promote awareness on responsible caving among different users from the cave and karst community.

4. Fossil collection management at Naracoorte World Heritage Area

The Naracoorte Caves *Local Collection Management Guidelines* outline the requirements and expected practices for the short and long-term management and protection of fossil materials recovered from fossil sites within NCWHA. The Naracoorte Caves World Heritage Area preserves and presents one of the world's most outstanding vertebrate fossil records, with the first collections of vertebrate fossils made in the mid-nineteenth century. From the first systematic fossil excavations in the 1970s several excavations and projects have occurred in a number of the Park's caves, resulting in a large fossil collection of scientific, heritage and educational significance. However, this fossil collection has been until recently, divided between the South Australian Museum under formal curation and within the field collection held onsite at the Naracoorte Caves under the care of the Department of Environment, Water and Natural Resources (DEWNR). At any given time materials may be in the care of research institutions as part of an active research program. Materials held in the onsite field collection or being used in active projects are in various stages of preparation and have a variety of storage, labelling and data recording methods, reflecting the priorities and methods of the researchers involved in their collection or use over the last 45 years.

With the support from Commonwealth funding, DEWNR completed an audit of the on-site collections and developed *Local Collection Management Guidelines* to establish a clear set of practices and protocols for the management of fossil materials held onsite at the Caves and involved in active research projects. These guidelines were primarily developed to ensure consistent and best-practice fossil collection management for all palaeontological projects conducted at the Naracoorte Caves and to guide the retrospective management of existing collections. Here a summary of the outcomes of the collection management project, including aspects of onsite fossil storage and management and novel solutions for data and record keeping is presented.

Figure 6. Peter Majoros and sample storage

Over a six-month period in 2015 an audit of the onsite fossil collections held at Naracoorte World Heritage Area was completed. All fossil records are now entered and held in a central biological database managed by DEWNR and publically accessible. This project reorganised the on-site fossil laboratory to improve fossil storage and accessibility of collections for researchers and others with interest in the fossil collection. Management at the Caves have also developed loan procedures to ensure fossil materials only removed as approved by DEWNR – based on same criteria used by the South Australian Museum to assess loan applications. This approach now ensures that all palaeontological work by researchers is collated and that all collections are tracked over time when removed from either the SAM or on-site laboratory for research. The guidelines specify steps that researchers are required to undertake when conducting palaeontological research and collecting and managing fossils at Naracoorte Caves World Heritage Area. Once permission is granted to conduct research at the Caves, the researchers are required to register their projects online in the Biological Databases of South Australia Projects Register (see Fig 2). Where a research project involves fossil excavation, researchers are required systematically record all bones and sediment bags and comply to set post-excavation standards while preparing and processing the samples. The researchers use a BDBSA Data Entry Tool to enter meta-data for their projects. All data is lodged with the BDBSA and SAM and permit reports are provided to DEWNR and the Australian government.

The Guidelines also specify how projects involving fossil loans are to be managed. Just like research involving exaction, researchers submit permits for fossil loans to the Naracoorte Caves World Heritage Area. The fossil loan may be for unsorted sediment bags, or sorted material or individuals and the projects have to be entered into BDBSA. Fossil loans are only loaned to institutions within Australia. The fossil collection project gives management oversight to the SAM or DEWRN. Whereas some fossils were initially unregistered, held either at the SAM and/or onsite facility, the fossil collection project was designed to ensure consistent recording, storage and curation of all fossil collections.

5. Conclusions

Naracoorte Caves World Heritage Area is a special place with state, national and international significance. It is important to support scientific investigations to general data on past megafaunas and paleoclimate environments. As with many cave and karst systems around the world, the effects of humans on these systems has risen significantly over the years. This calls for proactive strategies to protect not only the cave and karst features but also preserve the World Heritage values of the site. The protection and management of these values require a multi-pronged approach. This is particularly so given that irrespective of their speleogenetic histories, all caves within Naracoorte Caves World Heritage Area are constantly changing over time, either by natural karstification processes or simply due to continued exploration and visitation. The management strategies adopted for different cave systems are guided by interrelationships between environmental conditions prevailing on the surface and those underground. In some cases, this may involve restricting above ground access as to protect underground karst features, while in other instances, protection involves controlling below ground access and preserving specific sections of cave systems and cave deposits as reference sites. It is probable that as new technologies emerge, these reference sites could be studied using modern techniques and build on our existing knowledge base. As the Cave Access Zone System was developed through close engagement with stakeholders from different backgrounds – recreational cavers, scientists, other cave managers, it is expected that results of the trial will improve management strategies for different caves. The development of the cave zone classification system addressed competing values and interests represented by conservation, commercialisation and tourism.

Naracoorte Caves World Heritage Area is one of earth's special places rich in fossils, in terms of diversity, completeness, preservation and quantity. These fossils have fascinated researchers, cavers and members of the karst community over the years. As visitation continues to rise, management has been under pressure to manage visitation and balance research in the caves and protect the valuable fossil deposits. Removal of selected fossils for study is supported only if they will be studied and only where a proper framework is in place to manage the deposition of the fossils, and if there is an enduring record of what was excavated. The recording of fossils in the biological database is a step in this direction as researchers can build on existing work. It addresses the challenges that come with staff turnover and lack of coordinated approach in fossil collection and management. The protection of Pleistocene vertebrate fossils in situ is important. The long-term protection, management and conservation of caves and cave fauna communities, wild heritage values of Naracoorte Caves World Heritage Area will rest both on a legislative footing and on better public recognition and understanding of the complexities of cave microenvironment and cave fauna, knowledge of karst processes and understanding of susceptibility of karst environments to damage. Continued applied research and monitoring as well as proper collection of fossil records is one of the many ways to ensure that these sites are managed sustainably for future generations.

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(Abstract) **The denunciation as a tool to protect the speleological heritage in Brazil**

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Abstract

On April 5th, 2014, an expedition was carried out to the municipalities of Botuverá and Vidal Ramos, eastern center of Santa Catarina State, southern region of Brazil, with the objective of locating and mapping the "Gruta do Cinema" (Movie Theatre cave). The cavity, developed in a marble lens, had been explored by the GEEP-Açungui caving group in the 1980s, which estimated its development in 250 m, being the second largest cave registered in the State of Santa Catarina, behind only Botuverá Cave, with 1.123m. Arriving in the area, we were informed that the entrances to the cave had been buried, and that a local mining company had already begun to destroy the massif. Some locals showed us the place, and we saw that the two entrances to the cave were completely obstructed by dirt and rubble. There was a tillage started on top of the cave and all around the mass there was perforations for the placement of dynamite. Concerned about the scenario presented, we recorded the coordinates and photographed the mined area, and on April 16th, we sent a denunciation addressed to the environmental agencies of Santa Catarina State (FATMA), with copies to the Public Prosecutor's Office and to the National Center for Research and Conservation of Caves - CECAV / ICMBio (Federal Government of Brazil). We were quickly contacted by the environmental agencies, which did surveys, interviewed residents and sought evidence that the cave actually existed, as the initial map was not found. Thanks to the records of biologists who carried out a survey of bats in the cavity, they obtained the necessary proofs of the existence of the cave. Less than two months after the denunciation was filed, on 07/09/2014, the Superintendence of IBAMA of Santa Catarina assessed the mining company at R$ 189,000.00 (€ 51,500), embargoed a polygon of 2 hectares in the region where the cave is located, and required the reopening of the original cave entrances and the restoring of the degraded area. It is important to emphasize that Brazilian legislation provides for the possibility of cave destruction, but preliminary studies must be carried out to determine its relevance. These studies were not performed in the case of Cinema Cave. We hope that this denunciation, which resulted in the rescue of an important cave, will serve as an example for other speleologists and environmentalists from Brazil and around the world.

(Abstract) **Stalagmite isotopic record from Mallorca (Western Mediterranean) over the last 120 ka: paleoclimatic implications**

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Abstract

With global climate change, the Western Mediterranean is projected to become warmer and drier, thus, likely to generate major societal and economical impacts. In the light of this, a thorough understanding of climate forcing and responses triggered by past global events is essential. Here we present a detailed, accurately dated isotopic record spanning the past 121 kyr from a stalagmite (CAM) collected in Campanet Cave (Mallorca Island). The growth history combined with the isotopic record, mineralogical and petrographical analyses, provides evidence of climatic changes in the Western Mediterranean.

A high-resolution chronology was obtained based on 25 U-series dates, all of which are in stratigraphic order. The dates reveal that CAM begun its growth ~121 ± 0.6 ka and, except for one major hiatus (67 to 53 ka), it grew continuously until present. $\delta^{18}O$ values range from −6.2 to −0.6‰, whereas $\delta^{13}C$ vary between −10.4 and 0.5‰. The speleothem formed in isotopic equilibrium with seepage waters as suggested by four Hendy tests and if comparing $\delta^{18}O$ of modern drip water with newly precipitated calcite soda straws. However, $\delta^{2}H$ values in fluid-inclusion from this stalagmite along with a strong correlation between $\delta^{18}O$ and $\delta^{13}C$, indicate that kinetic fractionation have dominated during at least few parts of its growth (e.g., MIS 5c).

Considering the modern hydroclimatic setting in Mallorca, we argue that during the intervals of poor correlation between $\delta^{18}O$ and δ13C, the variability of $\delta^{18}O$ in CAM is likely related to changes in amount and source of precipitation. During periods when $\delta^{18}O$ and $\delta^{13}C$ covary, we interpreted the carbon isotopic profile assuming that high $\delta^{13}C$ would most likely reflect low biogenic CO_2 productivity in soil, thus a dry climate.

Based on this, the major climatic events identified by the $\delta^{18}O$ and $\delta^{13}C$ time series are: MIS 5e termination, C24, and C23 cold events, prolonged aridity during MIS 5c, dry-to-wet shift at MIS 5c/5b boundary, and moist climate at the beginning of MIS 5a. The growth cessation of CAM is tentatively associated with Heinrich event H6, which brought much colder conditions and sparsely vegetated landscape. The low growth rates and monotonous C and O isotopic profiles across MIS 3-1, suggest relatively stable climatic conditions with effective precipitations that remained slightly above the growth/cessation threshold.

(Abstract) **Proposal For Valuing Geosites From João Guimarães Rosa's Books: Creating The "Sertões De Minas Gerais" Geopark In Brazil**

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Abstract

As mentioned before in other works, Brazilian carbonate areas cover between 425,000 and 600,000 sq.km, which represent approximately 7% of the country's total area. Considering this potential, it is desirable that more research is done in such areasto better educate people living on karst. For this reason, the country has great potential for establishing conservation areas or geoparks in karst areas rich in geodiversity, biodiversity, archaeological, cultural and historical aspects. In Minas Gerais State the percentage of karst areas is also high, allowing it to be part of everyday life of many people. Among them, was a famous writer, João Guimarães Rosa (1908-1968), who established good relationships between people and the environment where they live. In this way, this research proposes an association between geography and literature, highlighting places as sites of human experience in a semi-arid region of Minas Gerais. The "beautiful colourless landscape" mentioned in his books are a fundamental part of the regional geodiversity. In addition to the scenic beauty, one can identify scientific elements that deserve to be highlighted for geotourism in a perspective that seeks the appreciation of nature but also knowledge about the local geodiversity and biodiversity. Thus, the research is proposing the creation of a geopark which should cover the municipalities mentioned in Rosa's books, such as Cordisburgo, Araçaí, Curvelo, Inimutaba, Presidente Juscelino, Morro da Garça, Corinto, Buritizeiro e Pirapora. The objective is the identification, valorization, dissemination and conservation of its geological and geomorphological heritage. Thus, it is believed that this interface between geography, literature and geotourism can help a better management of the regional karst.

Keywords: Geopark; Karst; Cordisburgo; Minas Gerais.

Evaporite karst of the Emilia-Romagna Region (Italy): why should they become a UNESCO World Heritage?

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Abstract

Up to present over 50 karst sites have been inserted in the World Heritage list of UNESCO, and therefore in the near future only a few more are expected to join that list. Possibilities exist only for those karst types that are still totally unrepresented. This is the case of the evaporite karst, which was therefore specifically inserted in a list of possible new World Heritage locations by IUCN (International Union for the Conservation of Nature). In any case only the best example, representative of the whole karst phenomena in a given lithology, may have a chance to be nominated. Evaporite karst is mainly developed within halite, gypsum, and anhydrite formations, which are relatively widespread all around the world, but are still scarcely explored and studied.

The evaporite outcrops of the Emilia-Romagna Region (Italy), although relatively small (their total extension is about 50 km2), consist of two different lithologies: Triassic anhydrites (~ 20 km2) and Messinian gypsum (~ 30 km2), corresponding to less than 0.5% of the whole regional territory. But they host among the largest and deepest epigenetic caves actually known for these formations, the genesis of which ranges from intra-Messinian age to present days. But lithological variety and richness in surface and deep karst morphologies are only some of the many reasons which suggest that they have a real chance to attain the rank of World Heritage. Evaporite karsts of the Emilia Romagna Region where the first to be studied (since the 16th Century): therefore many of the main classical gypsum and /or anhydrite karst features have been firstly studied and described from these territories. Even today Emilia-Romagna evaporite karst is the best known from a morphological, speleogenetical, mineralogical and biological point of view: printed papers on these areas are more than those regarding all the other evaporite karsts in the world. Moreover, beside their natural peculiarities, they represent also extremely important archaeological, paleontological and historical sites. Finally over 90% of the regional evaporite karst, and 100% of the proposed World Heritage, is already fully protected being inserted within Natural Parks or Reserves.

In 2016 the Regional Speleological Federation, together with the local Government, decided to start the procedure to apply for the UNESCO official recognition of a selected portion of the regional evaporite karsts.

Keywords: Keywords: Anhydrite karst, Gypsum karst, World Heritage, Emilia-Romagna Region,

1. Introduction

Karst and caves are actually well represented, with over 50 sites spread over 5 continents, in the UNESCO World Heritage. Recently the IUCN (International Union for Conservation of Nature), as advisory body of the UNESCO World Heritage Convention on natural heritage, printed a global review on World Heritage karst properties (Williams, 2008). In this book the present situation, the future prospects and the management of the Karst World Heritage was shortly presented. Moreover it was clearly stated that in the near future only a few more karst sites are expected to attain the status of World Heritage, even if theoretically it meets one or more of the needed criteria for inclusion in WH list (UNESCO 2013, p. 20-21):

(vii) to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;

(viii) to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;

(ix) to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, freshwater, coastal and marine ecosystems and communities of plants and animals;

(x) to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Moreover: To be deemed of Outstanding Universal Value, a property must also meet the conditions of integrity and/or authenticity and must have an adequate protection and management system to ensure its safeguarding.

For this reason in the IUCN book it is clearly written:

Possibilities exist only for those karst types that are still totally unrepresented in the WH list. That is the case of karsts on evaporite rocks…

…In cases where karst features on evaporite rocks are demonstrably of outstanding universal value in relation to geoscience, and are not just of a specialized scientific importance, but are accessible and comprehensible by civil society, then such cases could merit consideration for World Heritage inscription…

And few pages later the Recommendation 4 says:

That States Parties whose territories include karst terrains situated on evaporite rocks consider the potential of their sites for natural World Heritage recognition….

Consequently, … the highest priorities for completion of a comprehensive range of karst World Heritage sites are:

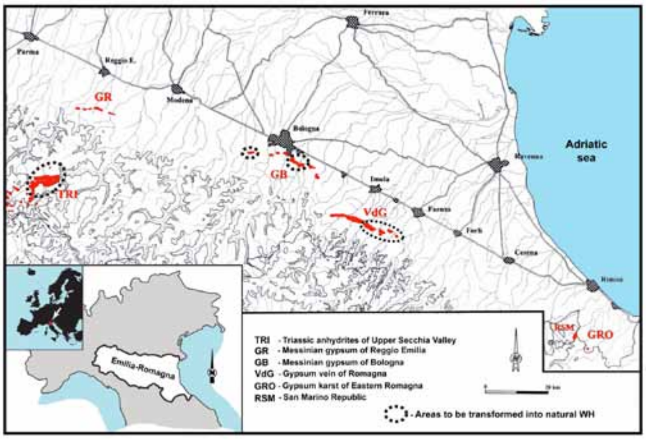

Figure 1. Evaporite karst outcrops (red areas) of the Emilia-Romagna Region: areas within the dotted lines are those to be submitted to UNESCO for becoming a new natural World Heritage

- *to cover more adequately the karst type region of Europe,*
- *to fill gaps in coverage in cold regions, arid/semi-arid regions and tropical oceanic regions,*
- *to identify evaporite karst sites of outstanding universal value.*

Evaporite karst is mainly developed within halite, gypsum, and anhydrite formations, which are relatively widespread all around the world, but they are still scarcely explored and studied and even less protected. This is not the case of the evaporite (gypsum & anhydrite) karst of the Emilia-Romagna Region (Italy). Therefore in 2015 the Regional Speleological Federation of the Emilia-Romagna (FSRER) decided to tray to submit the candidature of the most relevant portion of the regional evaporite karst to UNESCO in order to obtain for them the rank of natural World Heritage.

2. The Emilia-Romagna Evaporite karsts

The Emilia-Romagna evaporite karst outcrops (Fig. 1) are very limited (less than 0,5% of the whole territory) and consist of two different lithologies: Triassic anhydrites (with a global area of ~ 20 km2) and Messinian gypsum (~ 30 km2).

Even so small these areas host well developed and varied surface forms (blind valleys, dolines, roofless caves, tumulus, candles etc.). Over 700 caves (https://applicazioni.regione.emilia-romagna.it/cartografia_sgss/user/viewer.jsp?service=grotte) have been so far explored and mapped.

Presently the Emilia-Romagna anhydrite caves are the single epigenic ones in the world: in fact the only other known cavities in this lithology are ipogenic (Kempe, 2014). Among them there are also a completely new kind of cavity (the “hypogean bends”) (Malavolti, 1949), the development of which is strictly controlled by the hydration of anhydrite and the tensional release along the external surface of the anhydrite-gypsum-halite diapir (Chiesi & Forti, 2009). Finally they hosts the world deepest anhydrite cave (Caldina Abyss with a total depth of 265 m) (Franchi & Casadei, 1999) and the largest salt karst spring of Italy (Chiesi et al., 2010).

The gypsum outcrops underwent two different speleogenetic cycles: the first intra- Messinian (De Waele & Pasini, 2013)

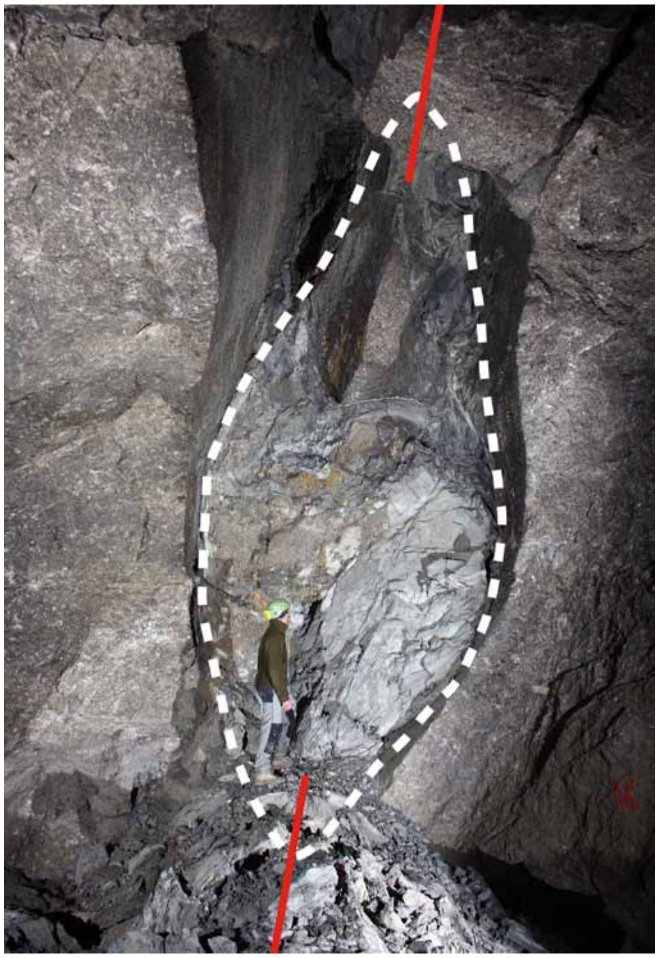

Figure 2. Zola Predosa, Bologna, Italy: a large Messinian karst developed along a gypsum interbed. After the evolution of the cave, gypsum strata were displaced becoming quite vertical (red line), while the cave (white dot line) were filled of marine sediments

(Fig. 2) and the second, started over 500.000 year BP, which is still going on today (Columbu et al., 2015).

Some of the caves are among the deepest and longest world epigenetic caves in these lithologies: the Spipola Acquafredda karst system near Bologna is the longest (over 12 km of mapped galleries, De Maria et al. 2012) (Fig. 3), while some others exceed 5 km in length (Ercolani et al., 2013, Forti & Lucci, 2010). Moreover they host peculiar solution-corrosion forms and speleothems (Forti, 1997) and important paleontological and archeological remains, while some endemic organisms are restricted inside them.

Finally over 90% of the regional evaporitic outcrops and 100% of the proposed areas are fully protected being inserted in National or Regional Parks, thus matching the needed prerequisite to apply for natural WH.

3. Main reasons supporting the WH candidature

Many evaporite outcrops of the world are probably better known worldwide than those of the Emilia Romagna Region. Among them surely the gigantic gypsum caves of Ukraine (Klimchouk, 2009) and the big and widespread anhydrite cavities of Germany (Kempe, 2014) are worth of mention. Actually these areas lack of protection and therefore cannot be taken into consideration by UNESCO. Anyway they both are hypogenetic and therefore completely different from the

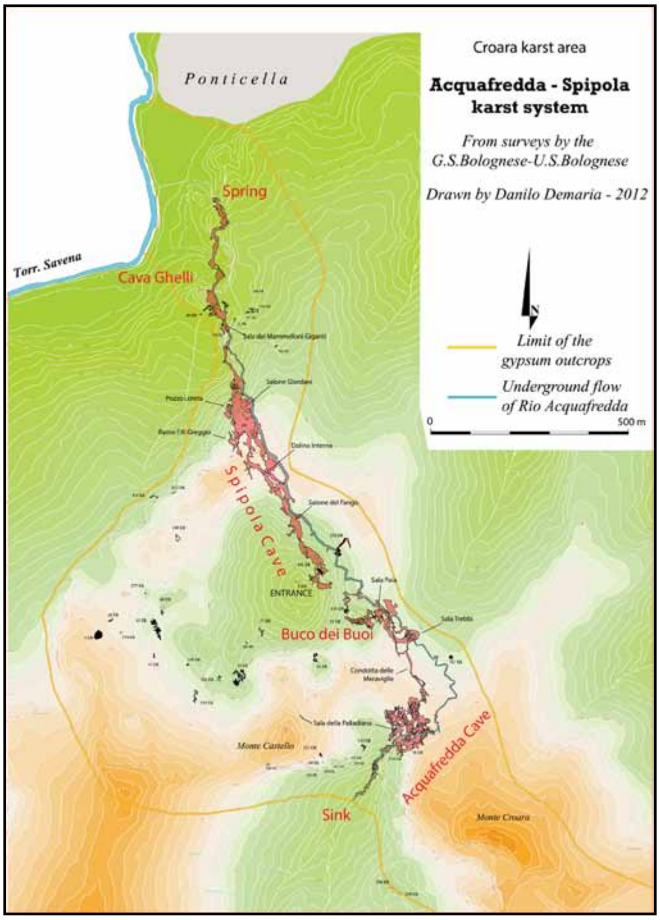

Figure 3. Map of the Spipola-Acquafredda karst system, within the Messinian gypsum of Bologna, is the longest gypsum cave of Italy (after De Maria et al. 2012).

epigenetic ones of Emilia Romagna: thus the candidature of the latter do not prevent a future one from Germany &/or Ukraine.

By sure the lithological variability, the presence of 2 different (intra-Messinian and actual) speleogenetic cycles, the richness of epigean and ipogean karst forms and the huge dimension of both anhydrite and gypsum caves of Emilia-Romagna are factors supporting their candidature. But many other much more effective reasons exist to strengthen the idea to transform them into a UNESCO natural World Heritage.

First of all the historical reason: in fact the "gypsum karst" of our Region was the first in the world to be studied already in the last part of the XVI century (Aldrovandi, 1648). Since then its study never stopped (Altara et al., 1995) and therefore some of the most peculiar forms (e.g. the "candle like erosion", Capellini, 1876) and deposits (Laghi, 1806; Santagata, 1835) of the gypsum caves were firstly described from these territories.

Presently the evaporite areas of Emilia Romagna are by far the best explored, documented and studied evaporite karst in the world, as it is testified by the over 2000 printed paper over them (Bentini & Lucci, 1999; Chiesi & Forti, 2009; De Maria et al., 2012; Forti & Lucci, 2010; Lucci & Rossi, 2011; Ercolani et al., 2013; Lucci & Piastra 2015; and the references therein), which are much more that the cumulative bibliography related to all the other gypsum and anhydrite caves in the world.

Many of the speleogenetic studies on gypsum and anhydrite caves were made in the Emilia- Romagna, among which the following ones are worth of mention: 1) on the underground bends in anhydrite caves (Malavolti, 1949), 2) on the antigravitative evolution (Pasini 1975, 2009), 3) on the role of CO2 in the dissolution of gypsum and the deposition of carbonate speleothems (Forti & Rabbi, 1981), 4) on the role of condensation in gypsum speleogenesis (Cigna & Forti, 1986), 5) on the possibility to use stalagmites and the deviations in their growth axes as indicators of past earthquakes (Forti & Postpischl, 1979), and finally 6) on the possibility to use calcite speleothems in gypsum caves as paleoclimate proxies (Calaforra & Forti, 1999, Dalmonte et al., 2004; Calaforra et al. 2008).

But the evaporite karst of our Region is important not only from the point of view of geomorphology and mineralogy but also for paleontology, hosting some rare and well preserved remains of intra-Messinian (Costa et al., 1985) and upper Pleistocene fauna (Pasini, 1969, 1970).

Furthermore, our gypsum and anhydrite caves are extremely important biological shelters, hosting some of the largest and varied bat colonies of Europe, and several peculiar endemic troglobitic species, actually restricted in these environments.

Finally, thanks to the Natural Parks administrations, two abandoned gypsum quarries have been transformed into open air geological and paleontological museum. Moreover several thousands of tourists visit the surface karst areas and have also the chance to enter one of the 5 show caves of our Region, which are mainly devoted to didactic activities on environmental protection for student of the primary and secondary schools (Forti, 2004, 2017).

For all these reasons we think that Evaporite karst & caves of the Emilia Romagna not only perfectly fit the prerequisite to be in "...the conditions of integrity and/or authenticity and must have an adequate protection and management system to ensure its safeguarding.", but also meet the criteria VIII, IX and X of the UNESCO guide for implementation of the WH list.

Beside their naturalistic relevance, some of the caves within the proposed WH are archeological sites of primary archaeological importance for the copper,bronze and iron ages, and some perfectly preserved roman aged mine-caves for "Lapis Specularis" were recently found and studied (Guarnieri, 2013). Finally many of the caves are important for the recent history, having being used, during the World War 2, as shelter for local population. Thus the candidature of the Emilia-Romagna evaporite caves is also strengthened on behalf of the III criterion: "…bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared"

4. Final Remarks

At the beginning of 2016 these shortly outlined peculiarities of the Emilia Romagna evaporite karst convinced the Regional Speleological Federation to start with the procedure to apply for the UNESCO official recognition as natural World Heritage of a selected portion of them. On December 21, 2016 the Government of the Emilia Romagna Region officially decided to support this candidature (Giunta Regionale dell'Emilia Romagna, 2016) and to be the leading Organism in the Committee appointed to prepare the submission report.

In 2017 the preliminary document to be submitted to the UNESCO National Committee will be prepared in order to obtain the inscription of our evaporite karst in the Tentative List for becoming new WH hopefully in 2018.

We are confident that in a span time of 4-5 years the evaporite karst of the Emilia Romagna Region will attain the UNESCO rank of World Natural Heritage.

Acknowledgments

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Speleo Education In Hungary

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Abstract

This paper discusses Regular and organized speleo education in Hungary started in 1983. The education was separated as follows: scientific education was organized by Hungarian Speleological Society (HSS) and technical education was organized by Hungarian Naturefriend Federation. The base course was done by different clubs and groups, but they had to use the given curriculum. The examinations were in front of a central examining body. Next level was the safety technique course. After the successful completion of them, the cavers could go for "cave tour leader" (for wild caving) and for "cave research leader". There were also some special and refresher courses for different sciences. The legal background changed in 1998, so the educational system had to be reorganized. Since then a lot of speleo activities need permission which is only given to qualified cavers. The new qualifications are state authorized based on legal regulation. Now all courses are organized by HSS. There is a new generation of instructors and regularly revised and maintained handbooks were completed for each course. Basic levels are held also at clubs, but higher levels are centrally organized. Teaching theoretical knowledge occurs in rooms and practical training and residential courses are held in real cave areas, usually for a week. During the practical trainings there is one instructor for three students. The frequency of the courses are as follows: technical courses are 2 times a year, tour guide for wild caving is in every two years, research leader is in every three years. Since 1999 when the new educational system started almost 800 cavers have been qualified. The results of the effectiveness of education reflected in the number of accidents in caves.

Keywords: education, training, course, tour, guide, research

1. Caves and caving in Hungary

Research of caves in Hungary was not a regular and directed activity until the beginning of the 20th century. The first speleological organization was established as the Speleological Committee within the framework of Hungarian Geological Society in 1910. It had mostly scientific targets (Székely, 2010a). In 1926 Hungarian Cave Research Society became an autonomic organization which collaborated with two tourist clubs. There was lot of organizational changes during following decades. The current national speleological organization is Hungarian Speleological Society (HSS) since 1958 (Székely, 2010b).

Hungary is 93.000 km^2 and 1.5% of it is karst. There are 4130 caves in the cave cadaster; 138 caves are longer than 200 meters; 37 caves are longer than 1 km and 97 caves are deeper than 50 meters. Approximately 1100 caves are non-karstic. (Magyar állami természetvédelem hivatalos honlapja/Barlangok, 2017) There were 380 members of HSS at the end of 2016.

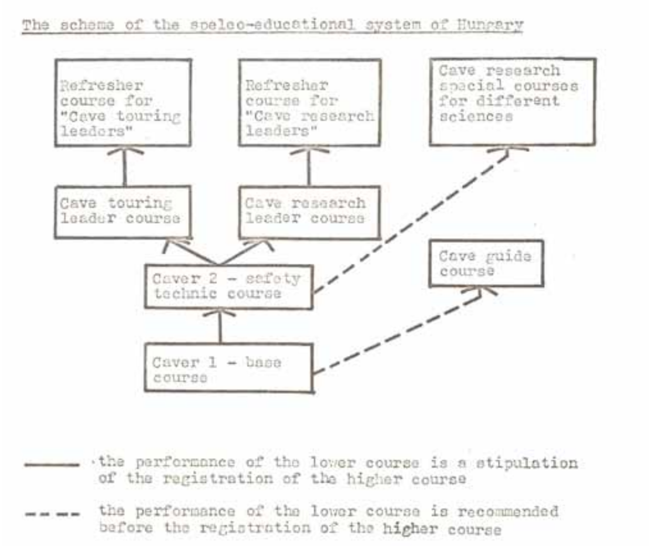

Figure 1. Hungarian Speleo education scheme (Hegedűs, 1984)

2. Speleo education from 1984 to 1998

After many years of work the first organized speleo education system was created in 1983 and it students the next year. There was an agreement among all state and civil organizations who were dealing with caving. Those were the National Authority for Environment Protection and Nature Preservation; HSS; Cave Committee of Hungarian Naturefriend Federation (HNF). The scheme outlined below (Fig.1).

2.1. Caver 1 – base course

Those courses were organized by different groups or clubs, but they had to use a defined curriculum. There were 30 theoretical and 40 practical hours to get the essential knowledge of caving and to prepare cavers for the examination. The regular examinations were twice a year in front of a central examining body. If there were more than 10 examinees at the same time, the organizer of that course could ask an another place and time for examination. After the successful theoretical and practical exam the cavers received a qualification.

2.2. Caver 2 – safety techniques course

Those courses were organized for more experienced cavers to give them safety and technical knowledge for harder caves. The prerequisite for participation was the "Caver 1" qualification. There were 40 theoretical and 30 practical hours for participants. After a successful theoretical and practical examination the cavers could get the "Caver 2" qualification and the right to go for the "Cave touring leader" and/or "Cave research leader" course(s).

2.3. Cave tour leader course

These courses only had a small scientific aspect. The main aspect was the responsibility for the tour group. Besides the qualification “Caver 2” a condition of participation was a recommendation from club’s leader or from HSS. There were 65 theoretical and 30 practical hours for the participants. Half of the mandatory curriculum was given by HNF and the other half was specific to caving. After a successful examination the participants received permission to lead caving tours for 3 years.

2.4. Cave research leader course

Those courses were organized for experienced cavers and main aspects of them were scientific. They gave information on successful research work and documentation in both domestic and foreign regions. As all cave research activities are subject to authorization in Hungary, only qualified cave research leaders could get research licences.

2.5. Cave research special courses for different sciences

Those were specialised, highly scientific continuation courses in different subjects for specialized cave scientists. The “Caver 2” qualification were a recommended prerequisite for those courses.

2.6. Refresher courses

These courses were mandatory for qualified “Cave tour leaders” and “Cave research leaders”. They gave up-to-date information on the latest results and administrative situations.

2.7. Cave guide course

These courses were organized for show cave guides. They gave information not only about local caves but basic skills of other fields of speleology. Refresher courses were organized regularly.

The different courses were organized by the following organizations:

- Caver 1 – HNF or clubs
- Caver 2 – HNF
- Cave touring leader – HNF
- Cave research leader – HSS
- Cave research special courses for different sciences – HSS
- Refresher courses – HSS or HNF
- Cave guide – HSS

Because the system was new and there were many experienced cavers, there were some exemption possibilities, from both courses and examinations. You had to request in writing and there was a limitation period.

3. Speleo education since 1999

The legal background of caving changed significantly in 1998. The new laws determined the conditions of both caving and for obtaining qualifications for cave tour guides and cave research leaders. Legislation required mandatory number of hours of training, professional standards, the conditions to pursue the privilege of training, exam requirements and exam schedule. As a result we had to set up the training system (Fig 2).

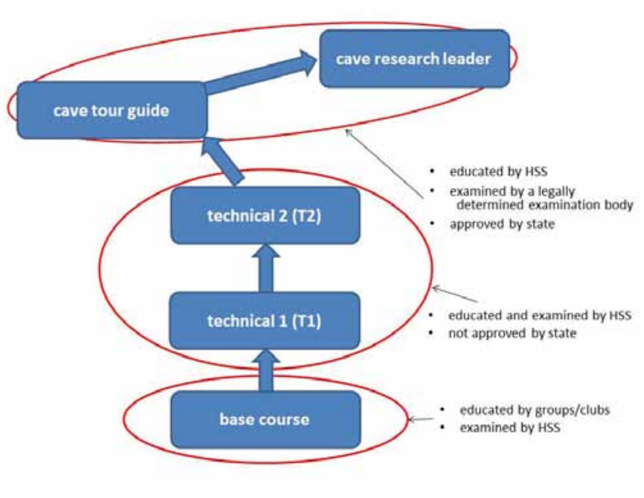

Figure 2. The current education system.

The basic courses are organized by individual clubs as previously. Technical 1 (T1) and Technical 2 (T2) courses are organized and examined by Education Committee of HSS, but those qualifications are not approved by the state. The Cave Tour Guide and Cave Research Leader courses are organized by Education Committee of HSS and the examination must be done in front of a legally determined examination body. That 5-member examination body contains representatives from the following organizations:

- Authority for Nature Preservation
- National Park Directorate
- Ministry, which is responsible for nature protection
- NGO dealing with wild caving / cave research / cave rescue
- the training organization

Successful examination is approved by state and a numbered card with photo is issued by the Authority for Nature preservation.

3.1. Basic course

The basic courses are designed for people who decided to be cavers and at the same time popularizing and deepening commitment to the natural environment. The transfer of basic theoretical, practical and scientific knowledge to the task required a minimum number of participants, with which they can safely go to caves in Hungary. Base courses are organized independently by cave research groups/clubs, but supervised and examined by the Education Committee of HSS (contacts are Péter Börcsök, borcsokpet@gmail.com and András Hegedüs, hegeduposta@gmail.com).

The basic themes of courses are as follows (Dolgos, 2015):

- organizational knowledge
- equipment
- rules of cave tour practice
- basic knowledge of scientific aspects

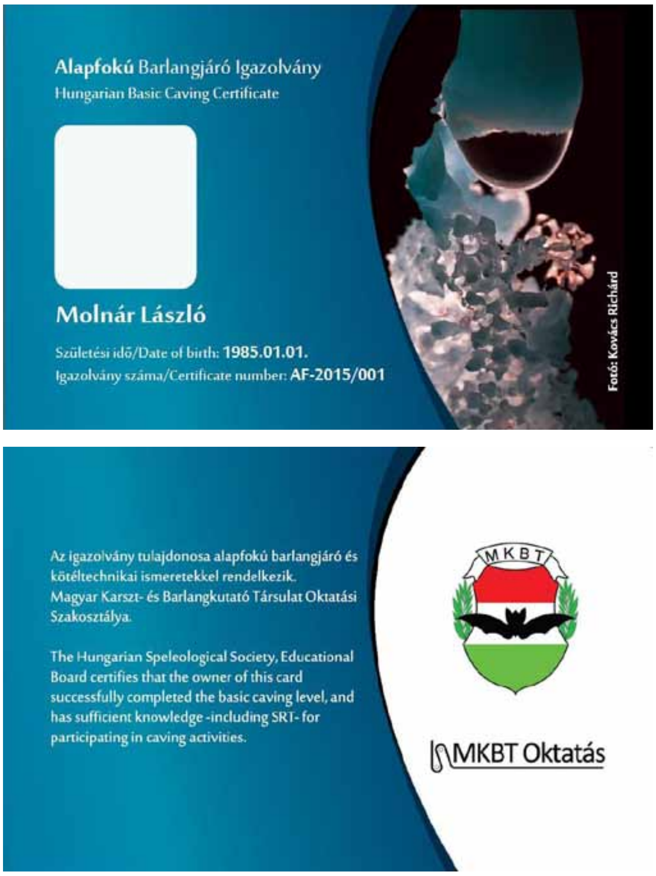

Figure 3. Basic course card

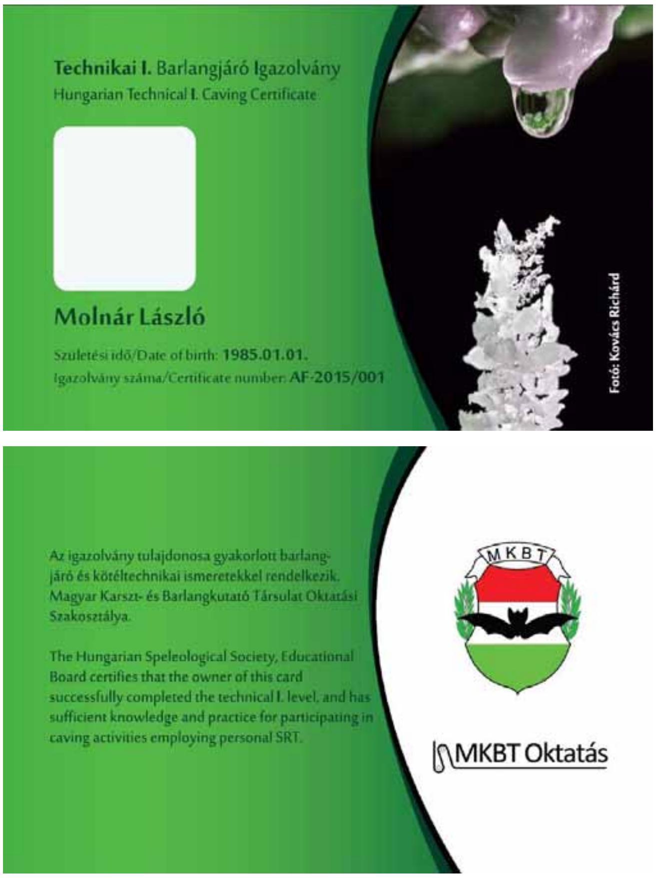

Figure 4. T1 card

- karst areas of Hungary
- history of Hungarian cave research
- first aid

Students receive a credit card sized, numbered card with photo for successful basic course exams (Fig 3).

3.2. Technical 1 (T1)

The T1 courses are designed to build on the basic course gives all the important information that is needed for a safe cave crawl in different caves. The course prepares the participants to be a helpful member of a group who are ready e.g. to help for transport, remove tools etc. Another object of the course is to prepare candidates for T2 course. Only T1 examination holders can apply for T2 courses. T1 courses are organized and examined by Education Committee of HSS.

The theme of the courses are as follows (Dolgos, 2015):

- transport on different rope bridges
- ascending and descending different ways
- remove ropeways
- create and use pulley blocks
- partner rescue

Students receive a credit card-sized, numbered card with photo for successful T1 exams (Fig 4).

3.3. Technical 2 (T2)

The aim of these courses is to raise the level of technical knowledge and to acquire rope installation techniques (ropeway construction of the vertical sections of the cave). T2 courses are organized and examined by the Education Committee of HSS usually twice a year. The optimal number of students is 10-12 persons with 4-5 instructors. These are residential courses in North-Hungarian cave area (around Aggtelek) for a week.

The themes of T2 courses are (Szabó, 2014):

- additional equipments for group caving
- single rope technique (SRT) with personal and group equipment
- arising forces during SRT
- knowledges of different ropes
- security techniques
- using different knots
- create and set up different ropeways in different situations
- rope bridges
- SRT with 8 millimeter rope
- pulley blocks and counterweight systems
- partner rescue from rope
- bivaque
- alpine caving during winter
- preparation for accidents
- cave protection during technical caving

Students receive a credit card-sized, numbered card with photo for successful T2 exams (Fig 5).

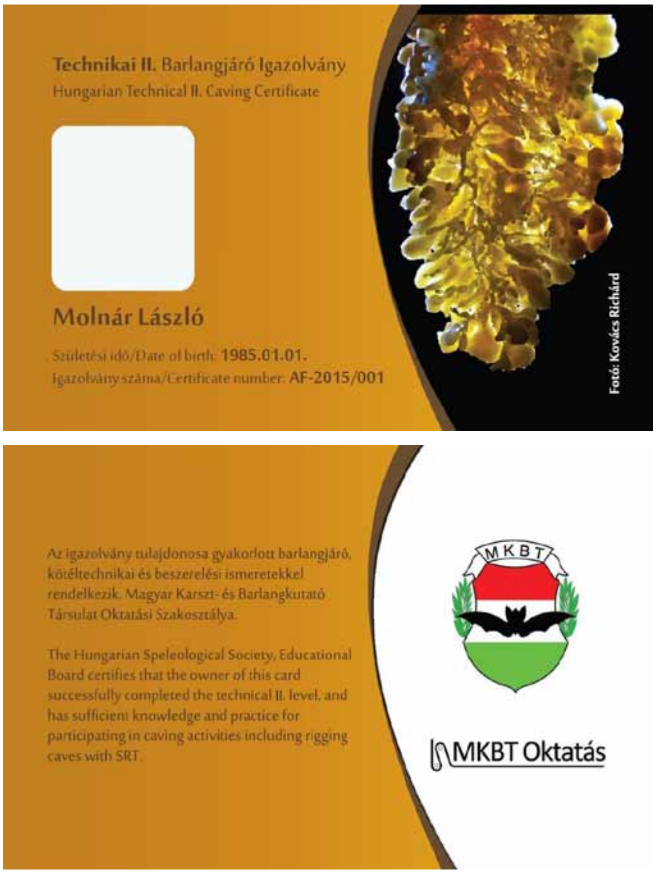

Figure 5. T2 card

Basic course, T1 and T2 cards are not accepted by the state, but are well known and accepted within the circles of Hungarian caving circles. They facilitate the choice of an unknown partner for a domestic tour or foreign expedition.

3.4. Cave Tour Guide and Cave Research Leader

The *Cave Tour Guide* training aims at providing professional and safe guiding and information for visitors of caves which are not developed for tourism and tourist traffic. The mandatory number of hours of a cave tour guide training is 200 hours. Cave Tour Guide trainings are held every 2 years.

The *Cave Research Leader* training aims at unknown caves, cave exploration stages, to learn to manage scientific work professionally. The mandatory number of hours of a cave tour guide training is 100 hours. Cave Research Leader trainings are held in every 3 years.

The mandatory number of hours is divided up as 50% theoretical and 50% practical knowledge at both trainings. A card is provided on satisfactory completion (Fig. 6).

General requirements for both trainings are as follows:

- natural values of caves
- activities in caves
- organizational knowledge
- geology of karst and caves, cave genetics, morphology, sediments
- karst hydrology
- cave biology

Figure 6. Cave Tour Guide card and Cave Research Leader card

- cave climatology
- cave recovery
- karst and cave protection
- research history

Specific requirements for Cave Tour Guide and Cave training listed in Table 1 and Table 2 (KTM, 1998).

4. Results of education

Courses between 1999 and 2016:

T1 courses	4 times	98 participants
T2 courses	26 times	308 participants
Cave Tour Guide courses	9 times	252 participants
Cave Research Leader courses	5 times	108 participants

As a result of this education cave accidents have significantly decreased during that period, as only 2 educated cavers suffered accidents in domestic places and 3 others on abroad (Börcsök and Hegedüs, 2014).

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Table 1. Specific requirements for Cave Tour Guide and Cave Research Leader training

Technical knowledge	**Cave tour guide knowledge**
• equipment • rope techniques • safety techniques • climbing techniques • creating and setting up different ropeways • underground bivouac and necessary equipment • risk factors, accidents, rescue techniques • first aid and basic psychological knowledge	• cave touring • orientation • rights, responsibilities & behavioral standards of a cave tour guide • legal knowledge • group organizational & educational knowledge • organizing and leading an expedition • karst and caves of Hungary • most important karst and caves of the world • show caves of Hungary

Table 2. Specific requirements for Cave Research Leader training

• organization, leadership • rights, responsibilities and behavioral standards of a cave research leader • legal knowledge	• excavation, exploratory research surveying and measuring technology • scientific studies, experiments • documentation

International Cave Conservation and Restoration Course in Brazil

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Abstract

Coordination of the first International Cave Conservation and Restoration Course was prompted by the urgent need to initiate on-going monitoring, mitigation, and restoration in several popular show caves in Brazil. Evidence of anthropogenic impact spans more than 100 years of public use in some of the fragile cave environments of southeastern Brazil. Cumulative consequences of infrastructure installation, maintenance, and visitor-flow operations include graffiti, trash, construction rubble, broken speleothems, stained formations, and disturbed sediments with resulting detrimental impacts to fauna, habitat, and microclimate. Conservation recommendations described in cave management plans written in 2010 were not yet implemented in these federally protected tourist caves. Enabled through Brazil's environmental compensation laws and cave protection legislation, Instituto do Carste (Brazilian Karst Research Institute) in cooperation with corporate sponsor Anglo American Mining Company invited authors of the comprehensive manual titled *Cave Conservation and Restoration* to collaborate in conducting the course with authors of the cave management plans. Together, we structured the seven-day training to introduce current best techniques, philosophy, and ethics through daily hands-on cave projects. We designed theoretical and practical activities for students to apply current best management decisions and produce tangible restoration progress.

Students gained valuable field experience in resource assessment, identification of conservation issues, impact mapping, low-impact caving ethics, cave cleaning, lint and debris removal, speleothem restoration, lampenflora control, and trail delineation, with special attention for historic and cultural materials and markings, site analysis for contemporary graffiti removal, and visitor routing to enhance safety and mitigate impact. Positive outcomes include creation of minimum-impact protocols written by course participants and implemented in federal programs, specifically for scientific investigations in cave archeology and biology. We will target our next courses to stimulate continued training and motivate ongoing annual restoration events. This first course prompted significant progress on conservation actions recommended in cave management plans and furthered Brazil's pioneering initiatives in karst outreach and restoration. International Courses in Cave Conservation Management and Restoration provide global training in assessment-based decision processes; initiate strategies to motivate after-the-course continuation of projects; and promote world-wide collaborative improvements in cave restoration techniques.

Keywords: cave conservation, cave restoration, cave management, conservation management, international course, current best practices, human impact, resource conservation, anthropogenic impact,

1. Introduction

Cumulative consequences of human impact are of great concern for cave resource conservation. Several Brazilian show caves are protected for environmental, historical, and cultural significance. Evidence of anthropogenic impact in a few popular tourist caves spans more than 100 years of public visits. Graffiti, trash, construction rubble, broken speleothems, stained formations, and disturbed sediments have resulted from decades of infrastructure installation, maintenance, and visitor-flow operations. Without proper conservation management, the cave habitats, microclimates, and faunal populations may be at risk. The urgent need to implement conservation activities with ongoing monitoring, mitigation, and restoration in fragile Brazilian cave environments stimulated coordination of the first International Cave Conservation and Restoration Course in Brazil.

Augusto Auler, President of the Instituto do Carste (Brazilian Karst Research Institute), in cooperation with corporate sponsor Anglo American Mining Company, invited Jim Werker and Val Hildreth-Werker to collaborate with Luciana Alt and Vitor Moura in conducting the seven-day training course. Held during April 2014 in Brazil's southeastern state of Minas Gerais, we designed the Course to introduce current best techniques, philosophy, and ethics with daily hands-on cave projects.

For on-site training, we used two heavily-visited Brazilian show caves, Gruta do Maquiné and Gruta do Rei do Mato. Cave management plans for these two caves describe the cumulative anthropogenic impacts of installations, maintenance, and commercial operations, as well as resulting detriments to fauna, habitat, and microclimate (Alt, Moura NCKMS 2013).

For the Course, the two cave sites provided very different types of installations, infrastructures, management characteristics, and impacts for students to practice resource assessment, project planning, and mitigation strategies. Participants benefited from theoretical discussion in the classroom followed by practical application in the caves. Each day, students used what they learned in the classroom to produce real mitigation plans and achieve in-cave skill development through hands-on restoration work.

The Course, an important step toward initiating conservation actions set forth in management plans for both caves, was enabled through environmental compensation laws and cave

Figure 1. Brazilian state of Minas Gerais, location for the International Course in Cave Conservation and Restoration. (Brazil_State_Minas Gerais.svg by Raphael Lorenzeto de Abreu - Own work, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=724836)

2. History, Impacts, Motivation

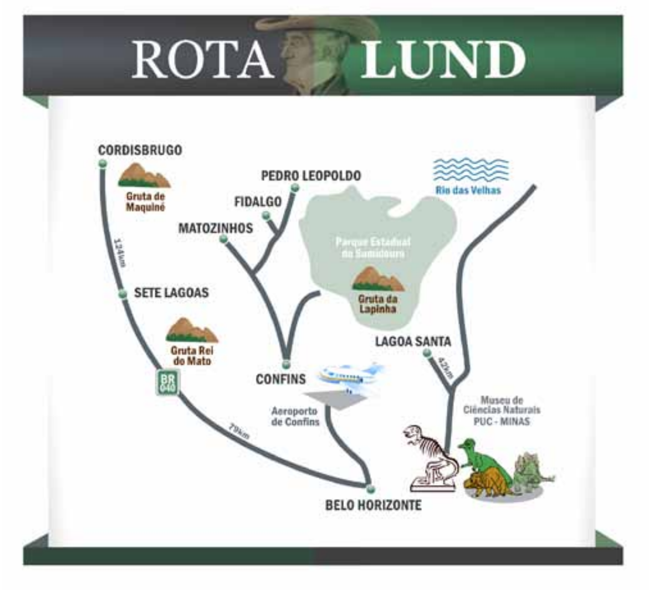
Gruta do Maquiné, located in the highlands of Minas Gerais, is a popular national destination renowned for paleontological discoveries made during the 1830s by accomplished Danish scientist, Peter Wilhelm Lund.

Famed twentieth-century Brazilian novelist, João Guimarães Rosa, who was born in the nearby small town of Cordisburgo in 1908, described the magical chambers and beautiful speleothems of Maquiné.

About a century ago, Maquiné became an important tourist site and the first Brazilian cave developed for organized visits; and in the late 1960s, also the first to install an electric lighting system. This show cave is one of the most popular commercial caves in Brazil and receives about 50,000 visitors per year.

A second show cave named Rei do Mato lies about 50 kilometers from Maquiné, near the city of Sete Lagoas. State and municipal agencies organized commercial tourist visiting in the 1980s and installed walkways and stairs. The walls of Rei do Mato protect a splendid mutli-level chamber filled with speleothems of rare beauty.

Administered under the supervision of the State Forestry Institute, both caves are in protected areas and operate through public-private management partnerships. The State Tourist Board of Minas Gerais implemented a national advertising campaign promoting the Peter Lund Museum and three show caves, including Maquiné, Rei do Mato, and Gruta do Laphina, as destinations located on highways north of the major city of Belo Horizonte along a regional tourist route known as Rota Lund (Lund Route).



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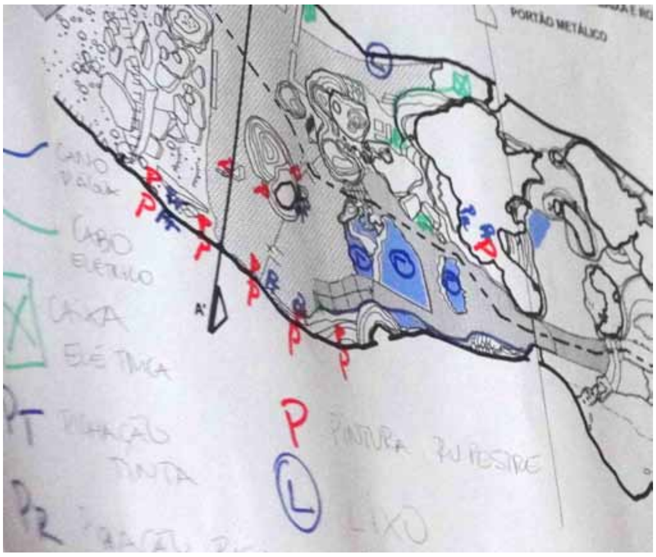

Figure 2. Students worked in small groups, identifying anthropogenic impacts in Gruta do Maquiné and creating impact maps for their assigned areas. Photos Luciana Alt, Val Hildreth-Werker

3. Cave Management Plans

Both cave operation units began implementing resource management plans written by Alt and Moura in 2009/2010. These plans include detailed studies and diagnoses of environmental impacts, provide recommendations for visitor activities, document concerns regarding installed infrastructure, and propose measures to reduce harmful consequences by improving infrastructure and mitigating negative-impact activities (IEF 2010).

In addition to historic and contemporary signatures, graffiti, trash, broken speleothems, and debris from development, Alt and Moura describe a variety of specific problems such as iron stains on speleothems, metal flaking from walkway degradation, accumulations of iron plates under the catwalk, and deteriorated wood left from old walkways in Rei do Mato, as well as compacted soils, disturbed sediments, undelineated visitor pathways, questionable handholds, and other concerns in Maquiné.

Between 2009 and 2013, cave managers began to implement a few of the conservation recommendations proposed in the management plans, but progress was slow and sporadic. For example, an LED-based lighting system was installed to replace old high-voltage lamps.

With many issues described in the management plans, and little remediation initiated at the cave sites, the Brazilian Karst Institute (Instituto do Carste) partnered with Anglo American Mining in applying federally mandated environmental compensation fees to support the first International Course on Cave Conservation and Restoration.

The main objective of the Course was to provide hands-on training in identification, mitigation, and control of environmental impacts linked to tourism and public visiting.

4. Brazil's First Cave Conservation and Restoration Course

To reinforce the conservation-management progress of these two show caves, the Course Directors defined four objectives: 1) train and engage conservation stewardship; 2) initiate mitigation projects; 3) teach monitoring techniques; 4) and motivate ongoing restoration progress.

A pioneering initiative in Brazil, the first International Course on Cave Conservation and Restoration is a milestone for future cave conservation and restoration activities in the country. The intent was to train, motivate, and establish practical experience to enhance ongoing advances.

Delivered by Val Hildreth-Werker and Jim Werker who authored the NSS manual titled *Cave Conservation and Restoration* (2006), coordination and logistics of the Course counted on the expertise of Luciana Alt and Vitor Moura, who authored the 2009/2010 Management Plans for both caves, Maquiné and Rei do Mato (IEF 2010).

During the seven-day Course, all theoretical and practical activities were carried out in the facilities and caves of Maquiné and Rei do Mato. Lectures, discussions, demonstrations, and group assignments filled the week with conservation management activities.

Following classroom presentation and discussion of theoretical concepts, we assigned small teams with daily hands-on cave projects involving resource assessment, impact analysis, decision-making, planning, group dynamics, consensus building, and execution of cave management tasks.

The seven-day schedule enabled participants to spend many hours each day in small groups, literally planning and executing a variety of in-cave conservation-management projects. Student teams took our classroom theories and restoration methods directly into the caves, used the information we presented to identify problems, discuss and plan mitigation strategies, make decisions, and then performed actual hands-on application of the tasks.

Figure 3. Course participants spent a day collecting trash in Maquiné, completing the tasks by sorting the garbage to determine what activities generated the waste. Students defined the need to improve communication of conservation protocols to maintenance teams and to visitors. Trash sorting in the parking lot blossomed into spontaneous art statements using objects found in the cave passages. Lata lixo is Portuguese for trash can!

Photos Luciana Alt, Val Hildreth-Werker

As projects became more complex, participants adapted plans and techniques to better fit the specific situations they encountered. The Course provided opportunity for in-depth analysis, application of decisions, and fine-tuning of skills.

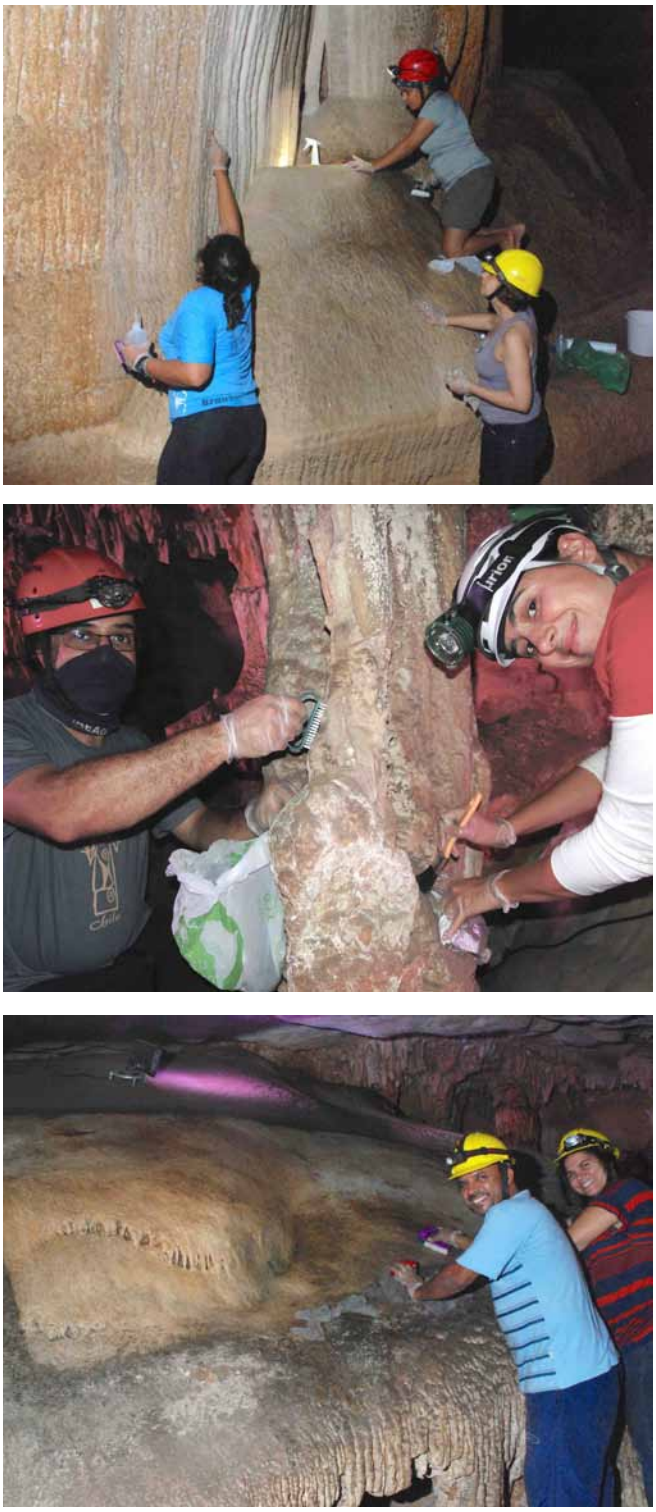

Figure 4. Testing to find the best techniques for removing a thick lint layer covering speleothems in Rei do Mato included careful protocols for invertebrates, wildlife, and minimum-impact. Participants gained valuable hands-on experience in a variety of restoration decisions and tasks. *Photos Luciana Alt, Val Hildreth-Werker*

5. Participation

Through an application and selection process, 27 students with diverse skills and backgrounds attended this first Course. Some represented federal and state environmental protection agencies, and some were from private companies specializing in speleological studies. We also had long-time interpretive guides from the two caves; archaeologists from federal agencies; lawyers representing environmental agencies; biologists; a few members of the caving community; and some mining company officials. Other applicants fill a waiting list for future courses.

Figure 5. Participants of First International Cave Conservation, Management, and Restoration Course in Brazil attended a full week of in-cave practical learning activities. *Photos Luciana Alt, Val Hildreth-Werker*

Classroom information and practical in-cave activities gave students technical training for performing current best practices in caves based on the foundation of *primum non nocere* – first do no harm (Hildreth-Werker 2006). The first objective in cave conservation is to avoid creating new problems.

Drawing from current best practice concepts published in *Cave Conservation and Restoration* (Hildreth-Werker and Werker 2006), the Course curriculum covered techniques, philosophy, and ethics of cave management. We include the word current in front of best practices, as a reminder to stay abreast of new studies and use science-based information to continually improve and redefine standards and practices in cave conservation (Spate, *et al.*1998; Hildreth-Werker 2006).

6. Summary and Outcomes

Participants accomplished much impressive conservation work in the two protected show caves during the Course week. Teams identified, documented, and initiated restoration projects addressing some of the conservation concerns described in the cave management plans.

All students gained tangible field experience in resource assessment, identification of conservation issues, impact mapping, low-impact caving ethics, cave cleaning, special attention for historic materials, lint debris removal, speleothem restoration, lampenflora control, trail delineation, historical and cultural marking analysis, contemporary graffiti removal, and visitor routing to enhance safety and mitigate impact.

Following the Course, participants employed in various federal, state, and private cave-resource-management jobs created new minimum-impact protocols for work in their respective scientific disciplines. Results include new protocols for cave archeologists and biologists. These documents represent tangible positive outcomes of the philosophical discussions, technical methods, and impact-reducing ethics presented during the Course.

The week of instruction, discussion, and practical training inspired participants to propose follow-up programs for continuing the work initiated through the Course. However, the proposed plans for continuing conservation and restoration projects in the caves have not yet been implemented. Much still needs to be done – thus, we will design our next course to stimulate continued training and especially to motivate organization of ongoing annual restoration events.

Brazil's first International Course in Cave Conservation and Restoration is an important initiative for karst outreach and instigates new pathways forward in the protection and conservation of caves in South America and throughout the world. We appreciate this opportunity to share and expand conservation methods. As well, we are enthusiastic about reinforcing these initiatives and continuing to develop future training events.

Acknowledgements

We extend gratitude to the Anglo American Mining Company and their supportive representatives; to our friends and colleagues from the Brazilian Karst Institute – Instituto do Carste; Chico Mendes Institute for Biodiversity Conservation–ICMBio; National Center for Research and Conservation of Caves – CECAV; Minas Gerais State Forest Service – IEF-MG; Maquinetur Foundation; Gruta do Maquiné team; Gruta Rei do Mato team; and all the amazing people at Brazilian cave sites we visited. We deeply appreciate the opportunity to participate in Brazil's conservation management and karst outreach.

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(Abstract) Caves And Ancient Human Life

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Abstract

People know a place to live or stay since Mesolithic times. Before that time people did not know where to live and live nomadic (moving). After getting to know where to live, people started farming using simple tools made of stone, animal bones or wood. Karst regions provides places that can be directly utilized by human prehistoric times, both for shelter, daily activities, and as a place to live. The first place to stay is a cave or rock shelter which one day will be abandoned when the surrounding food source runs out. Selection of caves and niches as human habitation for specific purposes include morphology and the environment around the cave. Environmental resources and the morphology of different caves result in the existence of various types of shelter, namely the type of shelter with central location (central place) activities and other locations as a supporter in conducting activities and also the place of activity.

Caves of prehistoric residents are not only used by humans at that time as a place to live but for shelter from climate, weather (wind, rain and heat) or from attacks of wild animals or other human groups. They also serve as graves and as places for industrial activities such as stone tool workshops. Relics of past human activity, in the form of stone tools, shells, animal bones, pottery, and cave paintings are found in caves. The work is in the form of rock art with various motif images. The motive shown implied various information about the values of local wisdom of society at that time, because there are various motifs as symbols or symbols that are directly related to human behavior.

World-Wide Largest Biosphere Reserve On Sulphate Karst And The Schlotten Caves – Endangered Geo- And Biodivesity Hotspots In The South Harz, Germany

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Abstract

The karst area at the South Harz Mountains (Central Germany) is a landscape with a unique character based on its geology. It features small-scale diversity of semi-natural structures and is important for the conservation of certain species. The South Harz area forms a 100 km long continuous belt of evaporitic rock from the Upper Permian (Zechstein) stretching from Osterode (Lower Saxony, Göttingen district) via the Nordhausen district (Thuringia) to the south-eastern edge of the Harz Mountains north of Sangerhausen (Saxony-Anhalt). The most important characteristics are the large areas of outcropping gypsum rocks, the largest and thickest anywhere in Central Europe. The solubility of gypsum in combination with high levels of precipitation has created intense karstification with an amazing diversity of gypsum karst features in a geologically short period of time. Amongst the about 170 caves are the largest anhydrite caves of Europe outside the Russian Platform. This is unique world-wide for sulphate karst areas. Only small areas of the landscape are effectively protected. Quarrying for gypsum, anhydrite and dolomite threatens core areas of the landscape. This also endangers the sustainable development of the South Harz Mountain region. Protection in form of a large-scale biosphere reserve is only given in Saxony-Anhalt – the only one of its kind world-wide. This illustrates the under-representation of sulphate-karsts in the global network of protected areas and sites.

Keywords: South Harz, karst landscape protection, evaporate karst, gypsum, anhydrite, world heritage

1. Introduction

The landscape of the South Harz is dominated by gypsum karst, forming one of the largest continuous gypsum karst areas in Europe (Kempe 1996). It occupies a narrow belt extending through the States of Lower Saxony, Thuringia and Saxony-Anhalt (Federal Republic of Germany) from Osterode am Harz in the West to Sangerhausen in the East. This sulphate belt has developed a remarkable density and variety of karst phenomena throughout the Pleistocene and Holocene. Karstification occurs mostly in the gypsified anhydrite layers of the Upper Permian, i.e. the anhydrite members A1, A2, A3 of the Werra, Staßfurt and Leine Zechstein (Upper Permian) salinar series, respectively. Dolomite and limestone outcrops complement the karst area. This outstanding landscape is worthy of preservation and several important sections are legally protected. However, the area and its outstanding importance is not well known internationally.

2. Epikarst and Biodiversity Hotspot

The most pronounced features of the South Harz karst landscape are more than 20,000 sinkholes in addition to countless uvalas, ponors and karstic springs, periodic lakes, about 170 caves and other karst phenomena plus many archaeological sites. All are confined in the small spaces of the individual gypsum outcrops. These natural conditions are a vast mosaic of closely interconnected but diverse habitats, including dry meadows, beech forests on sulphate rocks and dolomite (*Hordelymo-Fagetum lathyretosum*), gypsum escarpments, stony terrain, spring bogs and water-filled fens. The South Harz gypsum karst area is also an important habitat for many bat species and the European Wildcat (*Felis sylvestris*).

The highly structured surface and its dry soils limits housing development, agriculture and forestry. Many parts of the karst are therefore in a semi-natural state. Calcareous beech woodlands are particularly worth protecting and dominate the flora together with dry calcareous grasslands. In addition, the north-western Atlantic and south-eastern continental climate zones overlap in the Lower Saxony part of the gypsum karst. The geological conditions, especially the diversity of different karst types and climatic conditions, allow a specific large biodiversity. This has been the main reason why the German Federal Agency for Nature Conservation (BfN) has added this area to a list of 30 biological hotspots under the name of **"South Harz Zechstein Belt, Kyffhäuser and Hainleite"**. Even though, only parts of the landscape are protected.

3. Hypokarst and Mining

Since the 16th century, copper shale miners in the area of Mansfeld have known phreatic anhydrite caves without natural entrances in the subsurface and named them "Schlotten" (Kempe 2014). They are mostly situated in the Mansfeld Basin within the Zechstein anhydrite, but some underlie the Biosphere Reserve and are open for restricted public visits. TheseSchlotten-type caves are the largest anhydrite caves in

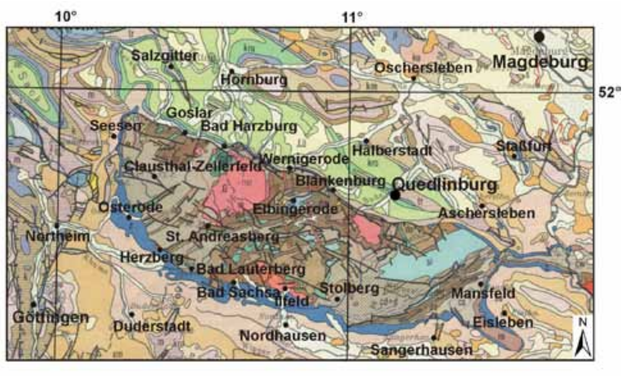

Figure 1. Geological map of the South Harz Zechstein belt between Osterode and Sangerhausen plus the Schlotten cave area near Eisleben and Mansfeld. Graphics: Geopark Harz . Braunschweiger Land . Ostfalen, modified by Stefan Mohr.

Figure 2. Sachsenstein sulphate cliff near Bad Sachsa. Photo: Detlef Tront.

Figure 3. Beech forest on gypsum in the Höllstein area near Walkenried. Photo: Hans-Georg Mendel.

Figure 4. The Wimmelburger Fluchtwegschlotte, one of the largest Schlotten cave rooms near Eisleben. Photo: Klaus Stedingk.

Europe outside the Russian Platform. The most famous of them are the “Wimmelburger Schlotten” near Eisleben. Four geological and geochemical preconditions are required to form these caves: Inflow of sulphate-poor and carbonate-rich groundwater via a locally fractured limestone karst aquifer, superposition by an impermeable rock (in this case anhydrite),presence of steeply inclined fault zones in the anhydrite yielding the initial permeability, and development of a secondary calcium-sulphate solubility due to carbonate precipitation near the boundary between limestone and anhydrite. The water input derives from meteoric precipitation sinking into a jointed limestone aquifer. The easily soluble, but impermeable anhydrite forms the upper boundary of the caves and induces the formation of a pressurised aquifer between limestone and anhydrite. Anhydrite is generally impermeable because tectonic fissures are quickly closed again by a volume increase during the gypsification. The Mansfelder Schlotten can be classified as strata-boundary caves between limestone and anhydrite rock. The cavities start to develop along horizontal shear zones with sigmoidal joints. When the carbonate-rich water meets the anhydrite rock at such a fault, the solubility equilibrium changes, and fine-grained carbonates precipitate. By this process, the water gains a secondary calcium-sulphate solubility and large hypogene cavities develop by slow, density-driven convection. The karst water regime is a siphon-drainage system (Kupetz and Knolle 2015).

4. Landscape History

The fens and lakes in the South Harz gypsum karst sinkholes are excellent archives for the reconstruction of vegetation, land use and emission rates over millennia. Pollen is preserved very well due to the anoxic conditions in bogs especially in the hypolimnion of lakes. Studies of the varved sediments of the Lake Jues sinkhole in Herzberg provided a well-dated, continuous and highly sensitive environmental and climatic reconstruction of the Holocene for the mid-latitudes in Central Europe. The results serve as an important link between the better investigated neighbouring regions. This sinkhole is one of the largest of its type in Germany and collapsed during a Laacher See volcanic event ~ 13,000 BP. Tephra from this event was found at the base of Jues sinkhole (Meischner and Grüger 2008).

Climate shifts, mainly in phase with those recorded from other European regions, are inferred from changing limnological conditions and terrestrial vegetation. Significant changes occurred at 11,600 yrs BP (Preboreal warming), between 10,600 and 10,100 yrs BP (Boreal cooling), and between 8,400 and 4,550 yrs BP (warm and dry interval of the Atlantic). From 4,550 yrs BP the climate became gradually cooler, wetter and more oceanic. This trend was interrupted by warmer and dryer phases between 3,440 and 2,850 yrs BP and probably between 2,500 and 2,250 yrs BP (Voigt *et al.* 2008).

Figure 5. Gypsum quarry destroying the Zechstein landscape south of Walkenried. Photo: Reiner Cornelius.

Palynological studies provide reconstruction of vegetation and settlement history from the Preboreal throughout the Holocene. Deciduous primeval forests dominated by oaks (*Quercus*) spread from the beginning of the Holocene at 10,020 a BP. From 7,600 a BP on in the Neolithic period first settlements and arable farming began to affect the forests. Floral change again took place during Bronze Age when the beech (*Fagus*) superseded the primordial tree species. This process bearing significant ecological effects. Biomass and biodiversity of arthropods declined in the forests, since the number and biomass of foliage-feeding invertebrates associated with oak exceed those associated with the beech (Alexander *et al.* 2006).

Based on the landscape features and ecological qualities, there also exists a wealth of archaeological sites in the South Harz Zechstein belt. The Einhornhöhle cave near Herzberg-Scharzfeld, a cave bear site with Neanderthal tool findings has been known since prehistoric times. More recently the Lichtensteinhöhle cave near Osterode am Harz has become known. It can be dated to the Late Bronze Age by archaeological findings (Flindt and Hummel 2015) and comprises among others, a rich bat fauna. The tree-dwelling stenoecious Bechstein's bat had been the most frequent bat species in Holocene oak forests but was a rare species in the beech forests of the Late Bronze Age cultural landscape (Rupp 2017).

The beech declined in the Middle Ages when humans exploited large areas due to a demand for charcoal for mining. The extraction of metals started more than 4,000 years ago. Geochemical investigations of fens in karst sinkholes in the South Harz allow detection of the emissions produced by mining, as the high portion of low density organic material with very low background concentrations of heavy metals, and the near-neutral pH-values in most of these mires prevent migration of heavy metals. Emission of dust and other harmful elements can be correlated with changes in vegetation (after Hettwer *et al.* 2002).

Biosphärenreservat
Karstlandschaft
Südharz

Figure 6. Signet of the only Biosphere Reserve on sulphate rocks worldwide.

5. Threats and Chances

Unfortunately, parts of this landscape have already been destroyed. In many places gypsum, anhydrite and dolomite is quarried predominantly by globally operating business groups. Every year, millions of tons are processed for construction materials, such as gypsum wallboards, plaster, etc., and karst phenomena with their characteristic flora and fauna are irreversibly lost. Valuable natural heritage and long-term development prospects for the region are sacrificed for short-term jobs and profits. But this must not happen any more, since natural gypsum can be substituted by synthetic, especially gypsum from flue gas desulphurisation (FGD) in nearly all fields of application. FGD gypsum is a waste product of smoke desulfurization. Not all of this gypsum is used for the building industry and must be locally stored or even deposited. Phosphogypsum also can be used as a substitute material for natural gypsum in different technical fields (Yang *et al.* 2015).

Gypsum karst areas, which are now being unnecessarily destroyed, developed over hundreds of thousands of years and represent geosites and biotopes with a significant ecological importance for biodiversity, groundwater systems and the defining landscape elements in Europe. Compensatory measures such as restoration can never substitute primary ecotopes that evolved over a geological and rather than a biological time frame. Restoration would take centuries and the geomorphological structure of this unique habitat and also the karst phenomena would be irrecoverably lost. Because of the current tempo of species extinction, due to climate change, ecological niches like the gypsum karst become indispensable. For this reason sustainable production in the case of utilisation of synthetic gypsum instead of natural gypsum is an economic advantage, resource efficient and above all a guarantee for the protection of biodiversity and landscape ecology in Europe (Röhl 2003).

6. Protection by World Heritage Status?

The environmental and speleological NGOs in Lower Saxony, Thuringia and Saxony-Anhalt vigorously object to the issuing of new extraction permits. In order to ensure the long-term protection of the gypsum karst landscape they demand the establishment of a cross-boundary UNESCO Biosphere Reserve, designated "Karstlandschaft Südharz", and the nomination of more gypsum karst areas as Natura 2000 sites also in Lower Saxony and Thuringia. The environmental NGOs have lodged a complaint with the EU, because important gypsum areas comprising habitat types and species worth of protection have not been nominated for protection in the interest of the continued gypsum mining.

The South Harz gypsum karst is part of the Geopark Harz . Braunschweiger Land . Ostfalen since 2002, UNESCO Global Geopark since 2015 and was declared a German National Geosite in 2006. For more geo-tourist information see also http://www.karstwanderweg.de.

So far, Saxony-Anhalt has been the only German state to consistently protect its share of the gypsum karst belt as a Biosphere Reserve. Declared in 2009, it has an area of 30,034 ha and ranges from Stolberg in the West to Sangerhausen in the East. There is no other Biosphere Reserve in a gypsum karst area in the world.

Sulphate karst areas are massively under-represented in the global network of protected areas and sites. Following Guidelines 4 and 9 (IUCN 1997) and Recommendation 4 from IUCN (2008), parties whose territories include karst terrains situated on evaporite rocks should consider the potential of their sites for natural World Heritage recognition, and this consideration should be started for the gypsum karst landscape described above.

Acknowledgements

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The Detection of Human Activities' Impact on Show Caves Environment in Pacitan, Indonesia

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Abstract

is a regency in the East Java Province of Indonesia that known as 1001 caves city. Most of Pacitan's land is part of Gunungsewu karst area that has many caves. Several caves in Pacitan have been developed as show caves. Show caves play critical roles in this regency because it is one of the main local economic resources. It also provides many job opportunities and increases the economic level of local communities. The successful view of show caves in Pacitan leads to the opening of new show caves, not only in the same regency but also in other regions. Tourism is an alternative use of karst caves that is considered more sustainable than another potential uses, such as mining (an extractive industry). But the impact of tourism on cave environment in this regency particularly, and in Indonesia generally have never been evaluated. Unsympathetic management of show caves that only thinks about economic benefits and disregards the sustainability aspect will potentially destroy cave environment.

This study aims to investigate management issues occurring in Pacitan's show caves and identify the impact of human activities on the show cave environment. There are several issues about show caves management in Pacitan; 1. Installation of infrastructure inside caves, such as cement walkways, various colored electric lights, and big blowers with room perfume, 2. Weak regulation to limit visitor numbers and activities during visits 3. Breaking and damage of speleothems and 4. application of dangerous substances to lessen the smell of guano and repel cavernicolous biota. Several impacts on cave environment that occur due to tourism are the growth of lampenflora, thick dust covering speleothems, speleothem color alteration, garbage accumulation, cave vandalism, damaged speleothems, microclimate changes, and decline on biota numbers. This study clearly reveals that the development of cave for tourism in Pacitan brings some negative impacts that may cause cave environmental destruction, but this should not mean that show caves should be banned. Otherwise, that would lead to more problems and we need to give attention to and consideration for all stakeholders to evaluate and undertake better management.

Keywords: Destruction, Show Cave, Management, Evaluation

1. Introduction

Pacitan is a popular regency in Indonesia because of its beautiful and unique caves. It has many caves with the potential to be developed as a tourist attractions since most of its land is part of the Gunungsewu karst area. Gunungsewu is one of the best karst areas in Indonesia and has been a member of the UNESCO Global Geopark Network (GGN UNESCO) since 2015.

Several caves have been developed as show caves since 1995 and have given the highest regional income. For example, the Gong cave, the most famous show cave in Pacitan, is visited by more than 250.000 visitors and contributes more than US $200.000 per year. It shows that the development of show caves gives a positive impact to local communities such as enhancing job opportunities and successfully increasing an economic level of the surrounding communities. Therefore, the opening of several new show caves has occured recently. These are not only in Pacitan but also in other regions of Indonesia. The successful management of Gong and Tabuhan caves is used as a model for the new show caves.

Tourism is an alternative use of karst cave considered more sustainable than another potential uses, such as mining (an extractive industry). Yet, the impacts of tourism on the cave environment in Pacitan regency particularly and in Indonesia generally actually have never been evaluated. If the management of show caves only thinks about economic benefits and disregards the sustainability aspects, it will potentially destroy the cave environment. Caves are one of the most fragile ecosystems and very susceptible to disturbance resulting from human activities (Fernandez-Cortez *et al.* 2010). The destruction of cave environments would also potentially bring huge economic losses in the future. Therefore, this study aims to investigate show caves management issues occurring in Pacitan and to identify the impact of human activities on the show caves environment. The result of this study is a consideration in evaluating the management and conservation of show caves particularly in Indonesia.

2. Study Sites and Methods

The study was conducted from September 2016 to Januari 2017 in 3 show caves (Gong, Tabuhan, and Semedi) in Pacitan Regency, East Java Province. Gong and Tabuhan are the most famous show caves in Pacitan. Gong cave was opened as a show cave in 1995, while Tabuhan in 1997. Both Gong and Tabuhan are manamged by the local government. Semedi is a newer show cave opened in 2016 by a local community. Besides these 3 show caves, we also observed and explored 3 wild caves (Ponjen, Kalisat and Paesan) also located in the Gunungsewu karst area, for comparison and to get direct field data. We undertook in-depth interviews with cave managers, local communities and visitors to get additional information. Microclimate measurements were taken in each cave zone for air temperature, CO_2 level and light intensity. Cave biota (terrestrial arthropods) was sampled by standardized hand collecting methods by 3 observers with 30 minutes duration for each cave zone. Arthropod identification was based on morphological characters to the lowest taxonomic level possible.

3. Result and Discussion

3.1. Issues on Show Cave Managements in Pacitan

We observed that there are several issues on show caves management in Pacitan; 1. The installation of several infrastructure inside caves, such as electric lights, cemented walkways, and big blowers with a room perfume, 2. Weak regulations for limiting numbers of visitors and visitor activities during visits, 3. Activites that lead to speleothem damage and 4. Use dangerous substances.

Various colored electric lights can be found in all these 3 show caves. The installation of electric lights is not only for illuminating purpose, but also for decorating speleothems to attract visitors. Therefore, several different colored electric lights are intentionally installed near beautiful speleothems. The lights in Gong and Tabuhan caves are switched on every day from 07.00 am to 04.00 pm and may be longer when many visitors are present, particularly in holiday seasons. Whereas, the electric lights in Semedi are switched on and off irregularly. Usually, the lights will be switched on only when visitors come, but sometimes they are on even when there are no visitors.

Cemented walkways can be found in Gong and Tabuhan caves. A massive cemented walkway is present in Gong cave as the cave floor Gong cave is dominated by rocks and pools. The manager has built cemented ways to make a good and safe route for visitors. Unfortunately, the route is built through several beautiful speleothems, so visitors can touch the speleothems easily during visits. The cemented walkway in Tabuhan is also designed to guide visitors, but, it is designed without left and right fences. This means that visitors can leave the route easily. No cemented walkway is found in Semedi a several rooms of Semedi cave was so small that they are difficult to explored. The local community and the manager dug out the soil on the cave floor so it can be walked through.

Blowers (big fans) are found in Gong cave. Some blowers have room perfumes and are installed because visitors mostly feel hot and uncomfortable when they are inside the cave. In fact, many visitors are still feeling hot even though fans are been installed. The weak regulations for limiting visitor numbers allows too many visitors entering this cave together. Sometimes, traffic congestion occurs on the route inside the cave and results in a long queue outside the cave entrance., More than 3.000 visitors may visit this cave in a day, particularly in holiday periods. Furthermore, more than 750 visitors can enter this cave per hour although the maximum capacity of this cave is only 50 persons time. According to the cave manager's data, the numbers of visitors is increasing each year. Besides aesthetics of the cave, the cheap ticket price (less than US $1), is another factor that attracts many visitors.

In addition, visitor activity during visits is poorly controlled. The regulation actually states that every single visit should be accompanied by a guide and guides are available everyday in Gong and Tabuhan caves. Many local communities people work as guides in these show caves. But, the implementation of this in the field is very weak. Many visitors prefer to visit the caves without guides because they have to pay extra for the guide. Information boards on regulations installed by cave managers in front of cave entrances are not strong enough to warn the visitors. Also no guide is available in Semedi which that means visitors are unsupervised.

Speleothem damage occurs in several show and wild caves in Pacitan. This is done by visitors, cave managers and surrounding communities. Cave managers break speleothems to make routes for visitors. Speleothems that block the routes will be cut so visitors can pass easily. Besides, visitors and surrounding communities often cut beautiful speleothems and use the material to make traditional accessories. In addition, Pacitan is famous for traditional ring production and people think that the beautiful speleothems are a good material to make beautiful ring's eyes. In fact, the limestone cannot be used as ring's eyes as it will dissolve and broken during the grinding process.

Another important issue is the use if dangerous substances by show caves managements. We found several mothballs spread out in the dark zone of Semedi cave during our visit. Semedi is a new show cave to which not many visitors come yet. The bat population in this cave is still in at a good level so there is guano smell. We assume that the mothballs are spread out intentionally by the cave manager both to mask the smell of guano and to repel cave biota from the cave. Mothballs have strong fragrance and contain naphthalene, an active compound with toxic effects for insects (Fleming *et al.* 1934). In Indonesia, it is commonly used as insect repellent and room perfume.

3.2. Impact of Human Activities on Show Cave Environment

Several impacts on cave environment due to tourism in Pacitan show caves are the growth of lampenflora, thick dust covering speleothems, speleothem color alteration, damaged speleothems, cave vandalism, garbage accumulation, microclimate changes, and the decline of biota numbers.

The installation of artificial lights, particularly in dark zones, leads to the growth of lampenflora on speleothem surfaces. Lampenflora can be found easily in the dark zone of Gong and Tabuhan caves. It mostly comprises algae, mosses and ferns. Lampenflora gets little attention and is rarely removed by the managers, although the growth of lampenflora can cause damage to both to speleothems and cave fauna (Castello 2014). The installation of blowers in Gong cave particularly affects speleothem surfaces. Almost all speleothems located near fans are covered by thick dust. Several blowers are installed facing speleothems and concentrate airflow in a single direction. Dust from the blower follows the direction of air flow towards speleothems and finally accumulates on the speleothem surfaces. This dust gets little attention and is rarely removed by managers. Accumulation of lampenflora and thick dust will potentially disturb the growth of speleothems and lead to deterioration.

The weak regulations controlling the visitors' activities accentuates the negative impacts on speleothems. As mentioned above, several routes particularly in Gong cave are built near active speleothems that allow visitors to touch speleothems easily. This touching leads to speleothems to discolor and there are many black patches on speleothem surfaces in

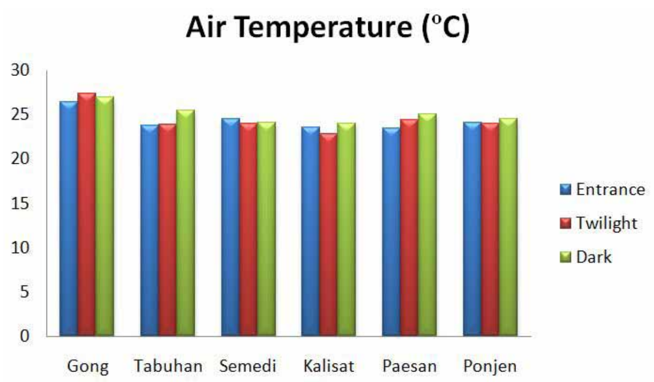

Figure 1. Air temperature measurements

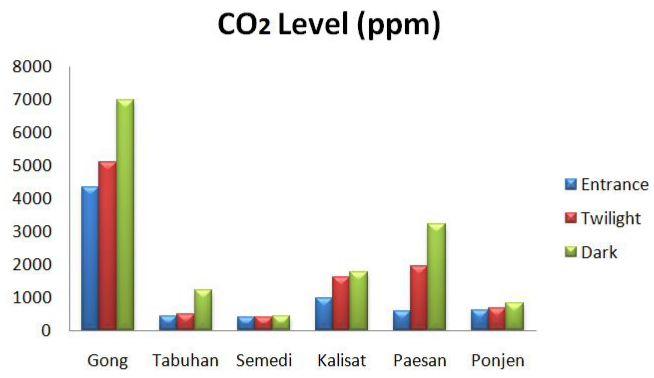

Figure 2. CO_2 Levels

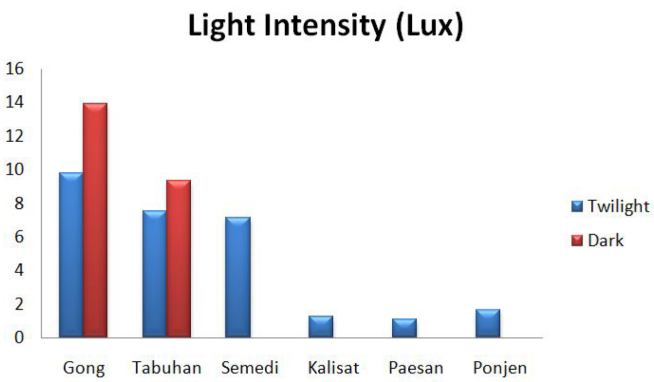

Figure 3. Light intensity

Gong cave. Cave vandalism also occurs, mostly in Tabuhan. Much scribbling (graffiti) is found on the Tabuhan cave walls. Another negative impact is damaged speleothems caused by cutting and breaking activities. Many beautiful speleothems in show and wild caves have been damaged by visitors and local communities sampling speleothems for accessories and by cave managers to build visitors' routes. The weak management controlling visitor activities leads to garbage accumulation and several piles of garbage can be found on cave floors and/or in spaces among cave ornaments. This decreases the aesthetic values of the caves and will potentially bring huge economic loss in the future.

The measurement of microclimate indicates the changes of microclimate occurring in the show caves environment. We compared the average measurements of air temperature, CO_2 level and light intensity between the 3 show caves and the 3 wild caves that have similar characters (i.e. horizontal and fossil caves). The air temperature in the show caves is higher

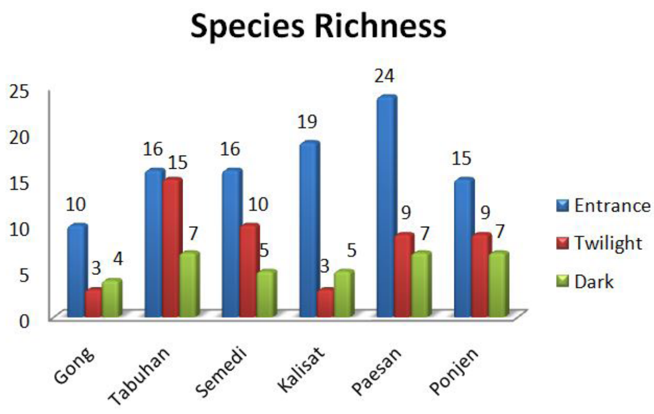

Figure 4. Species richness

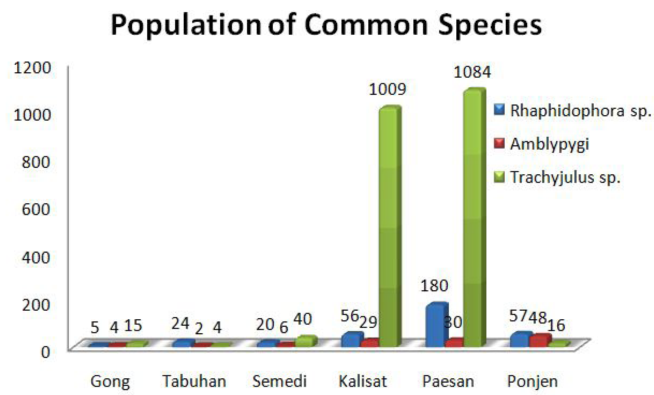

Figure 5. Populations of common species

than in the wild caves, particularly in the dark zone Fig 1). CO_2 measurement showed that Gong cave has a higher CO_2 level than the other 5 caves. The massive numbers of visitors and long tour periods have a large effect on the air temperature and CO_2 level increments, and potentially decrease air humidity in the cave environment (Sebela *et al.* 2014; Fernandez-Cortes *et al.* 2011). The high CO_2 level in wild caves such as Kalisat and Paesan is caused by the huge bat and/or swallow bird populations. Concentrations of bats will produce sufficient CO_2, heat, and water to affect microclimate (Lundberg *et al.* 2009). The dark zone of Tabuhan has high CO_2 level although the bat population in this cave is very limited (Fig. 2). It possibly indicates that visitors contribute to both the high air temperature and CO_2 increment in the cave environment. Light intensity measurements clearly show that the specific condition of the dark zone in show caves will disappear when electric lights are switched on. Besides the light pollution, electric lights can also contribute in air temperature increment (Cigna 2011).

Species richness of terrestrial arthropods in the show caves and wild caves is diverse. It depends on the kind of microhabitats existing in those caves. One of the important factors in all ecosystems is organic matter (source of food). All of the studied caves are fossil caves without water inlets. It means that organic matter only enters caves through wind, percolating water and mostly organisms. Bat guano is one of the main sources of food for other cave organisms (Culver *et al.* 2005). Gong cave has the poorest species richness of terrestrial arthropods because it has very few bats and limited guano.

There are 3 common species of arthropods found in the dark zone of these 6 caves (Figs 4 & 5). The specific characteristics of the caves are their darkness and stable environment

(Culver *et al.* 2005; Fernandez-Cortes *et al.* 2011). They are the millipede Trachyjulus tjampeanus, the cave cricket Rhaphidophora sp., and the whip spider Charon sp. and/or Sarax javensis. We used these species as indicators for the impact of human activities on the cavernicolous population. The comparison of population of each species in 6 caves shows that population decline in show caves compared to wild caves. Trachyjulus tjampeanus has lower population in Ponjen (wild cave) compared to Semedi (show cave) because previous use by humans. According to the local community', Ponjen was used as evacuation place during the colonial period and the bat population declined. Ponjen has fewer bats than Semedi. Trachyjulus tjampeanus is a guano feeder (mostly bat guano). The bat population decline simultaneously decreased this millipede population. Cave arthropod is highly sensitive with microclimate changes. The change of microclimate in caves caused by human activities results in the decline of the cavernicolous arthropod populations.

4. Conclusion and Recommendation

The development of caves for tourism in Pacitan enhances several negative impacts on cave environments. Inappropriate management, massive visitor numbers and uncontrolled human activities in show caves result in destructive impacts for both biotic and abiotic factors. Show caves however should not be banned because the livelihood of many people depend on it. Therefore, this result should be a major attention and consideration for all stakeholders to evaluate and undertake better management for show caves conservation.

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Preliminary Observations on Tropical Bat Caves as Biogeochemical Nitrogen Sinks

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Abstract

A previously unrecognized aspect of nitrogen biogeochemistry in tropical moist forests (TMF) relates to the spatial biogeochemistry of these systems. In general, high levels of herbivory in TMF's transfer large amounts of fixed nitrogen and other nutrients into the insect community, which itself is harvested by aerial insectivorous vertebrates (bats and birds), or moves directly into the non-volant vertebrate community through leaf eating mammals and frugivorous mammals and birds. In non-karstic TMF's bats and birds can be expected to redistribute this fixed nitrogen through defecation and urination throughout the TMF, contributing to the efficient recycling of this potentially limiting nutrient. However, in karst environments, TMF's may support very large (105 – 106 individuals) populations of bats and in Southeast Asia, birds (cave dwelling swiftlets), that occupy very spatially localized roosts. A single large cave may support a bat or swiftlet population in the hundreds of thousands of individuals that forages for insects over thousands of square kilometers of TMF, but then deposits a substantial fraction of its total excretory nitrogen within that single cave. A large but undetermined fraction of this nitrogen input is retained within the cave, or lost as diatomic nitrogen gas following biological denitrification. Such a cave then functions as a point-source sink for TMF fixed nitrogen. Recent work in Deer Cave, Mulu National Park, Sarawak (Malaysia) has mapped the ammonia plume emanating from a large bat guano accumulation. Relating this plume to airflow, first order estimates of ammonia production are ~ 9 g NH3/m2/day below the main Chaerephon plicata roost. An additional 4 g N/m2, or 45% of the total nitrogen budget, are retained in the guano and eventually lost to the external environment.

Keywords:

1. Introduction

Tropical (and in North America, warm temperate) environments may support very large colonies of certain hypercolonial cave roosting bat species. Caves that host colonies of hundreds of thousands of insectivorous bats are repositories for very large quantities of bat guano. Insectivorous bat guano consists primarily of undigested insect chitin – an N-acetylglucosamine polysaccharide that is highly resistant to degradation, together with normal vertebrate fecal products and urine. The fate of these cave guano accumulations is largely determined by moisture content. In dry conditions, insectivorous bat guano may be preserved essentially intact for thousands of years, where it has been shown to be an important archive of palaeoenvironmental data (e.g., Wurster et al., 2008). Under moist conditions, decomposition by chitinase-producing microorganisms can proceed much more rapidly, although very little work has been published on measured rates.

Fresh bat guano contains some 12% nitrogen by weight in the chitin component, together with a significant contribution from bat urine. McFarlane et al. (1995) postulated that the urea component is rapidly metabolized by ammonifying bacteria and volatized as ammonia gas, which can reach concentrations >1000 ppm in some caves, but is more commonly exported from the cave by air flow. Chitin-derived nitrogen is metabolized much more slowly to nitric acid, and either denitrified, or under appropriate conditions of moisture saturation and wicking, combines with calcium, sodium or potassium ions to form one of a family of nitrate minerals (Hill, 1981) that may appear as a solid efflorescence in low humidity environments, or carried away in solution in saturated deposits.

The world's tropical forests are the Earth's major repository of biodiversity and play important roles in global climate regulation and biogeochemical cycling (e.g., Maldhi and Phillips, 2004). Previous studies of nitrogen fixation rates in tropical forest ecosystems have provided widely disparate results; Reed et al. (2008) report published TMF canopy fixation estimates that span four orders of magnitude. Furthermore, Feeley and Terborgh (2005) demonstrate that mammalian herbivore density on land-bridge islands isolated in Lago Guri, Venezuela, is strongly correlated with reduced nitrogen content (increased C:N ratio) in TMF soils. Nitrogen fixation in TMF's has also been shown to be limited by phosphorus availability (Townsend et al., 2007). In general, high levels of herbivory in TMF's transfer large amounts of fixed nitrogen and other nutrients into the insect community, which itself is harvested by aerial insectivorous vertebrates (bats and birds) and the non-volant vertebrate community of leaf eating and frugivorous mammals and birds. In non-karstic TMF's bats and birds can be expected to redistribute this fixed nitrogen through defecation and urination throughout the TMF, contributing to the efficient recycling of this potentially limiting nutrient. However, in karst environments, TMF's may support very large (105 – 106 individuals) populations of bats and, in Southeast Asia, birds (cave-dwelling swiftlets), that occupy very spatially-localized roosts. A single large cave may support a bat or swiftlet population in the hundreds of thousands of individuals that forages for insects over thousands of square kilometers of TMF, but then deposits a substantial fraction of its total excretory nitrogen within that single cave. The magnitude of the flux and ultimate fate of nitrogen passing through tropical bat caves has not previously been investi-

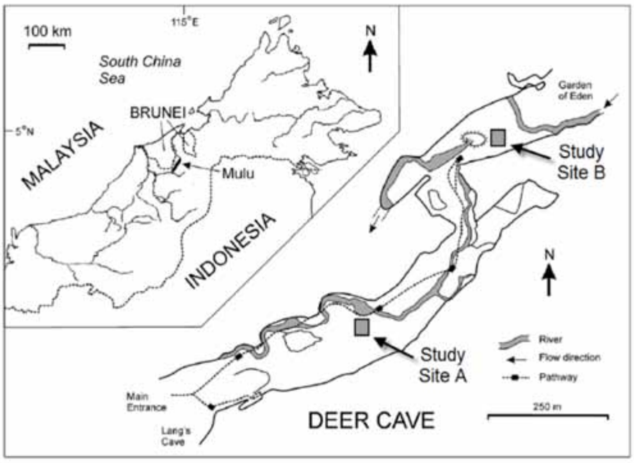

Figure 1. Deer Cave, Gunung Mulu National Park, showing guano study sites. (Cave plan modified from Brook and Waltham, 1978).

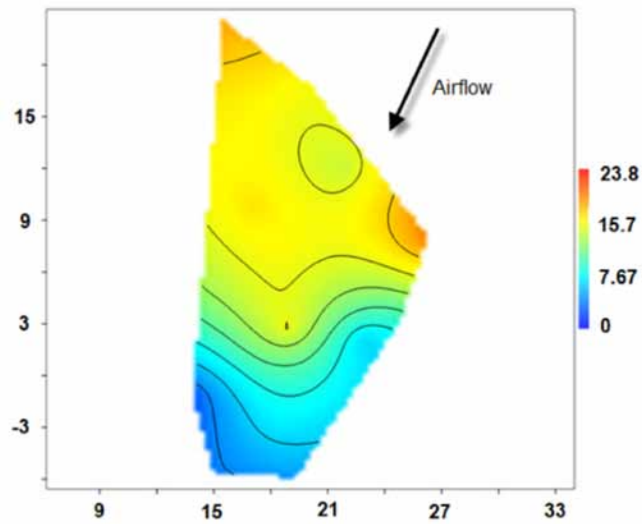

Figure 2. Ammonia plume, Site A, Deer Cave. Concentrations in ppm, X-Y scale in meters.

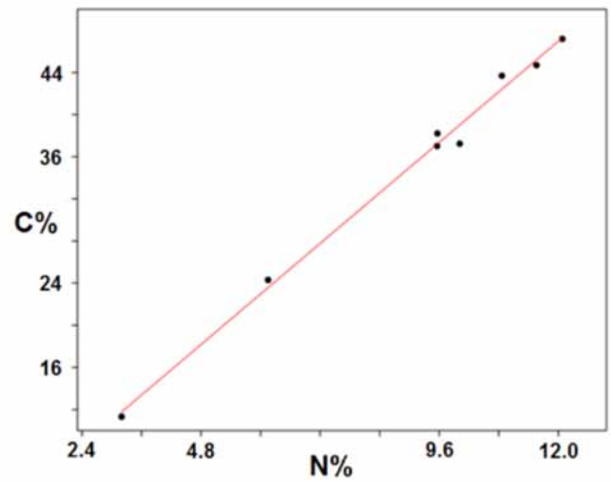

Figure 3. Relationship between chitin-bound carbon and nitrogen in Deer Cave guano.

gated; here, we argue that this represents an unrecognized but important component of tropical moist forest biogeochemistry in karst regions. In order to test this hypothesis, we constructed a simple input-output budget by measuring nitrogen sequestration in cave guano, guano decomposition rates, and nitrogen loss to the atmosphere by release of ammonia gas from the guano.

2. Location and Methods

Fieldwork was conducted in Deer Cave, Gunung Mulu National Park, Sarawak, Malaysia (Borneo) in April 2016. Two study sites were chosen: Site A beneath the main (south western) bat roost, and Site B, adjacent to the north eastern bat roost (Figure 1). Guano deposition was measured using a grid of plastic, 510 cm2, collecting plates mounted on 50 cm dowel rods coated with a ring of petroleum jelly to prevent access by guanophagic invertebrates. Collecting stations were surveyed in to the base map using standard cave survey techniques, to a demonstrated precision of ± 10 cm (x, y) and ± 15 cm (z). Guano pellets accumulating on the plates over a 24 hour period were collected, dried, and weighed, yielding average and peak guano accumulation rates for the site. Atmospheric ammonia concentration was measured at each station over 24 hours employing ammonia diffusion cartridges (Radiello corporation) mounted beneath inverted plastic cups at ~ 35 cm above the guano surface. These cartridges absorb ammonia at a calibrated rate of 235 mL/minute (25 ^{0}C and 1013 kPa). After return to the laboratory, absorbed ammonium ions were quantified by reaction with phenol and sodium hypochlorite, with pentacyanonitrosylferrate catalysis, to form indophenol. The intense blue reaction product was measured by visible absorbance spectrometry at 635 nm. The final spatial data matrix was contoured in PAST software (Hammer et al., 2001).

Guano samples were also collected from a 70 cm-deep excavated profile at Site B and were dried and analyzed for chitin-bound and free (soluble) nitrogen, together with carbon, on an Elementar VarioCube C:N analyzer.

3. Results

The nitrogen content of Deer Cave guano is 0.076 g N/g dry wt. The nitrogen mobilization (as soluble nitrate and nitrite) at 40 cm depth is 36.2%. The highest observed guano deposition rate (site A) was 30.2 ± 3.4 g /m2/day. Atmospheric ammonia reached 23.7 ppm (integrated over 24 hours) at Site A, generating an ammonia plume (Fig 2.) as the gas is washed from the cave by strong katabatic air flow of ~ 0.6 km/hr (cross sectional area at site A, 12700 m2) during the study period.

Analysis of the carbon:nitrogen fraction of the washed samples from the guano profile demonstrate an almost perfect linear relationship (Fig 3), consistent with the assumption that this component of the nitrogen budget nitrogen is present as part of the chitin molecule, and only released by the slow depolymerization of the polysaccharide by chitinase-activity.

Comparison of the soluble and insoluble (chitin-bound) nitrogen content down the guano profile (Fig 4) shows little difference, further confirming the rapid loss of urea and fecal nitrogen in the most superficial layer of the profile.

are Thiobacillus denitrificans, Micrococcus denitrificans, and species of Pseudomonas, Bacillus, Achromobacter, and Serratia.

At Deer cave, 9 g NH3/m2/day is lost from the guano. A further ~ 4 g/N/day/m2, or 45% of the total nitrogen budget, is initially retained in the guano, gradually released by microbial decomposition of the chitin and eventually either exported in guano drainage waters, or in drier, evaporative environments, crystallized as niter. With a conservatively-estimated population of ~250,000 individuals, the C. plicata population in Deer Cave harvests an estimated 450 kg of nitrogen per day as insect prey. A similarly conservative foraging radius of 30 km incorporates 2800 km2 of tropical moist forest, and amounts to a nitrogen "harvest" of ~ 0.5 kg N/day/ha, or some 48% of the typical TMF nitrogen budget. The cave is thus shown to act as a point-source sink for fixed nitrogen in the form of preserved guano or as crystallized niter; the nitrogen that is released to the atmosphere as ammonia gas is lost to the ecosystem; the nitrogen that is exported from the cave in the form of guano drainage waters is not distributed geographically and thus not available to most of the ecosystem. We conclude that the spatial bio-geochemistry of nitrogen is significantly modified in karst systems versus non-karst systems. Long-term sequestration of nitrogen in guano may be of the order of tens of thousands of years.

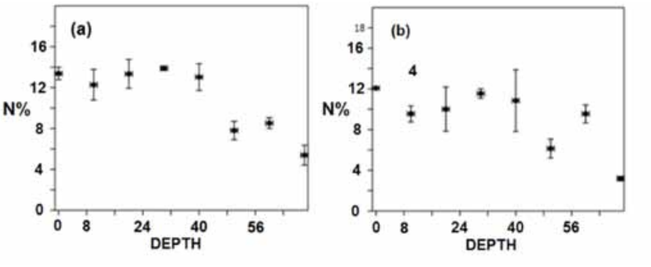

Figure 4. Relationship between chitin-bound nitrogen (a) and unbound nitrogen (b) and depth in the guano deposit.

4. Discussion

Guano diagenesis rate and long-term nitrate storage is closely tied to moisture content of the guano. In very dry conditions, such as those pertaining in caves of the arid southwestern United States, guano chitin fragments can retain their original structure over timescales of ~ 10 ka (McFarlane, personal observation, and Wurster et al., 2008). Significantly faster decomposition of guano chitin is observed in moist tropical caves, but the precise relationship between moisture content of the deposit and decomposition rate has yet to be determined. At Deer Cave, where the guano deposit contains >50% water, the decomposition and loss of a large fraction of the guano over ~ 70 cm depth, in circumstances of rapid continuous accumulation of fresh guano (~ mm increments per day) implies decomposition rates measured in years, not thousands of years. Work to date suggests that the urea component of the urine is rapidly (hours) metabolized, and the nitrogen volatized as ammonia. Microbial taxa associated with ammonification in soil include: Bacillus, Clostridium, Proteus, Pseudomonas, and Streptomyces (Wang et al., 2015). This process is aerobic, and in this context must occur on the surface and immediate subsurface of the guano accumulation. At Deer cave, a mean airflow of 0.6 km/hr across the Site A study area results in the export of the ammonia from the cave. Our modelling of the ammonia plume yields first order estimates of ammonia production of ~ 9 g NH3/m2/day below the main Chaerephon plicata roost (site A).

Ammonification of chitin-associated nitrogen is much slower, and occurs deeper in the guano deposit. The three stages are: (1) decomposition of organic nitrogen to ammonia, presumably associated with chitinase-producing bacteria such as Aeromonads (facultatively anaerobic), Bacillus, and Vibrio (aerobic). (2) The oxidation of ammonia ions to nitrite, brought about by ammonia-oxidizing bacteria; e.g., Nitrosomonas europaea, Nitrosococcus nitrosus, Nitrosospira briensis, Nitrosovibrio and Nitrocystis. The process is aerobic and perhaps limited by the depth of invertebrate bioturbation. (3) Nitrite oxidation (aerobic) to nitrate by nitrite-oxidizing bacteria such as Nitrobacter winogradsky, Nitrospira gracilis, Nirosococcus mobilis etc., and several fungi (eg., Penicillium, Aspergillus) and actinomycetes (eg., Streptomyces, Nocardia: Wang et al., 2015). Under appropriate evaporative conditions, this nitrate may be deposited as the mineral niter (KN03), the only nitrate salt which can crystallize under tropical cave conditions of >80% humidity and >20°C (Hill, 1981). The reverse process, in which nitrates are converted to nitrites and ammonia, occurs under anaerobic conditions (usually confined to the deeper, water-saturated layers of guano no longer subject to bioturbation). The most important denitrifying bacteria

Acknowledgements

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2013 to 2016 speleological explorations in Khammouane, Laos

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Abstract

We started our speleological explorations in Khammouane in 1991 and since we have been there every year until now. 2017 explorations are planned as well.

Over the 2013–2016 period, we continued exploring and mapping the cave systems that we had previously discovered and started studying. These are the Tham Koun-Dôn-Tham Houay Sai System, Tham Houai Sai sinkhole and Tham Lô in the polje of Ban Vieng, Tham Nam Non, Tham Song Dang, Tham Kwan Ha and Tham Phiseua. We also studied a number of smaller caves, which are of real interest to better understanding the karst of Khammouane. We also discovered some more caves.

Mapping newly discovered passages or other passages of interest was undertaken with scientific observations and measurements related to cave formation, karst organisation and speleothem distribution.

We made archaeological discoveries, such as hidden Buddha statues, some of them belonging to a previously unknown type, and pottery. We continued gathering information on the use of caves by man.

With this work, we are going to reach a number of conclusions, e.g. on the formation of hollow stalagmites, and on other types of speleothems.

Keywords:

During the International Congresses of Speleology, we have regularly presented papers on our explorations in Khammouane. A global paper was published in 1993 (Mouret and Vacquié, 2013). We returned to Khammouane from 10 December 2012 to 6 January 2013, then from 27 February 2014 to 18 March 2014, again in February 2015 (first author was not present) and from 15 January 2016 to 7 March 2016. We also planned an exploration campaign from 5 February to 7 March 2017. We work as a small team of 3 to 4 speleologists.

We have three main priorities in the field: 1. cave exploration and detailed cave mapping, 2. gathering new data and study karst characteristics, 3. continuing our photographic documentation.

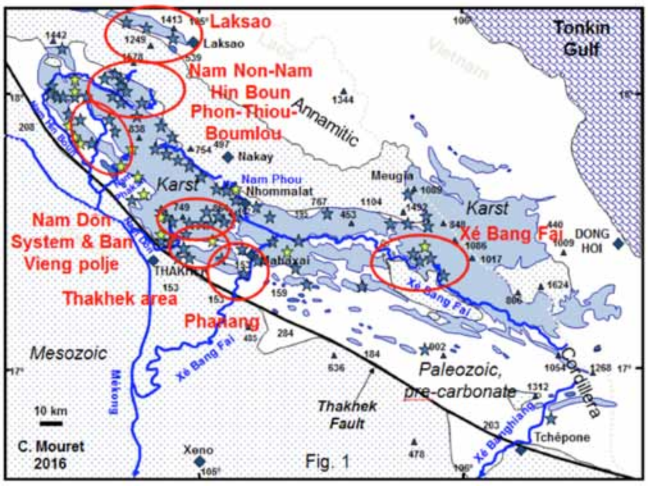

Figure 1. Main investigated areas over the 2013-2016 period. 7 areas are concerned: 1. Laksao, with Tham Mongkone, small caves and karst springs. 2. Nam Non-Nam Hin Boun area, with Tham Konglor, Tham Nam Non, Tham Kwai, Nameless Cave, Tham Kwan Ha, Tham Song Dang and smaller caves. 3. Phon Thiou-Boumlou area: caves related to Phon Thiou polje and to Boumlou polje, including Tham Nathan. 4. Nam Dôn System: Tham Houay Sai and Tham Koun Dôn, Tham Houai Sai sink and caves in the karst depression to the East of the System, including Tham Kwan Kaohung and kwan Kaohung Upper Cave. Nearby Tham Phiseua; Ban Vieng Polje: Tham Lo. Nearby Tham Lom. 5. Thakhek area: Tham En and other smaller caves, Pha Soung. 6. Phanang area: Tham Phanang and reconnaissance around.7. Xé Bang Fai area, studies in the cave and on the surrounding massif. Dark stars are the locations we studied in the past.

1. Explorations and cave mapping

We continued mapping the Nam Don System. Which we discovered in 1996, with Tham Houai Sai sinking river and Tham Kagnung. In 1997, it was Tham Houay Sai resurgence and Tham Koun Dôn (near the spring of Nam Dôn) [tham = cave; koun = spring; nam = water or river]. We continued exploring the latter caves during following years. They were linked in 1998. Kilometres of passages have been surveyed since. In 2011, we reached an upstream exit near the underground river and we gained access to a very large closed depression in the karst, called Kwan Kaohung [kwan = doline, depression]. A cave in the depression was spotted. During our 2012 and 2013 exploration campaigns, we had to face unfavourable hydrological conditions in the cave. Some passages were under water, especially those leading to Kwan Kaohung. This depression is included in a much larger one. In 2014 and 2015, hydrological conditions were good and the said upstream exit to Kwan Kaohung was open. The second author and his son went there in 2014, while the first author was busy elsewhere in the karst, and they went again in 2015, with Jacques Rolin.

In Kwan Kaohung, beyond a relatively short through cave (less than 200 m of development), a larger cave was explored in 2014: Tham Kwan Kaohung. It is a branching cave, with a total surveyed length of 2.2 km. From the entrance, a less than 400 m long, dry, passage leads to a section of the underground river encountered in Tham Koun Don- Houay Sai. The river (Fig 15) was surveyed over 1100 m, between two sumps. The

Figure 2. A fossil passage in the maze of Tham Koun Don-Houay Sai. (JFV)

Figure 3. Mapping Tham Phanang (CM). The cave is dark, due to abundant organic matter.

explorers have observed very high stalagmites with their basal part submerged by the river (Fig 9). A 750 m long second dry passage starts near the junction point of the entrance passage and the river; it leads outside.

From its exit, prospection in the main, gigantic, depression led to the discovery of a dry cave, Kwan Kaohung Upper Cave, which shows a 1.5 km long development. This cave crosses the pathway of Tham Kaohung, but at a higher elevation. A junction between the two caves cannot be excluded. Overall and by simplification, the first part of the cave goes up along dip, then it crosses downward a strata set. The second part of the cave also goes up along dip, the angle value of the latter becoming steeper towards the outlet in another closed depression. A 40 m high artificial climb was successfully conducted in 2016 in the cave, which gave access to short and narrow upper passages.

We continued our explorations in Tham Phiseua, Tham Nam Non, Tham Song Dang and Tham Kwan Ha, Tham Lo, where interesting results were obtained. In 2014, we surveyed a cave located to the South of Ban Na, Tham Dan Makhia, which shows a gigantic lake which has no aerial continuation. In 2016, we also mapped two through caves in the Pha Soung massif located to the West of Nam Don (River), in order to gather more information on karst setting. We checked maps of some caves discovered by us, e.g. Tham Lom.

We went to the polje of Ban Boumlou, in order to observe major caves, including Tham Nathan, and to the polje of Phon Thiou (or Nam Pha Thène).

Figure 4. One of the upper entrances to Tham Phiseua.

Figure 5. Flowstone of soft calcite (mixed up with moonmilk) in Nameless Cave.

Figure 6. The sinking river at the upper opening of Tham Mongkone.

In 2016, we also spent time on the Xé Bang Fai Massif where we checked and mapped a number of karst features (see also our paper on the formation of the upstream part of Tham Xé Bang Fai (Mouret, 2015).

We went in 2014 and 2016 to the karst of Laksao in Borikhamsai Province, a satellite karst of Khammouane (Fig. 1). In 2016, we completed our mapping of Tham Mongkone, a more than 1 km long river cave which flows broadly parallel to the edge of the massif. This through cave shows impressive logs carried by water during floods, up to a higher elevation than stalagmites resting on gigantic boulders.

2. Karst studies

We spent significant time in collecting more observations on the karst, especially on karst morphology, on hydrological behaviour and on speleothems. Emphasis was placed on understanding the formation of hollow stalagmites, which were discovered in 2002 by the first author (Mouret, 2005). This proved to be a long-lasting observation in many caves. The results are given in another paper in the present congress proceedings (Mouret, 2017). Many measurements have been made in order to be associated with the interpretation of such speleothems.

In 2016, we discovered that Koun Nam Don, which was supposed to give birth to the Nam Dôn (River), is not a full resurgence, but only an outflow during rainy season. It is mainly a window on the aquifer (Mouret, 2016). Therefore, phreatic passages must exist underneath morphological flats which lie downstream the cliff hosting Koun Nam Don.

Figure 7.   A flood front just arrives at the dry Tham Nam Non resurgence. On the view, we observe how it behaves and measure the timing of the event. Note the large vertical ray of water dripping near the cave entrance. (JFV).

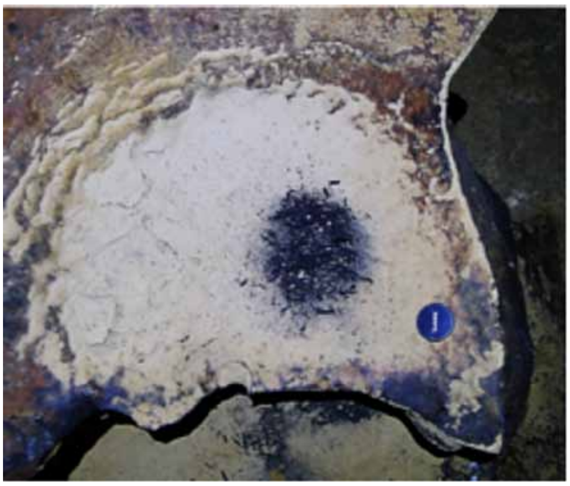

Figure 8.   Small pieces of charcoal from the cleaning of a torch. (CM).

3. Archeological and art discoveries

During our prospections, in 2013 and 2014, we discovered several caves with ancient Buddha images (Mouret *et al*, 2014). Together with other caves with statues we had studied in the past, they help understanding statues hiding by ancient local people. All these caves are usually short and have a complex shape. Precious images (in the religious sense) are placed on high ledges above the ground, which hides them well. Statues can neither be seen from outside the cave nor often from the cave floor.

Caves may show outside statues of a different style and monk's attributes (bowl…), but this is probably a relatively recent practice. In 2013, we discovered, high on a cave ledge, a group of around 62 tightly packed ancient statues (Fig 10). We did not touch any of them. Among the 62, eight are uncommon, as they represent two Buddha images placed back to back and carved in the same piece of wood (Fig 11).

In 2014, we had the chance to see more of double Buddha images, in another cave of the same area. We also found in Tham Koun Don an unbroken old pottery (Fig 12), the age of which is unknown.

Wall drawings were encountered in several caves, adding to the many discoveries made in the past (Fig 13).

Figure 9.   Gigantic stalagmite in Tham Kwan Kaohung. Arrow to canoe. (JFV)

Figure 10.

Figure 11.

Figure 12. Ancient pottery discovered in Tham Koun Don. The height is of 27 cm. (JFV)

Figure 14. Villagers write indications on the way to follow, a practice in Laos. (JFV).

Figure 13. Drawing on the wall of a small cave which was used as a hideout during Vietnam War. A man seated on an elephant drives the animal which seems to pull a log. (JFV)

Figure 15. The river in Tham Kwan Kaohung. Canoe for scale (arrow). (JFV).

4. Relations with local people

As often during our explorations campaigns, we took villagers with us to show them places of interest, for instance places where to fish or where to collect honey. In 2015, according to their wishes, two villagers (and Somsack Sodachanh, our logistic organiser) were taken to Kwan Kaohung, the remote closed depression that they had never seen before, due to the extremely difficult access at the surface and because of the need to cross through kilometres long, mazy, Tham Koun Don-Houay Sai.

Acknowledgements

The team was comprised of the two authors, together with Jacques Rolin and Jean-Félix Vacquié. We were helped in Laos by Mrs Poth Soumpholpakdy, and her husband Mr Somsack Sodachanh and by other guides.

We also address our warm thanks to the authorities who helped us as much as they could.

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Contribution to cave tourism promotion in Laos

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Tham En (Tham Nong Aen).
Photo 1: Non submersible canoes for the way upstream.
Photo 2: Western bank of the river, upper ledges and concrete stairs.
Photo 3: Picture board at cave entrance, including our map, photos in the cave and (besides) photos of Princess's Sirinthorn visit in 1993.

Modern cave exploration in Laos was started by the author as early as 1991 and it has been on-going ever since. From almost the beginning (at the end of 1992), it was agreed that, should we obtain necessary authorizations for cave exploration, then we would help the country developing wisely its tourist resources.

As we progressively managed exploring and mapping major caves in Khammouane Province, we started providing information to our Laotian counterparts on caves suitable for development. A few caves only were short-listed. Many were simply too short, or without sufficient educational and aesthetic value. Some others were fragile or were bearing sensitive ecosystems.

We first promoted a through cave named Tham En, which we mapped in 1992. It is now known as Tham Nong Aen and widely visited. This cave is conveniently located less than 15 km from the provincial capital and close to the border with Thailand, which represented at the time a good market. Now Laotians themselves currently visit the cave, as economic booming has brought up more ease in their everyday life. The cave offers beautiful landscapes of speleothems and a 1 km long navigation in non-submersible boats. Beyond that, a gigantic upstream cave entrance is among the largest in the world. Our cave map and our advices greatly helped taking the decision of promoting the cave development. Significant work in the cave was made by Laotians to achieve a good quality development.

The underground Nam Hin Boun, a through river, was mapped by us as early as 1994. The detailed map was offered to Laotians, who soon started promoting the place. It is now a world-class show cave.

Tham Pa Fa, discovered in 2004 by a villager, was also the matter of significant contributions from us, upon the request of Laotian authorities, as we asked to give recommendations on the development and protection of this major Buddha cave, now a landmark in the country.

When the author first came to Laos in 1991, the country was still subject to scattered, though significant, guerrilla activity. In Khammouane Province, there were only narrow dirt roads. Thick forest was present almost everywhere and bushes were quite developed as well. The provincial capital, Thakhek, was a somewhat sleepy place along the dirt track from Vientiane to southern cities of Savannhaket and Paksé. Despite although rare, hotels were present, tourism was nil and rare travellers were mainly national citizens or people from nearby Thailand, who were mainly acquainted with tin ore export or forestry. Nevertheless, although the roads were not so secure, some people dared sometimes to move out of Thakhek for refreshing trips to nearby breathtaking karst scenery.

After peace and order conditions in the country were stabilized development gradually appeared. New buildings were built here and there; roads were progressively improved and surfaced with tarmac. Tourism developed accordingly, slowly at the beginning, then more drastically throughout the years, until today's impressive boom. In Khammouane, caves are a real matter of interest for locals.

After his three-week reconnaissance in 1991, the author managed to organize the first cave exploration campaign in August 1992. Preparation proved to be a challenging task and required a search in Bangkok for additional contacts in Vientiane, which was eventually successful after several tries. Indeed, guerrillas were still active in some places along the Mekong River, but it decreased not long before our first exploration campaign in Khammouane in 1992. We were only two, the author and Jean-François Vacquié, plus our guide from Vientiane. We took the necessary risks to achieve our goal (Mouret, 2001).

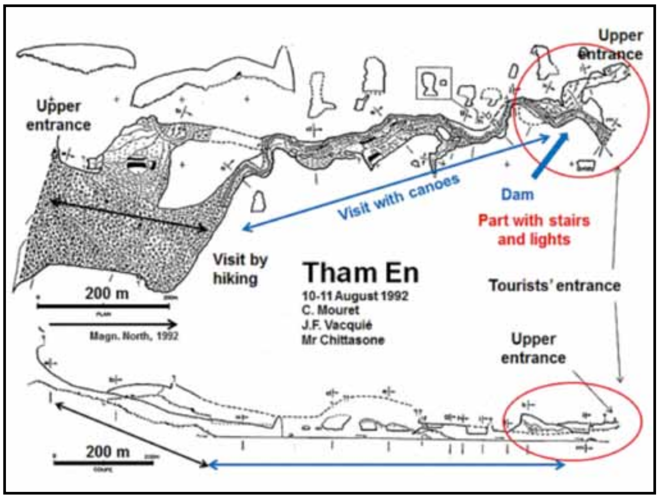

Figure 1. Map with tourist parts (Mouret, Vacquié, 1993).

1. Tham En, the first cave that we mapped in Khammouane, in 1992, was subsequently developed for tourism

After discussions with the vice-governor of Khammouane Province, we were able to go and explore a cave named Tham En (Cave of Swallows). We discovered that some local people used to pass through this cave to reach the other side of the mountain. Our local body guard was heavily laden with weaponry: a machine-gun, a gun, a revolver and a long knife hidden in his boot. The cave proved to be very interesting, being a through cave with a river and large pools, some of them deep. The usual entrance is at the water outlet, near a fossil opening. The upstream upper opening offers good scenery, being one of the largest in the world. Near the outlet, a succession of ledges shows nice speleothems.

Our work was quickly published (Mouret and Vacquié, 1992) and was given to the Khammouane authorities via our contact in Vientiane, Mr Claude Vincent. He was the co-owner and the manager of Sodétour travel agency and a businessman also experienced in running tours in communist Laos and he was promoting beautiful places in the countryside.

At the end of 1992 and several times in 1993, in Vientiane, the author told Mr Vincent that we could help him in developing cave tourism. We would tell him what caves could be developed and what ones could not, for physical or environmental reasons. This would be possible only if he could help us exploring caves. For this reason he managed, in 1994, for us to get in touch with his associate, Mr Vannivong Soumpholphakdy, who knew Khammouane Province extremely well. Mr Vannivong gradually became our main contact in Laos. With him, we went to Tham Konglor.

In the meantime, the president of the R.D. P. Lao passed away on the 21rst of November 1992 and general activity in the country became somewhat frozen. Speleological expeditions were not possible anymore. However, the author could still travel in the country, thanks to other contacts related to his professional work. He was regularly meeting Mr Vincent, and talked again of the tourism potential of Tham En. Mr Vincent raised the issue with the authorities, who probably had some projects for the cave. This supplemented our discussions with Khammouane Vice-Governor in 1992. We gave advice.

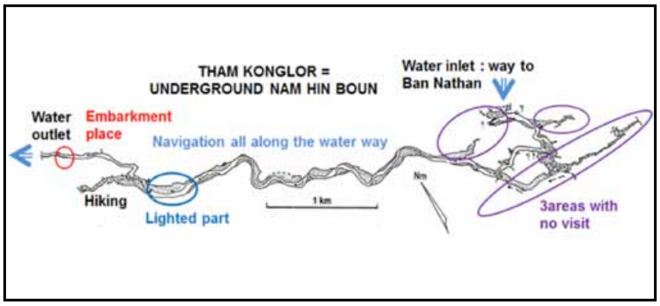

Figure 2. Tham Konglor (underground Nam Hin Boun). Map showing tourist parts.

Then, an unexpected fairy tale happened. In March 1993, Princess Maha Chakri Sirinthorn of Thailand, also named princess Phra Thep, King Rama IX's daughter, went to Thakhek and wished to visit places around, as she liked to do. She was led to Tham En and our map was shown to Her, as Mr Vannivong told us in 1994. She was enthusiastic about the cave and further development. She also recommended that we should pursue our exploration.

Tham En was successfully developed in the following years by the local authorities (Mouret, 1997). A garden park was installed in front of the cave. A wide part of the internal installations consist of stairs and concrete paths, together with coloured lights. The river was dammed in order to create a long lake which allows boat navigation up to near the upstream opening. This cave is now a major tourist place in Khammouane, with thousands and thousands of visitors per year.

2. Tham Konglor, a world-class cave

In 1993, the author presented a project to Mr Claude Vincent, which consisted of exploring the underground Nam Hin Boun. It was an approach to try reaching the even more remote underground Xé Bang Fai on the following year. At the time, underground Nam Hin Boun area was still remote. A two-day journey with a 4 wheel-drive car was necessary along the bumpy and dusty earth roads with muddy sections, and 30 km of jumping over rice paddy edge-walls on the last section. Mr Vincent had never heard of the cave, but he had an idea on how to obtain the information. On his part, the author knew of it because of his 1991 work on the geology of Khammouane and also thanks to Paul Macey's paper published in 1908, which includes a sketchy cave map, and to other papers related to 19th Century explorers.

As mentioned above, cave exploration became possible again, thanks to the interest of Princess Sirinthorn in Lao caves. In April 1994, the author was suddenly recontacted by Mr Vincent, who informed him that we were given an official ten-day authorization. We were very receptive to this and about two weeks later, we were in Thakhek (the author, J.-F. Vacquié and B. Collignon), where we met with Mr Vannivong for the first time (Mouret *et al*, 2012).

The most upstream village in the middle Nam Hin Boun valley, Ban Konglor, was a very traditional village with a 10 minute-walk to the cave outlet along a narrow trail. Local people were going into the cave almost every day, either for fishing or for crossing it with robust wooden canoes manoeuvred by hand, up to the other side of the mountain, a practice

   

Tham Konglor.
Photo 4: One of the many long-tail boats used for tourists.
Photo 5: Nice speleothems in the lighted section.
Photo 6: Navigating (arrow) in the large river cave, near water inlet.
Photo 7: Boards in the park near the cave, with our map displayed.

which lasted since time immemorial. We explored it with the same means. A local priest made prayers to the spirits for our work to bring good things and wealth on the village. A few old villagers came with us. One of them had experienced a major flood in the cave, during which several of his companions lost their life. Mr Vannivong's brother, Mr Naodarinh, also came with us most of the time and we taught him how to move in caves.

The cave can be broadly divided into three parts (Fig. 2): a downstream part where deep water fully occupies the single passage, a long central part where the cave is much wider and where the river is winding between large banks, some of them being rich in speleothems, and an upstream part where the water fills the whole width of the single passage. Fossil to sub-fossil branches are connected at each end of the central part (a former sink passage and a former outlet passage); the downstream branch offers great scenery of tall stalagmites and a bank which is nicely packed with speleothems.

We recommended the cave for tourism and this was implemented by Mr Vannivong. Our friend had long been the military officer responsible for the Khammouane region in general and this area in particular, during the Vietnam War. He loved the place and inhabitants liked him very much (Mouret and Vacquié, 2012).

Mr Vannivong decided upon our advice and decided that he would develop the area for tourism. He was encouraged in this way by his brother, Mr Naodarinh, his associates of Sodétour and his family. Mr Vannivong selected a beautiful and convenient place near Ban Phôn Gneng, on the bank of the Nam Hin Boun, some 10 km away from Tham Konglor. He obtained it thanks to his proposal to build a brand new school for the village. Beautiful bungalows in the nice traditional Laotian style were built as well, together with a charming restaurant. This became Sala Hin Boun, a romantic place to stay which opened in 1999. In the restaurant, one can see the gigantic cave map drawn after our first exploration in 1994.

Mr Vannivong also pushed the villagers of Ban Konglor to establish an association in order to organize themselves to guide tourists through the cave, linking the two entrances in a single trip. A type of rest station was installed upstream of the sinking point of the river, near Ban Nathan, where food and other commodities were made available.

Crossing the cave on canoes in relative darkness is very attractive for tourists and quickly the cave became world-famous. International guide-books soon mentioned Tham Konglor, the name newly assigned to the underground Nam Hin Boun. Actually, this is the name of the mountain above the cave (it means "the place where a gong was cast"). The cave is cited in the Smithsonian Institution book "*Earth*" (Luhr, 2003, p. 259), as one of the outstanding caves in the world. The 12.4 km cave length mentioned was set by us.

When the author first came in the area in 1991, Route 8 was under construction and Ban Nahin, today a large administrative and commercial place, was still an extremely isolated place, with a very few houses scattered in the middle of nowhere. The new road and the building of Nam Theun I dam and associated power plant accelerated local development. The electricity company built a water escape channel towards Nam Hin Boun (River) and a road through the forest in the same direction. It joined the older track to Ban Konglor and was quickly improved. Villages are being progressively relocated along this new road, especially villages from along the river. Mr Vannivong also acted with a lot with authorities to promote the construction of a sealed road, up to almost the cave entrance. This greatly boosted the development of the Nam Hin Boun valley. Many guesthouses and shops appeared. Wealth arrived in this previously poor land. There is now a service of regular buses between Vientiane and Ban Konglor. Local people do not have to leave the valley anymore.

The cave is included in the Phu Hin Phun National Biodiversity Conservation Area. This matter was largely addressed during a UNESCO-IUCN meeting in Mulu, Sarawak, in 2001, to which the author was invited.

In the 2000's, further development of Tham Konglor was made with the assistance of a French group of benevolent electricians and a sponsoring from Rhône-Alpes Region of France. Electricity was installed in the cave from the outlet up to the enlargement with speleothems in the downstream part of the larger central section. The dry banks and many speleothems are coloured by spots of light. Subsequently, light reinforcement was made in the embarking area near the outlet. A number of wooden boards were placed outside the cave: they explain the history of explorations and the cave setting.

Tickets are sold to tourists at a counter and cave maps (free copies of one of our published maps) are given at the same

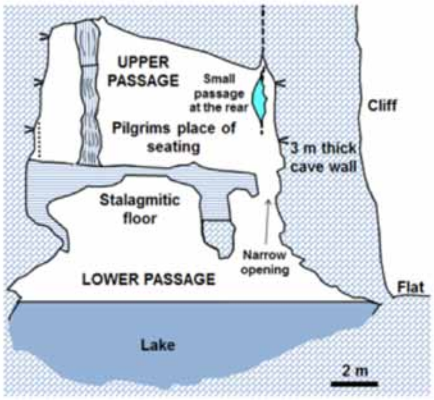

Figure 3. Tham Pa Fa. One of the author's cross-sections of the cave. It shows how thin the floor of upper passage may be, where Buddhists seat to pray in front of Buddha images.

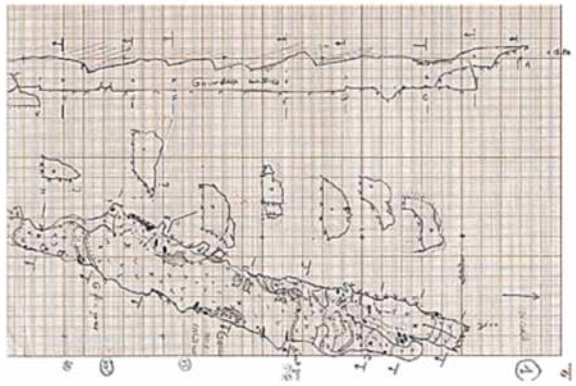

Figure 4. An example of the author's map and sections, which were scanned for final drawing.

time. Tickets correspond to round trips, but since recently, not all boats fulfil this requirement. More than 50 boats now operate in the cave. All are powered by long-tail engines. Electric torches have replaced the old torches made of resin, which smelt good and added romanticism to the trip in the cave.

3. Tham Nong Pa Fa, the treasured Buddha cave

Tham (Nong) Pa Fa was discovered incidentally by a villager in April 2004 and proved to contain 229 Buddha images, pottery and old writings (Burrows, 2005). After a while, Laotian authorities instituted a project to open the cave to tourists, firstly to Buddhist pilgrims. However, because of their lack of experience, they asked for help from speleologists who already had done exploration in Khammouane. Only the author responded positively (Mouret, 2005) and was prepared to pay for his own plane ticket. In addition, his very long experience of geology and caves in Asia, including the observation of more than 200 Buddha caves in Southeast Asia and a good knowledge of cave mechanical stability was of great value. Charles Ghommidh, a biologist, was asked by the author if he could come for to help in the cave. Before going, we could not obtain any reliable data on the cave length: we thought perhaps more than 20 m.

Prior to going, the author had to provide Laotian authorities with recommendations on cave conservation. In Laos, the cave was heavily protected by villagers and we were allowed only three days in the cave. The author drew a very detailed map of the 140 m long cave, while his colleague assisted him in the measurements. The clean drawing was made by the author on a millimetre-gridded paper (Fig. 4) at the hotel, then it was scanned and drawn on the computer by his colleague. Geological investigations by the author, on cave stability, proved very useful and showed evidence of both wall and floor fragility. This allowed us to stop some work had started without our agreement and which might have led to the collapse of a part of the cave wall in front of the statues. Indeed, the proximal part of the cave, beside the statues, is located in a prominent part of the cliff and it stands as a balcony high above a lake. Also, the floor is mainly a thin sequence of subhorizontal flowstone layers which may be interbedded with some shale and/or silt, the thickness of which is much less than 1 m in some parts. The outer cave wall is also less than 1 m thick in some places and sets of fractures are present around the passage.

The author recommended that necessary outer stairs should not be anchored to the cliff and that natural cave floor should be preferably covered by a pillar-supported wooden and metal platform. Pillars would be placed on the outer side only, through two natural holes in the cave floor, along the thin wall between cave and cliff (Mouret, Ghommidh, 2004).

A presentation to the Governor of Khammouane was then required by authorities, which we had not been told of in advance. C. Ghommidh prepared the PowerPoint file using comments and scanned drawings from the author. The latter made the presentation.

Tham Pa Fa, today Tham Nong Pa Fa, has become a major tourist spot in Khammouane and even in Laos. Large roads and wide parking places have been constructed especially for. Many shops have opened and hundreds of persons go there every day for a simple visit or for worshipping Buddha images.

4. Other caves

Our work, i.e. exploration and/ or cave mapping with maps and advice, was given to the Laotians to promote a variety of smaller caves, such as Tham Pha Noi (Mouret *et al*, 2011). Our work on the longer caves was also useful. For instance, to help the local villagers Tham Nam Non, we provided the Laotians with a detailed cave map and our publications. Indeed, they ask tourists to pay a local tax giving the right to visit the cave. These tourists usually go up to the upstream sump along a 3.5 km long walk from the cave entrance and a number of them venture in side passages. This is a kind of wild tourism.

In Tham Xé Bang Fai, that we re-explored in 1995, more completely 90 years after Paul Macey (Macey, 1908; Mouret *et al*, 2010, we made a large size, detailed map, drawn by B. Collignon and by the author, which we gave to Laotian authorities in 1996. After that, the area was closed to foreigners during nearly ten years, for reasons internal to the country.

Every year we asked for an authorization through Mr Vannivong, with no success. Finally, the author obtained in 2006 an authorization for 2007, but at the last minute a health problem did not allow him to reach the Xé Bang Fai. J.F. Vacquié surveyed new passages. In 2008 and 2009, the author and J.F. Vacquié undertook further mapping and checked with a laser-meter the widths and heights that were estimated in 1995, in order to produce a more precise map. Other surveys from members of our team have not been made available to us. Our new map was published in 2010 (Mouret *et al*, 2010). In the meantime, an American team produced a map, published a little time before ours. It followed the opening in 2005 of Xé Bang Fai cave crossing with kayaks, organized by a foreign company involved in tourism. These logistics were used by the American team.

In 2008 and especially in 2009, Mr Vannivong discussed with the author his views on how to develop the Xé Bang Fai Cave for tourism and that he had plans to develop something comparable to what he had on the Nam Hin Boun.

Terry Bolger, a consultant living in Laos, asked the author for the right to use (free of charge) our new map of the Xé Bang Fai Cave for its development and we agreed. The author also warned him about sudden floods difficult to forecast, because they originate from rains related to Vietnamese climate. The cave was organised with an embarking area at the resurgence, where wooden canoes are parked. Side high-level passages near the place were equipped with concrete stairs and hand rails made installed to guide the visitor. Visits on boats can be made with no guide.

Acknowledgements

M. Jean-François Vacquié kindly reviewed this paper.

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Use of cave environments by vertebrate animals: examples from Jenolan Caves, Australia

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Abstract

Use of twilight areas and the dark zones of caves by vertebrate species has long been observed. Many prehistoric vertebrates are known primarily from remains in caves. However, there are few descriptions of the use of cave environments by Australian vertebrates. Here I summarise what is known of vertebrate use of Australian caves and present the results of personal observations made at Jenolan Caves, New South Wales over a period of eight years. The 'twilight zones' fringing the dark zones of caves provide denning and roosting sites for a surprising number of vertebrates, primarily mammals and birds. These areas include such well-visited areas as the Grand Arch, Jenolan Caves, which hosts thousands of visitors per year. The species most often encountered by visitors is the endangered Brush-tailed Rock-wallaby (*Petrogale penicillata*), which utilises areas high in the Grand Arch (along with several other more remote sites) for denning and raising its young. Predators denning in twilight zones include the Spotted-tailed Quoll (*Dasyurus maculatus*), the largest marsupial predator on the Australian mainland and a potential threat to young rock-wallabies. Wombats (*Vombatus ursinus*) may den in rock shelters and may even incorporate limestone features in burrow construction. Twilight zone bats are regularly seen, and native rodents (e.g., Bush Rat *Rattus fuscipes*) are common. Bird species nesting in twilight zones include the Rock-warbler *Origma solitaria*, restricted to rocky areas of New South Wales, which constructs a hanging nest on cave roofs and under ledges, and the Welcome Swallow (*Hirundo neoxena*) which uses holes and ledges as roosts. Predatory owls such as the Sooty Owl (*Tyto tenebricosa*) hunt small mammals around the Reserve, feeding on them (and depositing owl pellets) back at their roosts in the twilight zones. Dark-zone inhabitants are fewer in number, and again include bats, rock-wallabies (which may travel deep into caves) and platypuses, which construct burrows well into underground streams. Reasons for the use of caves by platypuses include protection from predators along with possible predation on cave-adapted aquatic invertebrates. Navigation through the dark zone is made possible by the unique electrosensory system of platypuses. Such extensive use of cave environments by vertebrate animals – some of which are threatened or even endangered – suggests the need for a thorough understanding of the biology of these species, along with protection of the environments they use.

Keywords: vertebrate; Jenolan Caves; vertebrates; owls; rock-wallabies; bats; platypuses

1. Introduction

Caves have long been recognised as habitats or refuges for many vertebrate animals, which may use the twilight zones or the dark interiors of caves for shelter, dens, hunting or feeding. Many prehistoric animals utilised caves, including the Cave Bear (*Ursus spelaeus*) and European Cave Lion (*Panthera leo spelaea*), with much evidence of interaction between early man and cave-dwelling animals. Despite the absence or near-absence of light, caves provide a protected, stable environment for species able to navigate these subterranean areas. Shelters and dens can be defended and secured, and predators are scarce. All vertebrate groups – fishes, amphibians, reptiles, birds and mammals – have trogloxene or troglophilic species. Vertebrate troglobites (species restricted to caves with special morphological adaptations for cave life) are rare, and include only fishes and amphibians; no cave-adapted reptiles, birds or mammals are known (Romero 2009).

Many Australian vertebrates use caves, including several mammals (e.g., rock-wallabies, quolls and echidnas), birds (e.g., swiftlets, swallows, rock-warblers and owls) and more rarely reptiles, amphibians and fishes (e.g., a gecko, a blind cave eel and blind gudgeons). I discuss the literature on vertebrate use of caves, using examples from Australia and Jenolan Caves, and summarise results of a vertebrate faunal survey conducted by the Office of Environment and Heritage at Jenolan in 2011–2012 (OEH 2012). I include personal observations made at Jenolan over the past 8 years, in my roles as a Guide and resident palaeontologist/naturalist.

2. Results

2.1. Fishes

There are just three rare, stygobitic Australian vertebrates, all of which are from Cape Range in Western Australia. Cape Range is an arid region with at least 39 cave-adapted invertebrate species in 29 genera, many of which are relict wet forest species that now have no above-ground representatives (Finlayson and Hamilton-Smith 2003). The blind cave eel Ophisternon candidum is long, slender and finless (Bray and Thompson 2017). There are two blind gudgeons, *Milyeringa veritas* and *M. brooksi*, which have their closest relatives in Madagascar; they are therefore relict Gondwanan species, the only cave vertebrates known to have such a distribution (Chakrabarty *et al.* 2012). Cave adaptations in these Cape Range fishes include depigmentation, loss of eyes and enhanced sensory capabilities (Finlayson and Hamilton-Smith 2003; Chakrabarty 2010; Chakrabarty *et al.* 2012). To date, no other Australian caves are known to have stygobitic or troglomorphic vertebrates, although non-troglomorphic eels regularly use Australian and New Zealand caves, including Jenolan Caves.

a.

b.

Figure 1. a) Sooty Owl at Yarrangobilly Caves, NSW.
b) rock-warbler in nest at the Balcony, Lucas Cave, Jenolan.
Photos: Anne Musser.

2.2. Amphibians

There are no known Australian cave-adapted frogs (caecilians and salamanders do not occur in Australia). However, one species of tree frog inhabits sandstone caves, the rare *Litoria cavernicola* from the Kimberley region of Western Australia, (e.g., Cogger 2000).

2.3. Reptiles

Few Australian reptiles except geckos utilise caves. The Desert Cave Gecko (*Heteronotia spelea*) lives in caves, crevices and mines in the Pilbara and Tanamai Desert regions of Western Australia (Cogger 2000). The Southern Leaf-tailed Gecko (*Phyllurus platurus*) from New South Wales is found at Jenolan in twilight areas such as The Ballroom, Nettle Cave and the Devils Coach House, its mottled pattern providing ideal camouflage on limestone rocks. The Red-bellied Black Snake (*Pseudechis porphyriacus*) and Diamond Python (*Morelia spilota spilota*) may also enter caves at Jenolan, either escaping heat or perhaps seeking food within the caves (OEH 2012).

2.4. Birds

No bird species in New South Wales are obligate cave-dwellers. However, the Australian swiftlet *Aerodramus terraereginae*, known only from north-eastern Australia, roosts in caves and uses echolocation to navigate the darkness (e.g., Coles *et al.* 1987). Two rare Jenolan bird species depend on twilight caves for roosts and nesting sites. The Sooty Owl (*Tyto tenebricosa*) (Fig. 1a) uses twilight caves as roosts and nesting sites, and may feed on the small mammals found here. Listed as 'Vulnerable' in New South Wales, it is a threatened species with high priority for management within the Reserve (OEH 2012). Sooty Owls are heard calling regularly in the Devils Coach House, as well as from areas further from the twilight caves. The Rock-warbler (*Origma solitaria*) (Figs. 1b), found only in New South Wales, constructs a hanging nest attached to rock overhangs and roofs. According to some observers, its numbers may be declining at Jenolan (I. Eddison, cited in OEH 2012).

2.5. Mammals

Mammal species that use caves generally have enhanced sensory abilities that enable them to navigate the dark or near-dark zones. At Jenolan, bats, rodents, marsupials and monotremes use caves as habitat. Most of the accounts below are taken from Strahan (1995) unless noted.

2.6. Bats

29 species of Australian bats use caves as daytime or night feeding roosts, hibernacula and maternity sites (Hall and Richards 2010). As Australia's largest showcave system Jenolan is critical habitat, with bat numbers estimated in the tens of thousands (OEH 2012). There are 16 bat species at Jenolan, several of which roost in twilight zones, including the Eastern False Pipistrelle, Gould's Long-eared Bat, the Gould's and Chocolate Wattled Bats and the Lesser Long-eared Bat (OEH 2012). Three bat species are cave-dependent. The Vulnerable Eastern Bentwing-bat (*Miniopterus orianae oceanensis*) (Fig. 2a) roosts in caves, mines and other manmade structures. Colonies may be quite large and bats travel long distances seasonally, hibernating during winter in cold roosts when insects are scarce. It is the only hibernating bat with delayed implantation, and nursery caves are of great conservation interest. This is the most numerous cave bat at Jenolan (colonies up to 1000 or greater) and occurs in both show caves and wild caves (OEH 2012).

The Eastern Horseshoe-bat *Rhinolophus megaphyllus* (Fig. 2b) roosts in caves, mines and other manmade structures, using twilight zones as well as dark zones. It generally lives in small colonies, and maternity colonies are found only in natural caves. This bat will enter torpor in southern Australia and cave sites are important hibernacula. At Jenolan, the Eastern Horseshoe-bat is found in several show caves and numerous undeveloped caves.

a.  b.  c. 

Figure 2. a) Narawan Williams (OEH) with Eastern Bentwing-bats, Jenolan.
b) Eastern Horseshoe-bat, Ribbon Cave, Jenolan.
c) Long-eared Pied Bat, Lucas Cave, Jenolan. Photos: Anne Musser.

The rare, poorly known Large-eared Pied Bat (*Chalinolobus dwyeri*) from south-east Queensland and eastern New South Wales (Fig. 2c), listed as Vulnerable, is usually found in twilight zones of caves and mines and occasionally the abandoned nests of fairy martins. At Jenolan, it has been found in both the Lucas and Chifley/Imperial Caves, close to the outside but in complete darkness when lights are off.

2.7. Rodents

Rodents are the only placental Australian mammals that regularly den in twilight zones. Although the prehistoric record at Jenolan includes a range of native rodent species, almost all are either extinct or gone from the Jenolan area (eg, OEH 2012). Tracks of the Bush Rat (*Rattus fuscipes*), the only native rodent regularly encountered at Jenolan, are often seen in twilight areas of the Grand Arch, Nettle and Arch caves. Introduced rodents like the House Mouse (*Mus musculus*) and Black Rat (*Rattus rattus*) may also be found in twilight zones, although they are not in large numbers on the Reserve (OEH 2012).

2.8. Marsupial carnivores

Living carnivorous marsupials include Tasmanian Devils (found as sub-fossils at Jenolan), quolls and smaller species such as phascogales, antechinuses and dunnarts. The Spotted-tailed Quoll (*Dasyurus maculatus*), listed as Vulnerable, is the largest marsupial carnivore on the Australian continent and the only quoll known to regularly den in caves. Several den sites have been identified from the Grand Arch and nearby areas. Although it is a threatened species, this predator poses a threat to Jenolan's endangered rock-wallabies, especially the pouch young.

2.9. Rock-wallabies

Rock-wallabies are the only macropods that regularly use caves as dens or shelters. All species live in rocky habitats with extensive outcrops that include deep fissures and caves. All species are either vulnerable or threatened because of agricultural development, predation and other threats. They prefer sites with ledges, crevices and caves that provide shelter and multiple escape routes. The endangered Brush-tailed Rock-wallaby (*Petrogale penicillata*) (Figs. 3a, b) occurs at Jenolan. Jenolan's rock-wallabies have endured several population crashes, although they are now recovering their numbers and are often seen in public spaces such as the Grand Arch (where a small group of six wallabies is currently resident). Rock-wallaby dens can be found in areas relatively far from the surface, as seen for example in Mammoth Cave.

2.10. Possums and wombats

Although most possums are arboreal, the Common Brush-tailed Possum (*Trichosurus vulpecula*) may den in rock cavities and caves. At Jenolan, remains of Brush-tailed Possums have been found in cave areas with access to the outside, such as Bone Cave off the Chifley Cave, and have been seen high on rocks in the Grand Arch (personal observation). The Common Wombat (*Vombatus ursinus*) (Fig. 3c) digs burrows, and has been found to use natural cave features (half-tubes) in burrow construction at Jenolan. Other species have been seen to share wombat burrows (possibly concurrently), including rock-wallabies and quolls.

2.11. Monotremes

The Short-beaked Echidna (*Tachyglossus aculeatus*) cannot tolerate high temperatures, and regularly uses caves to shelter from heat (Augee *et al.* 2006). Platypuses (*Ornithorhynchus anatinus*) may build burrows in the banks of underground waterways connected to rivers or streams; their sensory system (electroreception/mechanoreception) permits navigation in the absence of light. Burrows have been found at Yarrangobilly Caves, Buchan Caves and in Tasmanian caves (Ellery Hamilton-Smith and personal observation). Although burrows are yet to be found at Jenolan, platypuses have been seen in two Jenolan waterways: Barry Richards, personal communication).

a. b. c.

Figure 3. a) Brush-tailed Rock-wallaby sheltering in crevice, Jenolan. b) Rock-wallaby feeding at base of limestone, Jenolan. c) Common Wombat in rock shelter, Jenolan. Photos: Anne Musser.

3. Summary

The twilight zones and dark zones of caves are important habitat for many vertebrate species, some of which are entirely dependent on these for their existence. The twilight zones of Australian caves like Jenolan provide critical habitat for threatened or endangered mammal species such as the Brush-tailed Rock-wallaby and Spotted-tailed Quoll. The dark zones of caves such as Jenolan are essential habitat for several bat species, including species of high conservation value such as the Eastern Bentwing-bat and Large-eared Pied Bat. Some of the behaviours of certain vertebrate species in caves have not been well-recorded, emphasizing the need for greater observation and study.

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Caver Quest – A New Paradigm in Cave Interpretation

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Abstract

Of the 50+ km of presently known passage in Fort Stanton Cave, in Lincoln County, New Mexico, USA, and jointly managed by the US Bureau of Land Management and the US Forest Service, only about 8 km is open to the public. The rest of the cave, including the remarkable Snowy River passage, is only accessible by cave researchers, and significant portions are very remote from the entrance of the cave. Because this cave is primarily on public land in the United States, there is an obligation by the managing agencies to provide interpretation of the cave to the owners, i.e., the citizens of the United States: the public. The Fort Stanton Cave Study Project has provided a mechanism for that interpretation in a ground-breaking simulation program known as Caver Quest.

Caver Quest is an avatar based simulation program that uses a gaming engine to simulate travel through the Fort Stanton Cave passage environment. The very realistic environment is based upon actual cave survey, both traditional and lidar based, as well as actual photographs. The program has evolved from a simulation of the Snowy River passage, to an educational tool and intellectual challenge involving many portions of the cave, including the historical sections as well as those that are only accessible to cave researchers. Because of the value of the program in interpreting the cave to the public, the Fort Stanton Cave Study Project provides this program free of charge via download from the organization's web site, www.fscsp.org. It is available in versions for Mac and Windows operating systems.

Both the Bureau of Land Management and the US Forest Service utilize the program in their outreach to the public about the cave. Caver Quest immerses the user in the cave by allowing the user to explore in whatever direction he or she wishes. It is about as close to actual cave exploration as one can get. It is truly a paradigm shift in the interpretation of a cave.

Keywords: Education, Simulation, Virtual Reality, Caving, Speleology, Cave Management

1. Introduction

Depiction of caves and the caving experience has been a challenge for cavers, especially when presenting to the general public. Stories, books, photographs, and maps have been the common methods in the past. Caver Quest attempts to convey the cave and the caving experience at a level of personal involvement by using an avatar in a 3-D virtual world to simulate travel through the Fort Stanton Cave passage environment. The very realistic environment is based upon actual cave survey, both traditional and lidar based, as well as actual photographs. The program has evolved from a simple depiction of the Snowy River passage, to an educational tool and intellectual challenge involving many portions of the cave, including the historical sections as well as those that are only accessible to cave researchers. Because of the value of the program in interpreting the cave to the public, the Fort Stanton Cave Study Project provides this program free of charge via download from the organization's web site, www.fscsp.org. It is available in versions for Mac and Windows operating systems.

A definition of terms and description of past methods of cave interpretation can help put this latest method in perspective.

2. Background of Cave Interpretation:

By cave interpretation, we mean the presentation of a cave to anyone who may or may not be actually participating in the process of cave exploration. We all engage in this activity when we attempt to describe a cave. The methods of description are varied and have evolved over time.

2.1. Cave Exploration:

The most basic and best method is direct experience: actually exploring a cave. This is not always possible. Many people are not comfortable with the activity, or do not have the skills or opportunity to go to a cave. As well, no one can really go to every cave in the world to experience each one directly. So we look for other ways to present or interpret caves.

2.2. Written Accounts:

For centuries, cavers have generated written descriptions, trying to chronicle their adventures in a way that allowed others to understand what they have experienced. The accounts vary from trip reports to other cavers, to newspaper and magazine articles, to books about caves and caving.

2.3. Photographs:

There is an idiom that says, "A picture is worth a thousand words!" That is often true in describing a cave. Cave photography has allowed cavers to show the caves they explore in images that convey the grandeur in ways that words cannot express. A good caving photograph entices the viewer to wonder what is in the darkness beyond the next bend, and wishing he or she could explore it.

2.4. Maps:

We like to describe the nature of a cave, but we also want to describe the measure of the cave. Where does it go? How big is it? How do the different parts of the cave "fit" together? We demonstrate the answers to these questions with maps. Over time we have developed an elaborate scheme for presenting the 3-dimensional world of the cave in a 2-dimensional representation with a complex symbology that conveys the measure of the cave.

2.5. Exhibits:

A static exhibit can bring together several of the aforementioned methods – written accounts, photographs and maps to have a more rounded presentation.

2.6. Audio-Visual Presentations:

When the visual sense is supplemented with an auditory aspect, as well as a directed sequence of images and verbal expressions, it can enhance the communication of what the cave is all about tremendously. The presenter and the audience are engaged in a way that the earlier methods don't allow.

2.7. Scientific Documentation:

While this doesn't really involve a different method than above and can incorporate any and all of the methods, the focus of scientific documentation is different, with more emphasis on the "how" and "why" of a cave.

2.8. Videography:

Movies and videos have presented caves for some time now – and video camera technology has made it even easier to add motion to the presentation of caves.

2.9. 3-Dimensional Representations:

The advent of computer technology has allowed for ways to combine data and photographs in such a way to present the cave in a 3-dimensional simulation. These technologies include photogrammetry and lidar mapping. The presentation can be a 360° view, where the user can look around specific points in the cave and see a 3-dimensional view of the surrounding room, or a "fly-through" where the user visualizes the cave in 3-dimensions, in the manner of a bat flying through the passage.

2.10. Experiential Representation:

Caver Quest takes the 3-dimensional representation and adds one more critical aspect – personal involvement. It does that through the utilization of an avatar, i.e., a representation of the user in the cave experiencing the cave in real time, and with choices of how to travel through the cave. In addition, it adds an educational component by including pop-up written or oral descriptions and explanations of things that may not be clear to the user. As well, there is a challenge component involving answering important questions about the cave before allowing the user avatar to continue the real-time travel through the cave. We can describe this as an **experiential representation**, a representation based upon experiencing the cave environment in a manner that is close to actual cave exploration.

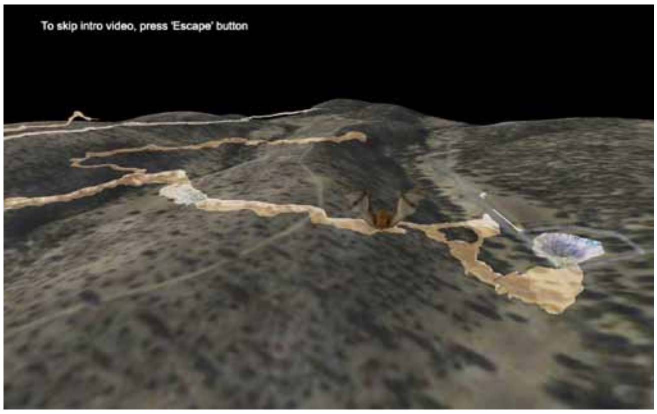

Figure 1. Video of bat flying over the cave.

Figure 2. Video of bat flying through the cave.

Caver Quest is an implementation of experiential representation at Fort Stanton Cave, Lincoln County, New Mexico, USA. It was developed by the second author, in an effort to provide the general public a way to experience the Snowy River passage of Fort Stanton Cave – an area of the cave that will likely never be accessible to the general public. It is based upon gaming engines and has evolved substantially since it was first developed in 2011.

While not the focus of this discussion, some mention of the process of making Caver Quest is appropriate. It starts with survey data – plan-view maps with cross sections and profiles that depict the location and size of the passages of the cave. Recently, the second author has been using lidar data to augment the survey data. From these data a frame, or mesh, is constructed via 3-D software, such as Blender (Blender Foundation 2017). Photos taken in the cave and referenced to locations on this frame are "painted" onto the frame. Finally, a gaming engine (in the case of Caver Quest, the Unity engine (Unity Technologies 2017) is used to place an avatar in the environment and produce the real-time experiential representation. While this all sounds straightforward, it is a very involved process and takes months of computer work to produce the results we see (or experience).

3. The Experience of *Caver Quest*

Caver Quest begins with an introduction consisting of an animation of a bat flying over the entrance area of the cave and then dropping into the entrance (Figures 1 and 2), flying through a section of the cave near the entrance. From there, the user is taken to a screen with some basic directions and

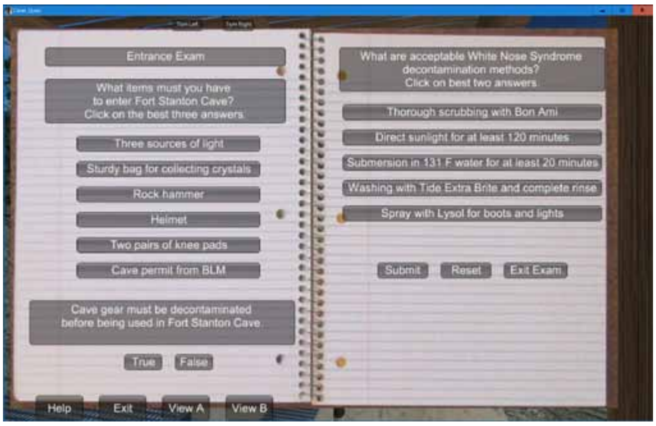

Figure 3. Entrance exam.

Figure 4. Entrance sinkhole.

Figure 5. Menu for transfer to different parts of the cave.

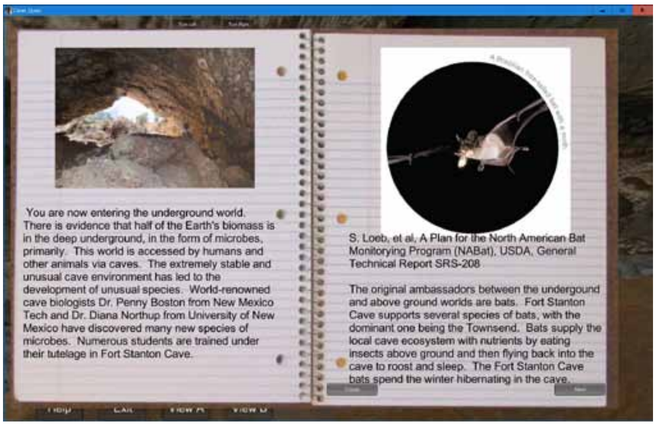

Figure 6. Educational pop-up note.

some options to choose from, including a choice of avatar. Another option allows the user to make a fresh start, reload a session or enter into an unlimited access version (with a password).

Once the options are chosen, the user is given a short introduction then taken to a 3-D representation of the surface around the cave entrance and must answer a fairly simple quiz in order to gain entrance to the cave (Figures 3 and 4). The user may switch between observing the avatar in the cave environment, or "1st person mode" where the user is observing the cave as if she were the avatar in the cave environment. (We will use the feminine pronoun for this discussion; an avatar of either gender is available.) The user can use the arrow keys on the computer or the computer mouse to direct the avatar where she wants it to go. She must direct it to the gate in the fence around the cave, open the gate, and head down the trail. If she forgets to close the gate, the program will announce that to her, and she will be forced to return to the gate and close it before continuing into the cave. This is part of the educational experience.

As the user directs the avatar down the trail into the cave, she will come across a gold ball on a pedestal with an invitation to "Click to Teleport" (Figure 5). This is a mechanism to allow the user to quickly move to different parts of the cave. These devices are located in many places throughout the Caver Quest representation, and save a great deal of time to get to remote parts of the cave, once the user is familiar with the environment and correctly dealt with the challenges that are presented to her. (Regrettably, such devices are not actually in the cave.) As well, she will see small yellow buttons on the wall that, if clicked on, will display a pop-up notebook that presents information about some aspect of the cave or the particular location that the avatar is at (Figure 6). At different points in the cave, there are buttons that can be clicked on that allow the user to turn "the lights" on or off. This allows the user to experience the cave either lit up much as a commercial cave would be, or with only minimal helmet mounted lights, as a wild cave would be experienced.

If the user clicks on the teleportation device, she may transport the avatar to selected locations in the cave (dependent upon whether she has passed different challenges that will be/have been presented to her). If not, the user may continue to progress down the passage at her own speed. There is a mechanism to cause the avatar to run, if desired. The user can also cause the avatar to go in different directions, off the trail, to investigate the nature of side passages or walls at a distance from the main route. The user may change the viewpoint from 3rd person to 1st person and make a close examination of the wall or anything else. In 1st person mode, it is possible to look down at the floor or up at the ceiling of the passage.

One of the things that the avatar carries is a small belt pack. Clicking on that belt pack will bring up a map of the cave, with a blinking dot on the map showing where the avatar is located (Figures 7 and 8). There is also a button to click to turn "the lights" on or off, or make a quick jump to the entrance if desired.

At various points in the cave, the ceiling height is not sufficient to allow a person to walk upright. At present, the Caver

Figure 7. View of cave passage.

Figure 8. Pop-up map with red circle for location.

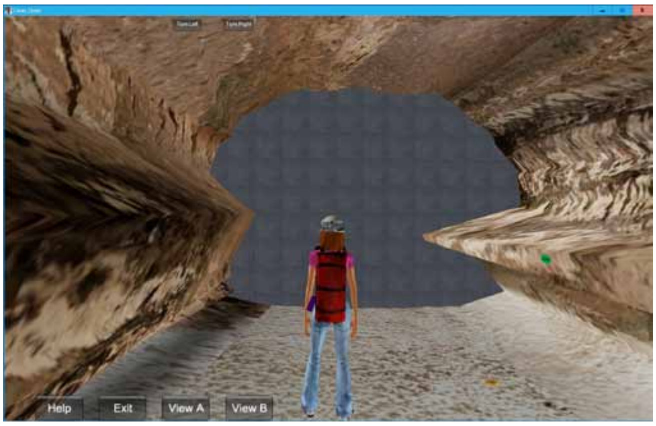

Figure 9. Barrier for test.

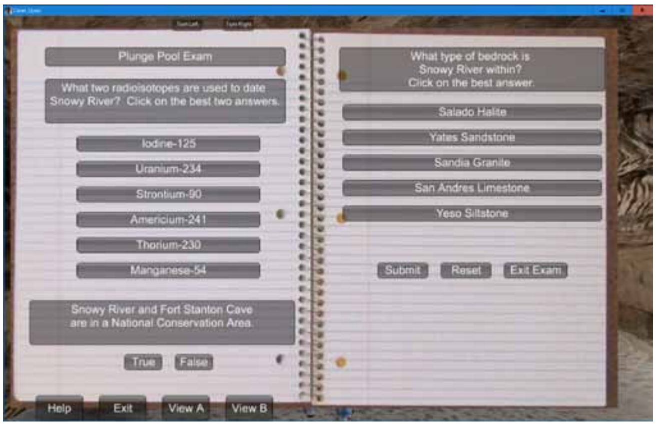

Figure 10. Exam to test knowledge obtained from pop-up cave notes and raise the barrier.

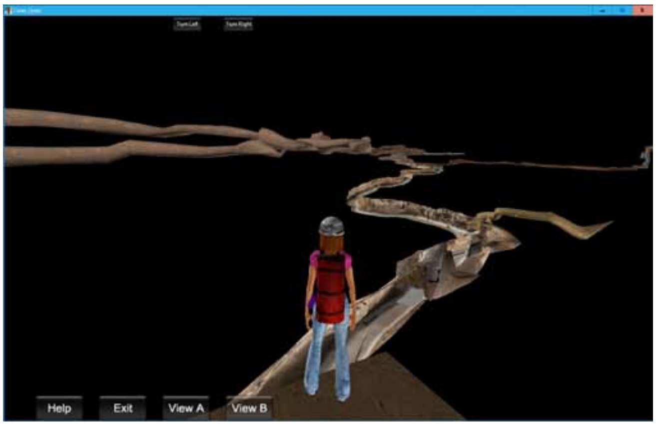

Figure 11. Hyperspatial overlook above Snowy River.

Quest program deals with this by automatically changing the avatar representation to 1st person mode. As the user directs the avatar onward, the program will automatically revert to 3rd person mode when the avatar passes the low ceiling area.

In one section of the cave, where the cave has been heavily impacted by vandalism, it is possible to experience the cave as it exists now, or to experience it as it was before the vandalism occurred. The pre-vandalism experience is based upon historical photographs of the area before the vandalism occurred.

The challenges that occur periodically take the form of quizzes that focus on information that is provided by the button popup notebooks. If the user does not read the information in those notebooks, there is a good chance that the user will not be able to answer the challenge questions correctly. The user is prevented from continuing further in the passage where the challenge quizzes are located by a representation of a solid gate, obscuring the passage beyond (Figures 9 and 10).

There are several places in the Caver Quest environment (called "hyperspatial overlooks") where the user can choose to observe the cave passage from the outside, as if the bedrock matrix surrounding the cave passage was invisible (Figure 11).

The Caver Quest environment is incomplete, at present, as only a few kilometers of the 50+ kilometers of the known cave at present have been simulated to date. Still, significant and stunning parts of the cave are already part of the simulation, including a good portion of the Main Corridor, Crystal Crawl and Decoration Passage, portions of the route to Snowy River, and major sections of the Snowy River passage itself (Figures 12 through 14). Because it is incomplete, there are points in the simulation where the avatar will come up to "openings" where the cave passage environment suddenly disappears, leaving the user to wonder what mysteries lie beyond.

4. Future Work

Caver Quest is very much a work in progress. Lidar survey and photo documentation of historical portions of the cave continues and is being used to extend the simulation throughout the historical sections. There are still unresolved issues with the avatars. It is possible to have the avatars walk, run, turn, back up and climb, but a mechanism for having them crawl has not been worked out. The vast majority of passages in Fort Stanton Cave are walking passages, but as with

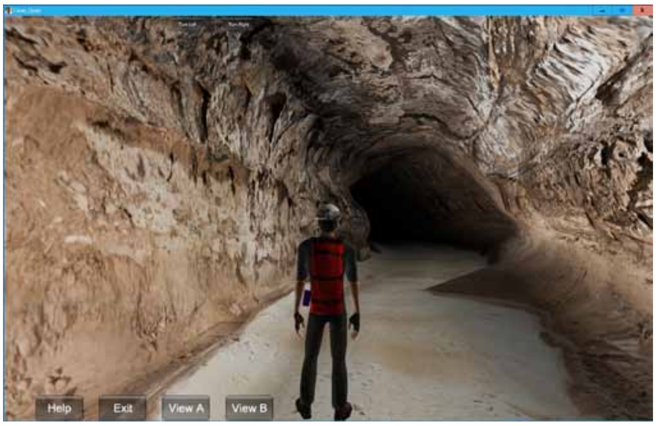

Figure 12. Snowy River North.

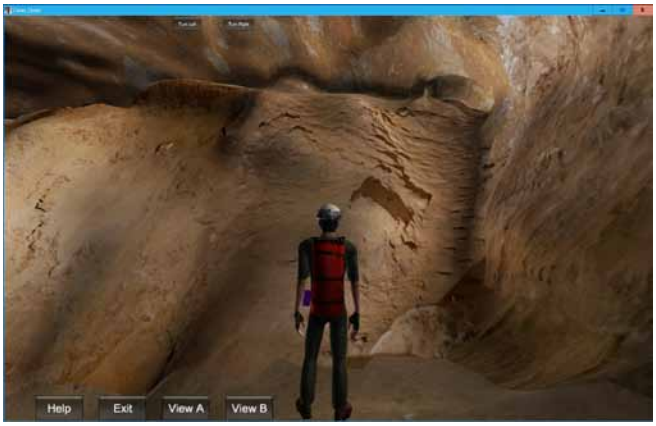

Figure 13. Twenty Steps in Main Corridor.

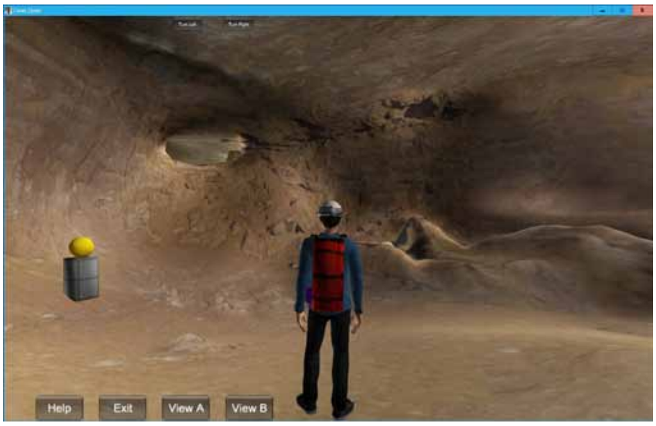

Figure 14. Rosebowl Room.

most caves, there are places where one cannot walk upright. Eventually, the second author hopes to incorporate a crawling avatar simulation into the program.

5. The Utilization of Caver Quest

Caver Quest can be used purely for entertainment purposes, but its utility goes beyond that. It has been used by the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) as a major interpretation tool. The BLM has used *Caver Quest* to introduce the cave to elementary school children. It is wildly popular and the children often outstrip the adults in their ability to adapt to the simulated environment. The USFS has installed a kiosk in a public visitor center to allow visitors to that facility to experience the simulation. Once again it is very popular, with the continual response being, "When can I go to the cave?"

Caver Quest is a scientific tool as well. One of the first sections of the cave to be simulated was a part of the Snowy River passage just upstream from the access point from the historical part of the cave. The simulation uses photographs of the wall, floor and ceiling to build the representation, and as mentioned before it is possible to put the avatar in 1st person mode and direct the avatar's gaze towards the floor, walls or ceiling. One of our experts on the cave used the simulation to take a close look at the ceiling and discovered boxwork. Because cavers traveling through Snowy River are almost always looking at the floor or walls in order to minimize their impact, they had never taken a close look at the ceiling to observe the boxwork. The documentation of this feature occurred from the utilization of the simulation, rather than direct experience.

There are several potential uses of *Caver Quest* in the management realm. One major concern for Fort Stanton Cave (and any cave in reality) is impacts to the cave from human visitation. Using Caver Quest, it is possible to give people who might otherwise be causing impact to the cave a very accurate impression of what travel to different sections of the cave will involve. This could be quite useful in preparing scientists, rescue personnel, or others who need to enter the cave, but are not familiar with what that will involve.

6. Summary

Caver Quest is indeed a new paradigm in the presentation of a cave. The experiential representation that it entails allows an appreciation for the cave environment in a way that none of the other presentation methods can match. We look forward to continual expansion and improvement of Caver Quest itself, and encourage other researchers to implement a similar experiential representation in other caves.

Acknowledgements

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The Application of a Cave Ecosystem Profile to Anjani Cave in Karst Jonggrangan, Central Java, Indonesia

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Abstract

Anjani Cave is one of the cave systems situated at Karst Jonggrangan, a Miocene karst with 700-800 m asl location. With its features, the Anjani Cave has become a tourism site initiated by the local community. It brings benefit and profit for the surrounding people. However, this cave contains a unique cave ecosystem. A lot of biotas are interrelated with the cave environment which will have been compromised by tourism activity. To manage the impact to the ecosystem, its characteristics must be identified. It will help the manager to recognize the fragility and the importance of Anjani Cave. Cave ecosystem profile is being used to visualize the spreading of the habitat spatially and the species within. Cave map is the most crucial element in making the ecosystem profile. The cave ecosystem profile of Anjani Cave exhibits various biota with their particular habitat. Some of the genera are chiroptera, diplopoda, and arachnida and the habitats include fissures, rooftops, and sediments

Keywords: Ecosystem, Management, Profile, Tourism

1. Introduction

Karst landscape and the caves within provide potential to be used; karst has various values (Samodra, 2001). Amongst those uses are for science, water, and tourism. As for Indonesia, caves are used for water (Jauhari, 2015; Syahidin, 2016) and for tourism. Especially in Karst Jonggrangan, some of the caves had been initiated for tourism use. Those caves are Seplawan, Kiskendo, and Anjani cave systems. The uniqueness, accessibility, and special features in the caves become the main strength in establishing cave tourism. Tourism is expected to be additional or even leading sector in people's income.

However, tourism practice leads into various impacts to the cave environment. the impacts occur with modifications of the cave (Russel and Mclean, 2008), microclimate (Fernando-Cortez, 2006) and the biotic aspects (Biswas *et al.*, 2011; Sari *et al.*, 2015). These impacts may degrade the quality of the caves and decrease the attraction inside the caves. Ultimately, it will end up in the decimation of tourism and lower the income for the people.

Anjani Cave System is located at Jonggrangan Karst, an early-late Miocene karst (Surawan, 2010; Rahardjo, Sukandarrumidi, *et al.*, 1995). This cave was initiated to be a tourism site by local community. Jonggrangan Karst or Jonggrangan Formation itself consisted by conglomerate, tuff, with limestone lignite inset and coral limestone (van Bemmelen, 1949; Rahardjo, Sukandarrumidi, et al., 1995). This area is located at 700-800 with a medium climate (Surawan, 2010), the climatic condition therefore supports the karstification process in Jonggrangan Karst. The karstification process yields cavity systems in this area and forms caves.

As a geoecosystem, Anjani Cave has almost uniform climatic condition. The temperatures are about 23° C inside the cave with the humidity of 92% (Harjanto & Rahmadi, 2011). Those conditions create an optimum condition for the Arthropods to breed (Suin, 2013). The pH of the soil varies depend on the zone. At light zone, the pH is 5 to 6.5. Meanwhile, at the twilight zone, the pH is 4 to 6.9 and at the dark zone the pH is 3.6 to 6.7. The humidity of the soil ranges from 60% to 80%.

As a cave to be used for tourism, Anjani Cave would be impacted by the tourism activities. In dealing with it, a strict management system must be adhered to. A crucial component in building a reliable management system is the monitoring aspect to identify and recognize problems as they develop. Some of the monitoring protocols can be used are the RAP-cei (Donato *et al.*, 2014) or CDI-CSI (Harley, Polk, *et al.*, 2011). However, difficulties can emerge in Indonesia with the lack of cave science expertise and multidiscipline study group in conducting the protocol. Therefore, a more simplistic and faster monitoring method is needed.

2. Methodology

To anticipate the impact, exact and appropriate strategies are strongly required. The appropriate strategies can be acquired by implementing a multi-aspect approach. In dealing with multi-aspect, environmental science approaches provide adequate tools and instruments. Environmental science uses abiotic, biotic, and cultural components in establishing its approaches.

A simple and easy-to-use instrument to be used in environmental science in cave environment is Cave Ecosystem Profile. One of the recent studies use this method to determine the zoning for tourism based on ecological fragility as performed by Wynne & Pleytez. (Wynne & Pleytez, 2005). Much research and many inventory studies have been conducted to support the conservation effort (Buhlmann, 2001; Schneider & Culver, 2004; Moseley, 2006; Graening, Slay, et al., 2006). However, inventory itself won't be adequate to make an appropriate management system. Beside the inventory and

Figure 1. Laniatores

Figure 2. Raphidopora

the classification, the manager needs to know where the biota is located. We need a spatial dimension to make the management effort more effective.

With the cave ecosystem profile we can identify and determine the habitat of the fauna. Inside the habitat, the ecosystem consists of the interaction between the biota and the abiotic components like climate, rock, and water. The cave ecosystem profile uses cave maps to show the biological distribution and the ecosystem as well. With ecosystem approaches, we can maintain the condition of the ecosystem by seeing the presence of the cavernicoles and the supporting habitat. The habitat suitable for the biota is: entrance of cave, endogenous medium, guano, walls with speleothems, liquid medium and the interstitial medium (Vandel, 1965).

3. Results

The cavernicoles found in Anjani Cave mostly are Arachnida and Insecta. We discover the cavernicoles in most of the part in the caves. The results of the inventory can be seen in table 1.

Each ordor has specific role or niche. Ordor that has the most crucial role is the microchiropteras. They provide food and organic ingredients in form of guano. From guano, other cavernicoles have their nutrition and food. The guano creates habitat for small cavernicoles. Gradually, bigger cavernicoles species will segregate to the guano. Those bigger cavernicoles then eat the smaller ones producing the food chain occurs.

Figure 3. Stygophrynus

Figure 4. Microchirpotera

Insecta, like Rhapidoporas, are detritus feeders. They also become prey for predators such as Arachnida, Amblypygi, and Microchiroptera. Therefore, their presence is also important to support the food chain.

4. Impact of Tourism for Cavernicoles in Anjani Cave.

Tourism activities lead to several impacts and alterations to the cave environment. Each cavernicole, as they have specific niche, will have different responses to the disturbance or the impact. By studying their response to the disturbance, we can adjust the disturbance limit from their niche and their role in the ecosystem.

Table 1. Biota of Anjani Cave

Class	Ordo	Family	Genus
Arachnida	Amblypygi	Charontidae	Styghophrynus
	Aranea	Sparassidae	Heteropoda
		Araneidae	-
		Pholcidae	-
	Opilliones (Sub ordo Laniatores)	-	-
Insecta	Grylloptera	Rhapidophoridae	Rhapidophora
Diplopoda	Polydesmida	Paradoxomatiidae	-
	Spirostreptida	Cambalopsidae	-
Mamalia	Chiroptera	Rhinolophidae	Rhinolophus
		Hipposideridae	Hipposideros
		Vesperidae	Miniopterus

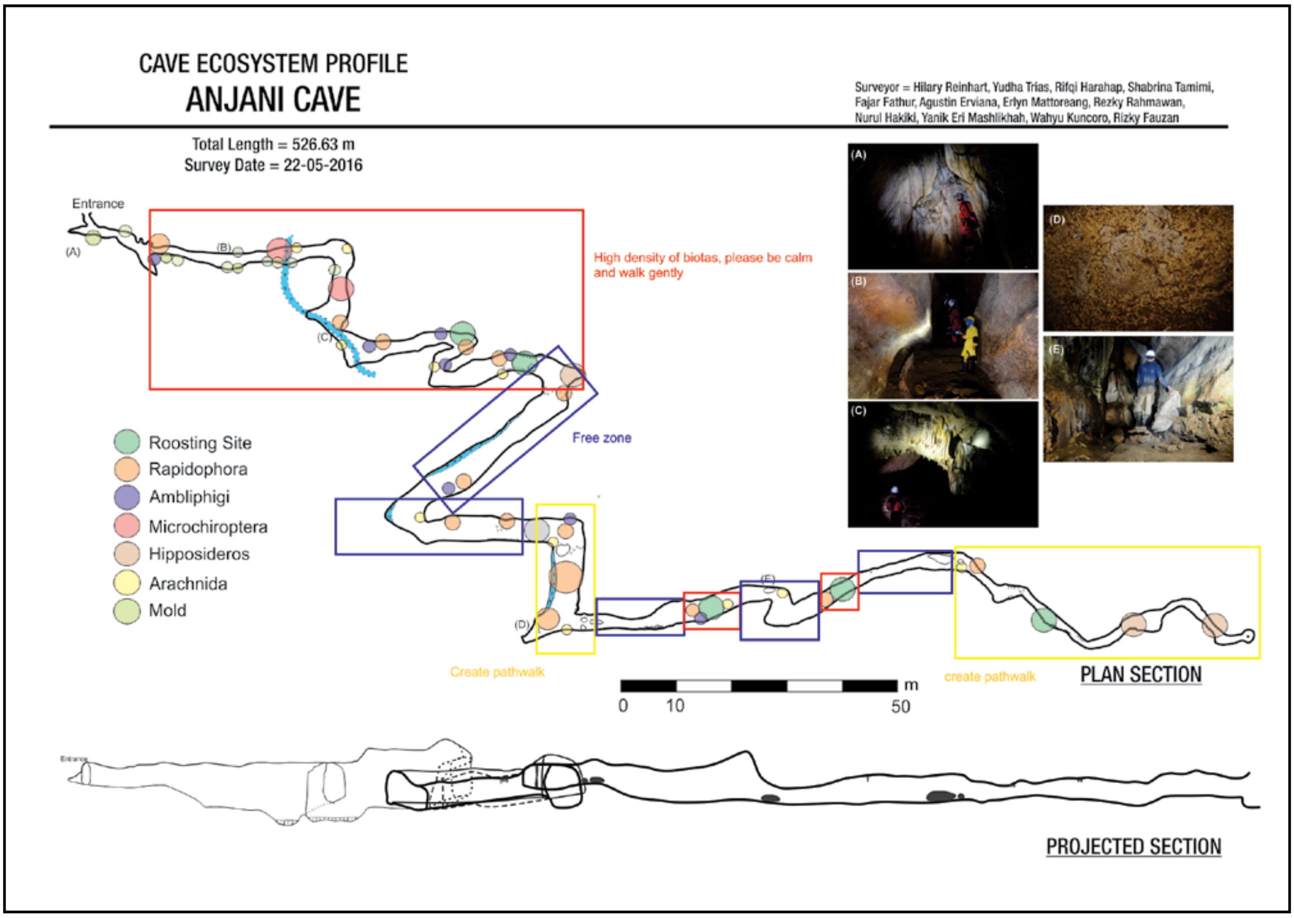

Figure 5. Cave Ecosystem profile and management strategyof Anjani Cave

4.1. Insecta

Rhapidopora is the dominant insect at Anjani Cave. They tend to be found more abundantly at the side of tourism path. This is related with their hiding behavior and their egg placement which takes inside the hole at the cave's floor. Tourism activities tend to lead into floor's substrate hardening. It makes the Rhapidopora cannot lay their eggs (Rahmadi and Yayuk, 2007:27).

4.2. Microchiroptera

Microchiroptera tend to roost at certain suitable places (Saroni, 2005). The alteration of climatic parameter will cause the microchiroptera to move to another roosting site. It will affect the floor community which depends on the presence of the guano. Once the roosting site is abandoned, there will be no more nutrient provided. The habitat then will disappear along with the biota within.

4.3. Management Strategy

Because using ecological approach with ecosystem protection as the objective, the management of the cave must put ecosystem balance as the primary concern. In other words, the management of the cave must adjust to the biota's characteristics inside the cave as the primary component of the ecosystem and the bio-indicator if there are any decreasing of environmental quality. For the Rhapidopora, the tourism activities must not affect the substrate and must not make the soil or the mud in the cave floor become compact. A certain path must be built using environmental friendly material and construction.

For the microchiroptera, the cave manager has to make sure tourist numbers do not exceed the carrying capacity. Over-capacity will affect the climate by increasing temperature and decreasing the oxygen. Tourists must also behave properly by not making noise or sudden movement. In the area where microchiropteras roost, behavioral regulation must be applied strictly.

By using cave ecosystem profile, the cave manager will be able to determine what management strategies to apply. It is very helpful in making explanation for tourists when they are briefed before entering the cave. Tourist also will be more aware because they have been introduced to what they can expect to see along the cave path..

From Figure 5, we can make delineation of the area using presence and density of biotas and the ecosystem. Figure 2 is a simplification and only an example to show how the tourism activities are regulated in spatial aspects.

In the red zone, tourist must walk gently in a particular path determined by the manager. Limited photography is allowed with low light. Noise is prohibited and the tourist may not gather in a place too much and too long.

In the yellow zone, a certain pathwalk must be made. Tourists may not explore recklessly or without supervision from guide. Photography is more allowable than red zone with higher yet limited light intensity. It is not as necessary to control noise than it is in the red zone.

In the blue zone, the tourist is free to explore and take photographs but under supervision from the guide. They may stop and gather around for longer periods than red or yellow zone. In this zone, tourist may take halt and have some snack with strict regulation on how to snacking and strict regulation with the garbage.

5. Conclusion

Ecosystem profile at Anjani Cave had been made using spatial distribution of biotas. By placing those spatial distributions on the map, we can make a management strategy more easily and spatially. It helps in controlling touriist behaviour and it also helps the guide in giving briefings and supervision of cave tourists.

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Evaluating the Status of Cave and Karst Protection in the United States of America

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Abstract

Twenty four years ago, the first USA federal piece of legislation to protect cave and karst resources was passed. The 1993 Lechuguilla Cave Protection Act, protects unknown cave, then and now. The 2009 Omnibus Public Land Management Act, resulted in the establishment of the Fort Stanton-Snowy River Cave National Conservation Area, designed to protect and conserve the cave resources of the Fort Stanton-Snowy River Cave system. Then in 2014, River Styx, a 0.4 mile subterranean segment of Cave Creek flowing through Oregon Caves National Monument received Scenic River Status. It appeared that the scene was being set for the future establishment of a federally designated Cave Wilderness. The election of Donald Trump as President of the United States of America has cast great concern regarding the protection of our nation's great natural treasures and heritage. The presidential cabinet and policies established under the Trump administration will be evaluated comparing past environmental protection policies and legislation and the future potential of establishing a Cave Wilderness during the Trump reign.

Methodological Planning For The Public Use Of Caves And Karst Based On Spatial Analysis Maps

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Abstract

Caves and karst landscapes are fragile environments those which preserve significant traces of Earth's history and our own history in which the time scale exceeds largely our existence. Their cultural, environmental and scientific importance make them unique spaces for education, science and recreation. However, increased public use without planning has caused negative impacts to this unique environment, which when destroyed is lost forever.

In this perspective, based on research in architectural design and having the Diabo's Cave in Brazil as a case study (Silverio, 2014), this paper proposes a methodological planning based on spatial analysis maps of potentiality and restrictions aim the conservation and public use of caves under the current good conservation practices and environmental experience.

Keywords:

1. Introduction

The increase in public use of caves has caused negative impacts with significant damage to the cave environment that requires adequate management to conserve it and ensure the goals of public use are achieved (Ford & Williams, 1989; Watson et al., 1997). The challenge of managing the public use of caves is to harmonize their relative vulnerability with compatible uses (Gillieson, 2011).

Any project of public use of caves must consider the vulnerability of the entire karst system (Dunkley, 2001) and the conservation must be his first goal, otherwise it fails. It requires the compatibility of at least two fundamental questions: A) maintaining the environment as authentic and pristine as possible and B) guaranteeing access and visitor safety.

This study introduce a methodological proposal of planning the public use of caves based on the spatial analysis of attributes and features that express their potentialities and restrictions. The thematic maps created guide the design decisions in the definition of uses according to the current good practices of conservation and of the user experience.

These attributes and features are represented in the topographic map of the cave and described to enable the analysis of the information in the design phase and subsequent evaluation. The strategy is based on the concepts of Webb (1991), Spate & Hamilton-Smith (1991), Spate et al., (1997), Dunkley (2001), Hamilton-Smith (2004), Webb (2007) and Brush (2009).

2. Diabo's Cave

Diabo's Cave (Fig.. 1) had been selected as a research laboratory for this proposed methodology for being one of the best-known show caves in Brazil, receiving about twenty-seven thousand annual visits, also for his restricted visitor and pristine areas. This study is focused on the cave portion next to the sink in which the show cave section is located, and the gallery known as the Erectus Hall (Fig.. 2), that has controlled access to research and small study groups (Silverio, 2014).

Located in the carbonate hills of André Lopes, in the speleological province of the Ribeira Valley (Karmann & Sánchez, 1979), in the southern São Paulo State, the cave is the sink of the Tapagem River, that penetrates the cave through the

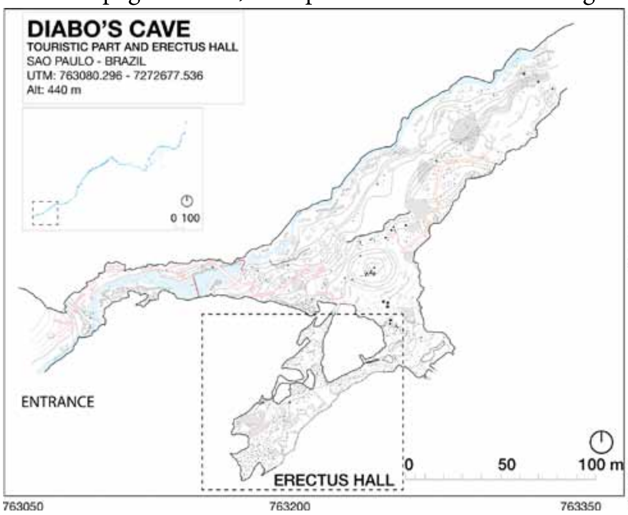

Figure 1. Diabo's Cave - Cathedral Hall

Figure 2. Diabo's Cave - Show Cave and Erectus Hall map

Figure 3. Erectus Hall

entrance known as Tapagem, and develops its underground course for about 4 km until it reappears in the Rio das Ostras Valley, a tributary of the right bank of the Ribeira de Iguape River.

3. Potential and restriction maps

It is suggested two types of analysis, those of potentiality, that favor the public use and those of restriction, which make it difficult (Fig. 4). Such as:

A - Fragility and vulnerability of the environment related with the public use such as geomorphological, ecological, cultural and archaeological.

B - Hazards and risks, related to user experience and use

C - Attractiveness (Lino et al., 1987; Lino, 1988 & GBPE, 2005),

D - Conservation status. The interruption of the agent causing the any damage and the possibility of recovery and restoration of damaged areas should be evaluated (GBPE, 2005),

E - Existing structures should be mapped and described for later evaluation of the viability of use, alteration or removal of them. Tracks, materials, constructive systems, state of conservation and damage caused by structures.

F - Current flow of visitors in the case of public use implemented.

Potential and restriction maps are based on the environmental diagnosis as defined on the planning scope of public use, proposed scenarios and proposed project plan. Each thematic analysis should be represented on the cave map with the description of the attributes and features, identified according to a color pattern corresponding to the classification of each one to facilitate its analysis.

4. Map analysis

The maps of potentialities and restriction produced in each theme should be evaluated and compared overlapping each other by the team responsible for planning to understand the current situation and to define the work plan according to the scope defined at the beginning of the process (Fig. 5).

The map evaluation look for future scenarios always considering the most conservative status. The areas identified as

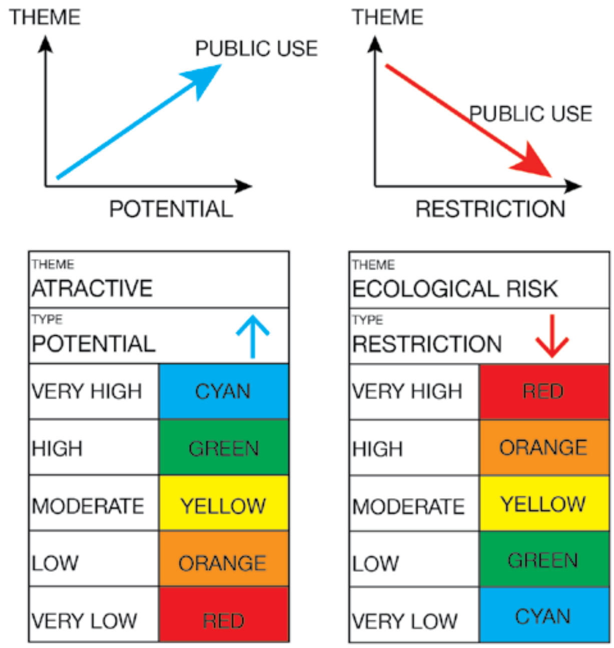

Figure 4. Potential and restriction analysis

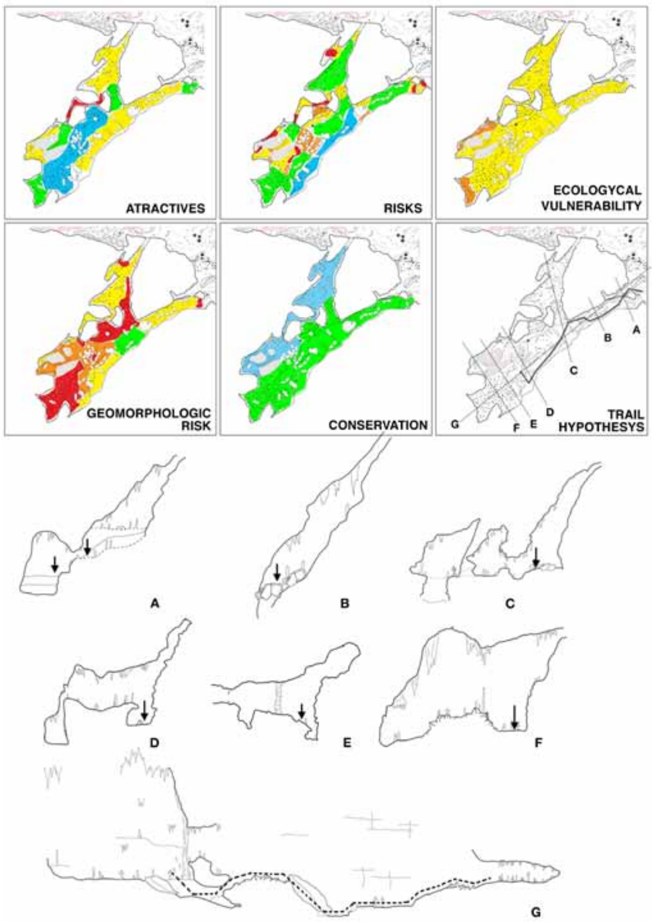

Figure 5. Spatial analysis and trail proposed.

less restriction and greater potentiality are the most viable to receive public use. It is highlighted that certain restrictions may be prohibit public use and therefore fragilities and risks should be the first characteristics considered.

Then a preliminary track plan is proposed, considering the scope, the objectives, the potentialities and the restrictions.

The definition of a trail is a simple and effective way of minimize traffic damage caused by people in a cave, restricting impacts to a linear path and keeping users away from fragile formations and hazardous locations as defined by Lino (1988), (1997), Lechner (2006), Werker & Werker (2006), Brush (2009) and Kržič (2011).

After the preliminary tracing of the track, the team needs to evaluate in the field their draft proposed. The trail might follow the most viable areas and, when necessary, propose structures to ensure the conservation of the environment and visitor safety and access (Fig. 4). That structure must consider the materials, techniques and construction methods more suitable ensuring the minimum interference in the cave environment and perception of the space, because the experience of a visit is greater the more untouched the environment is.

The spatial zoning is defined according to the characteristics of the space for its conservation and management of the use (Webb, 2007). Specially at this stage it is important that not only the technicians and specialists participate but also the managers, employees and users as this makes the process participatory, dynamic and more effective. (Dunkley, 2001).

5. Conclusion

This graphical method intends to enable the understanding and the analysis of the information for decision making as in the architectural design, in which the elaboration of the question is part of the solution. Which presupposes a frequent return to the guidelines and intents whenever new information is found or a decision is made. Making it a non-linear process but a project oriented, avoiding waste of resources in stages that do not contribute to the project. Using spatial analysis maps the information is easily comprehended, also allowing the participation of non specialists.

Furthermore these maps allow to create future scenarios and validate the results even in the study stage, because the utilisation of drawings of cognitive meaning, which are elaborated hypothesis and selected the most suitable solutions in successive approach, enable to demonstrate elements, formulate theoretical reasoning and achieve results that would not be possible to be achieved by the exclusive use of textual methods. Therefore this methodology is a strong tool for planning, management and monitoring the public use of caves and karst.

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It Was A Dark And Stormy Night When The Crickets Returned: Recovery Of Biota After Cleaning A Heavily Impacted Commercial Cave (Crystal Cave, Kutztown, Pa, Usa)

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Keywords: Human impacts; power washing; cave crickets; recovery of biota

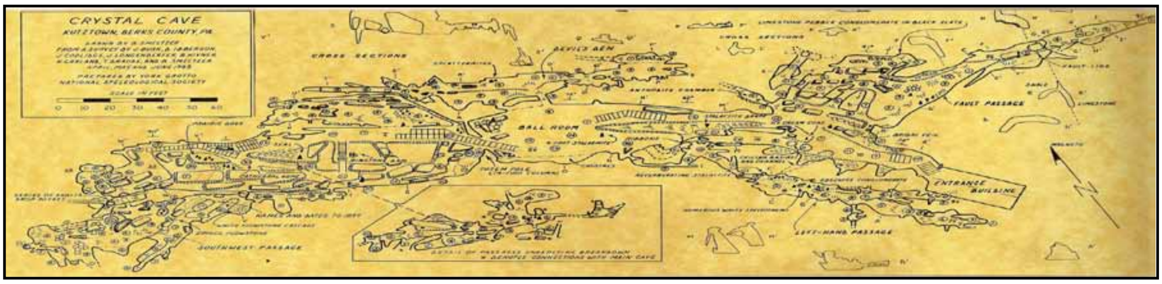

Figure 1. Map of Crystal Cave

Crystal Cave in Kutztown, PA, is the oldest continually operating commercial cave in the state (Fig. 1). It currently has about 40,000 visitors a year. Early visitors were guided using candles, oil, and kerosene lanterns. For a grand lighting, kerosene was spilled onto flowstone and set ablaze to illuminate some of the larger rooms. The first rudimentary electrical lighting was installed in the 1920s. The cave has been heavily impacted by humans, and showed it. There are no records of cave organisms from the cave.

1. Methods:

- Biological Inventories. Before and after cleaning a visual census was conducted to look for any invertebrates on and off trail.
- In 2007 the Greater Allentown Grotto began cleaning *lampenflora* growth around lights. In 2009 systematic power washing of formations and surfaces began of the estimated 80-90% of the visible rock that was coated with dark deposits of lint, dirt, grime, and smoke. It took three years to complete power washing the cave.
- Conversion to LED lighting: During this time lighting was slowly being changed out from 150 watt incandescent lamps to 23 watt LED bulbs.
- SEM studies of biovermiculations showed clay, synthetic fibers, algae, bacteria, and diatoms. The wash water showed silt and clay, but no hydrocarbon residue was detected Genetic Analysis: Crickets were collected for genetic analysis and identification by preserving individuals in 70% ethanol. We tested; the cytochrome c oxidase subunit I (C0I) and the small subunit of the 16s DNA. The regions were amplified using PCR, isolated, and sequenced. The sequences were analyzed for their validity and accuracy before being compared to existing cricket sequences in the NCBI GenBank database.

Figure 2. Collembola on a water film in Crystal Cave, possibly Onychiurus *(Dan Fong, Personal communication).*

2. Results and Discussion:

Occasional small animals were noted on the clean areas of the cave, such as collembola on a water surface (Fig. 2). Sand was mixed with clay and small rocks and placed off trail for possible use by cave crickets. In 2015 a large number of camel crickets arrived, observed massing by the entrance to exit the cave for nightly foraging (Fig 3, Fig. 4).

Preliminary genetic analysis of the cricket showed no close relatives in GenBank; the closest is a Diesteammena sp. There are few reported troglobites in Pennsylvania caves, and no historical records of cave animals from Crystal Cave.

We hope the return of the crickets and other small invertebrates shows the improved environment for cave animals, and we will continue to monitor the biological recovery of the cave. The cave is on a three year cycle of cleaning. We will continue to monitor and record cave biota. Commercial cave operators, cavers and research scientists, and cave biota can co-exist to the benefit of all.

Figure 3. One of the crickets. Possibly a Diesteammena *species.*

Doug putting out cricket egg-laying substrate off-trail.

Acknowledgements:

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Missouri Cave Database – a comprehensive tool for cave management.

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Abstract

The Missouri Cave Database (MCD) originated in the 1950's with a crude database cataloging cave names and approximate locations. It has since evolved into a sophisticated and fairly comprehensive database on a versatile FileMaker Pro platform, documenting more than 7200 caves. It includes a wide spectrum of information. Biological data was until recently managed by the State of Missouri, but when funding for that effort dried up, the detailed biological records were incorporated into MCD, which now includes more than 25,000 such records. The database is access-controlled, but selective portions are made available to field workers and to cave owners and land managers. Input from field workers is easily incorporated and output of data is readily tailored to the specific needs of managers and researchers. Plans are underway to expand coverage to include Arkansas. The capabilities of the database will be demonstrated and it is proposed that this system can serve as a model for other karst areas.

Keywords: database, cave location, biological records.

1. Introduction

Cataloging caves in Missouri arguably began with a 1922 listing of 76 archeological cave sites by Gerard Fowke (Fowke 1922). In 1952, Willard Farrar of the Missouri Geological survey produced a catalog of about 200 Missouri caves. This was soon surpassed by the 1956 book *Caves of Missouri* by noted geologist J Harlan Bretz (Bretz 1956), which listed and described 437 caves in much more detail. In the same year, the growing popularity of caves and caving in the United States led to the creation of the Missouri Speleological Survey (MSS), a private group who from the beginning worked in close collaboration with the State of Missouri's Geological Survey (MGS). The MSS expanded on Bretz' work, and the resulting collection of cave information was archived by the MGS (Lamping 2015).

2. Databases

The close relationship between the two organizations was cemented when one of the founders of the MSS, Jerry Vineyard, was hired by the MGS and eventually became assistant State Geologist. One of Vineyard's innovations was to take advantage of early computer technology to produce a cave catalogue - a crude database of recorded caves, listing little more than the cave's name and location, the latter using the idiosyncratic public land survey system. This format lasted into the 1990s with increasing amounts of information listed, such as cave elevations and date of mapping. Eventually, advancing technology, especially increased storage capacity, demanded going beyond the limited field size and column format of the early databases. In the mid-1990s one of us (SH) developed the Missouri Cave Database on a FileMaker platform, a sophisticated but user-friendly program, by 2001 it had become the operational database of the MSS, and it has continued to be refined and expanded ever since.

The documentation of cave life in Missouri followed a different path. The earliest records are from 1888, when Ruth Hoppin collected troglobiotic fish and crayfish from caves in SW Missouri. Records gradually and sporadically accumulated until in 1998 the Missouri Department of Conservation (MDC) hired William Elliott as the first and so far only State cave biologist. One of Elliott's innovations was to collect the biological records scattered throughout the literature and assemble them in Cave Life Database using the somewhat misnamed Access program. For the first time, nearly all of the available data was assembled in one place, and data from unpublished field work also began to be incorporated. After Elliott's retirement in 2013, MDC did not fill his position and Cave Life Database was therefore no longer supported. This presented an opportunity to replace the database with a more accessible format. The Access database required specialized knowledge to operate fully; data entry involved the bottleneck of a single compiler who had many other time demands, and it was often far from easy to retrieve data in a useful format. House exported the data into FileMaker and established it as a table within MCD, under the management of the MSS but in close collaboration with the government and private agencies who would supply records and would need access to the data.

3. Missouri Cave Database

We will not describe the database in exhaustive detail, but broadly it consists of a set of seven inter-related tables: main, faunal records, species table, maps, reports, monitoring and a to-do list, the latter still under development. The *main table* consists of all of the basic data on location, description, ownership, etc.; the *faunal records* contain the Cave Life Database records plus all biological records recorded subsequently; the *species* table lists of all of the taxa recorded from Missouri caves; *maps* is a list of what maps, if any, are available for each cave; *records* contains all of the available detailed information on each cave, drawn from both published and unpublished reports; *monitoring* contains forms filled out for every cave visit by CRF and MSS cavers to assess the level of public use and threats to the integrity of the cave.

The data in the various tables are presented in a number of layouts, some layouts showing data from one table, some from multiple tables. Figure 1 shows the *Data entry* layout for a sample cave, drawn mainly from the main table. There is too much information for one screen, so the data is separated into a number of tabs: *Location* is given in a variety of formats as well as verbal descriptions and entrance dimensions; *Status* gives ownership and management information; *Attributes* contains capsule summaries of archeology, hydrology etc. as well as length and depth statistics; *Brief description* is self-explanatory; *Related records* lists and links to any records for

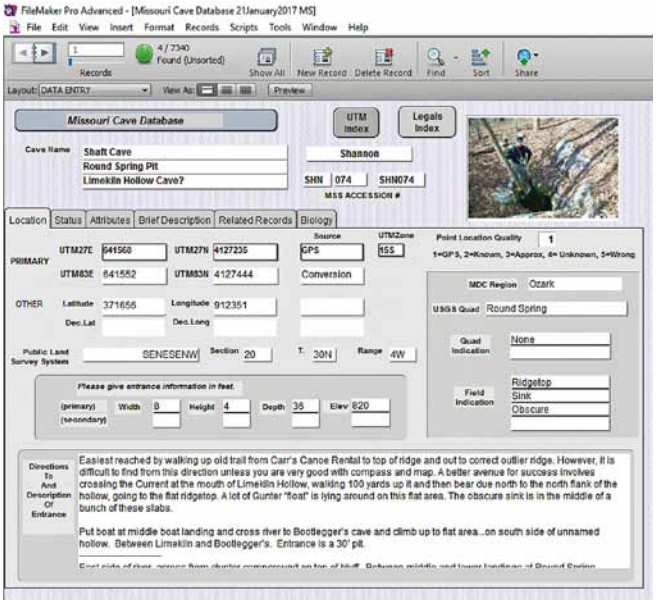


Figure 1. Main data entry page with the Location tab highlighted.

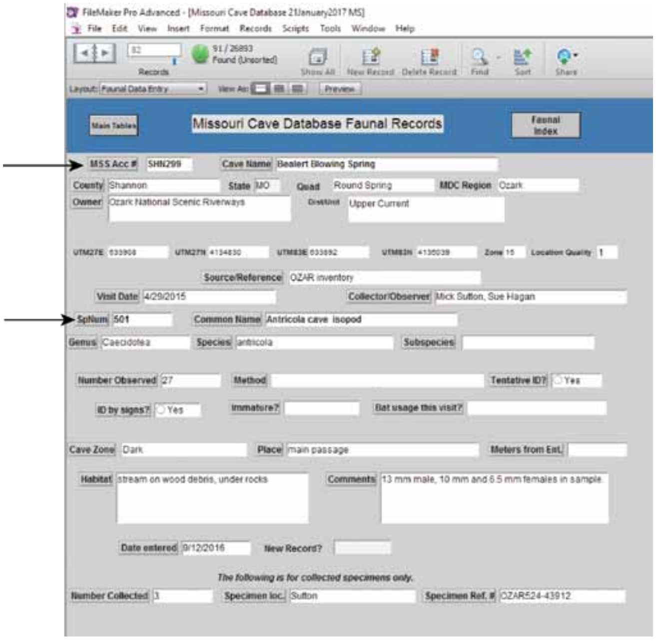
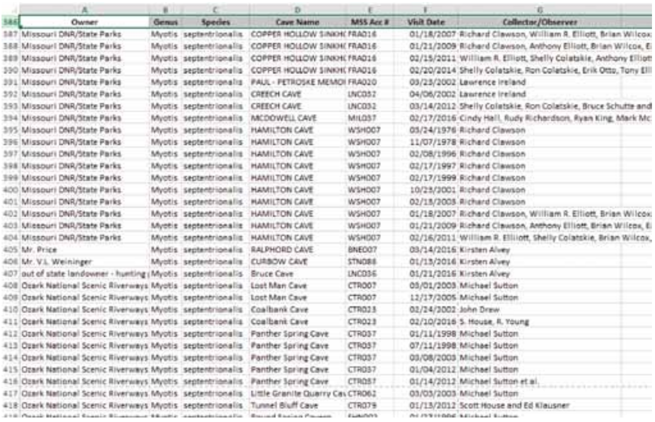


Figure 2. Faunal data entry – the MSS accession no. and species no. fields automatically populate many of the other fields.

that cave from the map, records and monitoring tables; *Biology* consists of verbal descriptions for each cave as well as a list of the faunal records with links to the detailed faunal records. There are 24 additional layouts presenting selected fields in a variety of list and individual record formats.

Tying everything together are two coded numbers. Each of the more than 7000 recorded caves has an accession number consisting of a three letter county code and a three digit cave number – e.g. Round Spring Cave in Shannon County is SHN002. This avoids the problem of multiple caves with the same name (e.g., there are 34 Bat Caves throughout Missouri) and the problem of caves with multiple names (e.g. Cave Spring Onyx Caverns = Onyx Cave = Current River Caverns). The second code is a species number. There are 1160 recorded taxa in the species table, a taxon being anything from a well-defined subspecies to an undetermined member of a broad group (e.g. generic troglobiotic amphipod). Species are numbered in a more or less taxonomic order – bats first, then other mammals, other vertebrates, etc. The convenience of this arrangement is best seen in the *faunal data entry* layout (figure 2). For a new record, one first enters the accession number – in this instance SHN299. This links to the main table and immediately populates the fields for cave name, ownership and location. Next the species number for each record is entered, and this immediately populates the fields for taxonomic name and common name. A print-out of the most commonly encountered taxa makes this process easier – less common taxa are looked up in the species table. The remaining information for the record can now be entered in as much or as little detail as is available.

Getting data back out is generally straightforward, and the output can be readily fine-tuned to meet specific needs. For example, figure 3 shows a sample from the listing of northern bat (*Myotis septentrionalis*) records, arranged by agency and within each agency by county and cave number. The data can be exported in various formats, export to an Excel spreadsheet being perhaps the most widely used. This particular instance is a good example of the value of the database to agency cave managers. MDC maintains a Natural Heritage Database of



	Owner	Genus	Species	Cave Name	MSS Acc #	Visit Date	Collector/Observer
387	Missouri DNR/State Parks	Myotis	septentrionalis	COPPER HOLLOW SINKH(	FRA016	01/18/2007	Richard Clawson, William R. Elliott, Brian Wilcox
388	Missouri DNR/State Parks	Myotis	septentrionalis	COPPER HOLLOW SINKH(	FRA016	01/21/2009	Richard Clawson, Anthony Elliott, Brian Wilcox, E
389	Missouri DNR/State Parks	Myotis	septentrionalis	COPPER HOLLOW SINKH(	FRA016	02/15/2011	William R. Elliott, Shelly Colatskie, Anthony Elliot
390	Missouri DNR/State Parks	Myotis	septentrionalis	COPPER HOLLOW SINKH(	FRA016	02/20/2014	Shelly Colatskie, Ron Colatskie, Erik Otto, Tony Ell
391	Missouri DNR/State Parks	Myotis	septentrionalis	PAUL - PETROSKE MEMOI	FRA020	03/23/2002	Lawrence Ireland
392	Missouri DNR/State Parks	Myotis	septentrionalis	CREECH CAVE	LNC032	04/06/2002	Lawrence Ireland
393	Missouri DNR/State Parks	Myotis	septentrionalis	CREECH CAVE	LNC032	03/14/2012	Shelly Colatskie, Ron Colatskie, Bruce Schutte and
394	Missouri DNR/State Parks	Myotis	septentrionalis	MCDOWELL CAVE	MIL037	02/17/2016	Cindy Hall, Rudy Richardson, Ryan King, Mark Mc
395	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	03/24/1976	Richard Clawson
396	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	11/07/1978	Richard Clawson
397	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	02/08/1996	Richard Clawson
398	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	02/17/1997	Richard Clawson
399	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	02/17/1999	Richard Clawson
400	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	10/23/2001	Richard Clawson
401	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	02/18/2003	Richard Clawson
402	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	01/18/2007	Richard Clawson, William R. Elliott, Brian Wilcox
403	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	01/21/2009	Richard Clawson, Anthony Elliott, Brian Wilcox, E
404	Missouri DNR/State Parks	Myotis	septentrionalis	HAMILTON CAVE	WSH007	02/16/2011	William R. Elliott, Shelly Colatskie, Brian Wilcox,
405	Mr. Price	Myotis	septentrionalis	RALPHORD CAVE	BNE007	03/14/2016	Kirsten Alvey
406	Mr. V.L. Weininger	Myotis	septentrionalis	CURBOW CAVE	STN088	01/13/2016	Kirsten Alvey
407	out of state landowner - hunting (	Myotis	septentrionalis	Bruce Cave	LNC036	01/21/2016	Kirsten Alvey
408	Ozark National Scenic Riverways	Myotis	septentrionalis	Lost Man Cave	CTR007	03/01/2003	Michael Sutton
409	Ozark National Scenic Riverways	Myotis	septentrionalis	Lost Man Cave	CTR007	12/17/2005	Michael Sutton
410	Ozark National Scenic Riverways	Myotis	septentrionalis	Coalbank Cave	CTR023	02/24/2002	John Drew
411	Ozark National Scenic Riverways	Myotis	septentrionalis	Coalbank Cave	CTR023	02/10/2016	S. House, R. Young
412	Ozark National Scenic Riverways	Myotis	septentrionalis	Panther Spring Cave	CTR037	01/11/1998	Michael Sutton
413	Ozark National Scenic Riverways	Myotis	septentrionalis	Panther Spring Cave	CTR037	07/11/1998	Michael Sutton
414	Ozark National Scenic Riverways	Myotis	septentrionalis	Panther Spring Cave	CTR037	03/08/2003	Michael Sutton
415	Ozark National Scenic Riverways	Myotis	septentrionalis	Panther Spring Cave	CTR037	01/04/2012	Michael Sutton
416	Ozark National Scenic Riverways	Myotis	septentrionalis	Panther Spring Cave	CTR037	01/14/2012	Michael Sutton et al.
417	Ozark National Scenic Riverways	Myotis	septentrionalis	Little Granite Quarry Ca	CTR062	03/03/2003	Michael Sutton
418	Ozark National Scenic Riverways	Myotis	septentrionalis	Tunnel Bluff Cave	CTR079	01/13/2012	Scott House and Ed Klausner

Figure 3. Excerpt from a spreadsheet export showing all northern bat records, sorted by cave ownership.

species of conservation concern. However, this is not helpful when a species newly becomes of conservation concern. Hence, when the US Fish and Wildlife Service began the process of listing northern bats under the Endangered Species Act, agency biologists needed to quickly assemble all available cave records for this species, and this was easily achieved using MCD. Other Missouri cave bat species unfortunately may in the near future need consideration for listing. MCD includes more than 800 records for little brown bats and more than 3000 records for eastern pipistrelles, both species suffering serious declines owing to White Nose Syndrome.

Conservation of caves and cave resources is a major concern, with an unfortunate history of vandalism and both deliberate and inadvertent damage to resources. Cave locations are therefore considered sensitive and confidential and the database must perforce be of limited distribution. Access is controlled by the MSS in collaboration with the government agencies. The database can also be distributed in part – for example, the staff at Ozark National Scenic Riverways

(National Park Service) have regularly updated access to data for the caves they own and/or manage, and the same is true of other agencies. MDC, being responsible for all matters related to Missouri fauna, have the entire database. Field workers, both private and agency, can be given data for the specific area they are working on. It is also easy for field workers to enter new data, which is easily incorporated into the master database, avoiding the data entry bottleneck of the old Cave Life Database. One of us (MS) monitors incoming records for veracity, taking into consideration the particular expertize or otherwise of the reporter.

4. Advancement

There are plans to expand coverage of the database to neighboring Arkansas and later possibly to other neighboring States in order to construct an Ozark-wide database. This will require expansion of the taxa list and other modifications to accommodate the requirements of Arkansas workers. The database is detailed and versatile enough that it should be adaptable to other cavernous areas.

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(Abstract) Cave access challenges at Sistema Huautla, Mexico

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Abstract

Sistema Huautla is the deepest known cave in the Western Hemisphere. It is 1,560m deep. 75.5km long, with 20 integrated entrances. The discovery of the caves in the remote Sierra Mazateca of the southern Mexico state of Oaxaca occurred in 1966. Since then, expeditions to the area have occurred nearly annually.

For the past 35 years, cavers have unsuccessfully attempted to access cave entrances on the highest ground at the north end of the karst drainage basin. Large, deep, impressive sinkholes are there in abundance. The Mazatec Indians who live around them have spiritual beliefs about the caves and have not given permission for cavers to enter them. They have stated that they fear cavers might upset cave spirits residing in them, resulting in upsetting nature's equilibrium, causing dire things such as their children becoming ill or their corn not growing.

With the restart of annual expeditions to the area in 2014, a new name of Proyecto Espeleologico Sistema Huautla (PESH) and a logo being adopted, PESH co-leader Bill Steele, a long time Huautla caver, devotes his time on the annual, month-long expeditions to addressing the challenge of gaining access to the highest entrances. Steps taken include a quality display about PESH's speleological work being installed in the area govenment building assemby room, the local newspaper has run articles, the local radio station has interviewed Steele, brochures about the project have been printed in Mazateco, and Steele has given many presentations to community groups and to school children. Also, at the urging of local govenment officials, a shaman was consulted and a spooky ritual was held, concluding with the sacrifice of a live turkey by dropping it in a 70m shaft, one of the entrances to Sistema Huautla.

Meanwhile, while this action is taking place on the surface, deep underground cavers are campnig long-term and ascending up-dip toward possible high entrances from within the caves. One way or the other, the cave shall be explored, studied, and understood with results published.

(Abstract) Geopark Proposal At The Arcos-Pains Speleological Unit, Minas Gerais, Brazil

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Abstract

In Brazil, carbonate areas cover between 425,000 and 600,000 sq.km, which represent approximately 7% of the country's total area. Considering this potential, it has encouraged more research in such areas to better educate people living on karst. For this reason, the country has great potential for establishing conservation areas or geoparks in karst areas rich in geodiversity, biodiversity, archeological, cultural and historical aspects. In 2006, the Brazilian Geological Survey created the Brazilian Geoparks Project which has as basic premise the identification, surveying, description, diagnose and broad disclosure of areas with potential for future geoparks in the country, including the inventory and quantification of geosites that represent a part of the geological heritage of the country.

Thus, this research presents a proposal of delimitating a geopark in the Arcos-Pains Speleological Unit, in the State of Minas Gerais, Brazil. The karst features in the study area develops in two geological units: the Sete Lagoas Formation and Lagoa do Jacaré Formation, both belonging to the Bambui Group mainly made of carbonate rocks from Neoproterozoic age. Thick layers of limestone with parallel plans are common; the bedding is horizontal and presents intense subvertical fracturing, with primary well-preserved structures. The regional karst of the Arcos-Pains Speleological Unit is an outstanding example of Brazilian intertropical karst for its geological, geomorphological, hydrological, and archaeological features. Therefore, its surface and underground development should be understood as a complex phenomenon.

In the study area, human activities may impose profound changes in the landscape, especially due to mining, since there are installed several limestone extraction companies and industries for cement and lime production. Such land use, coupled with poor management of the speleological heritage has caused significant environmental impacts on karst. Due to its intrinsic fragility and increasing anthropogenic disturbance, such landscapes require progressive care for their protection. The establishment of other protection areas besides the Jardim do Eden Natural Monument, the Corumba Ecological Station and the Dona Ziza Natural Municipal Park are needed and these can be done through public-private agreement, as conservation and sustainable use strategy in forms of a Geopark, which should help protect regional geodiversity.

Keywords: Geopark; Karst; Arcos-Pains Speleological Unit; Minas Gerais.

White-nose Syndrome Response at Mammoth Cave National Park (USA)

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Abstract

Since first identified in North America in 2006, white-nose syndrome (WNS) in bats has become an important issue in management of caves and bats at Mammoth Cave National Park (MCNP). Before its arrival in the area, challenges related to preventing spread into park and area caves. After arrival the challenges have been to prevent spread of the fungus by visitors from the site and to implement monitoring and conservation measures to address WNS impacts.

In 2009 MCNP initiated actions in response to WNS. Our original response targeted preventing spread of WNS to the park. Researchers were required to use clean or decontaminated gear. Visitors were screened for previous cave visitation, and shoes worn in other caves or mines were decontaminated before tours. We also required the use of park-supplied gear for our crawling tours. The park enacted a program to monitor bats for presence of WNS. Several hibernation sites were closed to non-bat related visits.

In 2011, when WNS was confirmed in the state of Kentucky, MCNP began having visitors walk over biosecurity mats after their tours. Although WNS was not at that time known from the park, we recognized the potential for visitors to spread it, if it was in the park undetected. From 2011 to 2014 we both screened visitors for previous cave visits and had all visitors walk over biosecurity mats after tours.

Between January and April 2013, WNS was identified in all six park colonial Myotis hibernacula. Continued monitoring has shown that populations of several species have declined precipitously since the arrival of WNS. Summer netting has also demonstrated a large decline in Myotis septentrionalis. By 2015 WNS had been identified in all sections of Mammoth Cave (toured and not) and several other caves without known Myotis populations. Since 2015, due to the widespread occurrence of WNS in park caves, some restrictions on movement between caves on park have been eased.

Beginning in 2014, WNS has caused unusual bat behavior on park, which resulted in increased bat-human contacts. The park worked the public and wildlife health officials to address and reduce those contacts.

MCNP's WNS response has varied over time as the nature of the issues confronting us have changed. However, we have continued to work within the park and with other agencies to protect people, bats, and caves, as well as to provide the public with information about this threat.

Keywords: Show Caves, White-nose Syndrome, Cave Management, Bats

1. INTRODUCTION

Since it was first identified in the United States in 2006, white-nose syndrome (WNS) in bats has become an important issue in the management of caves and bats at Mammoth Cave National Park (MCNP). First the threat of its arrival and later its actual arrival and effects have led to interventions with both the visiting public and researchers, restrictions on access to colonial bat roosts, increased monitoring of bat populations, support of scientific studies, and upgraded interpretation on bats, wildlife disease, and public health. Table 1 contains a timeline of activities and responses related to WNS that the park has undertaken.

2. MAMMOTH CAVE NP WNS RESPONSE

The most visible response to WNS at MCNP has been the interventions with visitors to prevent first human-caused arrival of the fungus in the park (before Spring 2014) and later (after April 2011) visitors potentially leaving with the fungus after a tour (or research). This is a very important aspect of WNS response at MCNP, since over 400,000 people visit caves at the park each year. Beginning summer 2009 park staff screened cave visitors to prevent accidental introduction of the fungus by visitors (Figure 1). Methods used to identify visitors to screen included public announcements, pre-tour briefings by guides, and printed posters in the Visitor Center. Visitors were asked if they have been in a cave since 2005. If so, they are asked about whether they were wearing or carrying things that have been in a cave. If they had things that had been in a cave, park staff worked with them to reduce the potential for bringing in fungal spores. Measures that were taken included decontamination, bagging items, or disallowing items from the cave. This type of pre-visit screening ended in spring 2014, when bats in major tour areas of the cave were found to have WNS.

Starting April 2011, when WNS was first identified in Kentucky, MCNP began requiring visitors to walk over a biosecurity mat after taking walking tours of the cave (Figure 2). This measure was taken to reduce the possibility that MCNP visitors could take the fungus away from the cave with them, even before it had not been detected in Mammoth Cave. The biosecurity mats consisted of a 12-foot run of outdoor carpet (to physically remove dirt and spores) followed by a six-foot-long wet walkover mat with a cleaning solution. From April 2011 through September 2012, the walkover mats used a Lysol® solution. Lysol® is a common household and industrial disinfectant in the United States. Its active ingredients are quaternary ammonium compounds. In September 2012, the park stopped using Lysol solution mats, because the use of

Table 1. Timeline of Mammoth Cave National Park WNS-related Activities and Responses

Date	Response or existing activity modifications
May 2009	Colonial bat roosts closed year-round (except approved WNS and batresearch); Decontamination required of incoming gear for researchers
June 2009	Screening of incoming tour visitors and intervention (decontamination,disallowing items, etc.). Park WNS intervention station and displays start
Winter 2009-10	Enhanced monitoring of caves for WNS, biennial counts of Corynorhinus hibernation roosts
August 2010	Begin requiring decontamination between caves and after cave trips for researchers
January 2011	Park releases original WNS Response Plan
Winter 2010-11	Enhanced monitoring of caves for WNS, biennial counts of Myotis hibernation roosts, no evidence of WNS seen
April 2011	KY (non-park) site confirmed with WNS; Tours began post-visit decontamination with walk-over mats containing Lysol solution
Winter 2011-12	Enhanced monitoring of caves for WNS, biennial counts of Corynorhinus hibernation roosts
August 2013	Tri-colored bat swabbed during fall trapping at Colossal Cave tests positive for Pseudogymnoascus destructan.(Pd). Analysis occurred after WNS found on park. Earliest evidence of Pd on park.
Sept. 2012	Post tour walk-over mats changed to dry carpet due to restrictions on Lysol use
Fall 2012	Filming for NPS series on bats and WNS on park
January 2013	WNS confirmed at park in Long Cave
Winter/Spring 2013	WNS found in all six colonial Myotis hibernation sites known on park. Biennial counts of Myotis roosts show normal count numbers and no evidence of increased mortality.
July 2013	Post tour walk-over mats changed to Woolite solution; Filming on park for Battle for Bats: Surviving White Nose Syndrome
Winter 2013-14	Enhanced monitoring of caves for WNS, biennial counts of Rafinesque big-eared bat (Corynorhinus rafinesqueii) hibernation roosts; WNS identified in three largest Corynorhinus hibernation sites (in other species); WNS located on some park cave tour trails; prior cave visitation screening of incoming visitors ceases
Spring 2014	Increased human bat contacts on cave tours. Increase training and preparation on human-bat contact and rabies issues.
March 2014	Associated Press and WKYU stories on WNS impacts at park
Sept. 2014	Filming of bat research and WNS discussion for CW Network
Fall/Winter 2014-15	Develop enhanced human-bat contact procedures with Public Health Service and state assistance
Winter/Spring 2015	Biennial counts of Myotis roosts indicate significant decreases in little brown, Indiana, and tri-colored bat counts. Numerous dead and dying tri-colored bats recovered along Historic Tour Route. Elevated bat-human contacts and rabies intervention. Increased bat surveillance. WNS at all tour entrances.
February 2015	Louisville, Bowling Green, and Glasgow, Kentucky, USA stories on WNS impacts at park
April 2015	Relaxed decontamination procedures between Pd+ sites on park
May 2015	Seasonal (summer) reopening of WNS+ hibernation sites for research and education
	-eared bats, little brown bats, and tricolored bats during research bat eased summer bat counts.
	NS, biennial counts of Rafinesque big-eared bat (Corynorhinus rafin- ut still elevated numbers of dead and dying tri-colored bats recovered t elevated bat-human contacts and rabies intervention. Continued
	thern long-eared bats, little brown bats, and tricolored bats during summer bat counts.
	cate further significant decreases in little brown, Indiana, and tri- ing tri-colored bats recovered along Historic Tour Route. Decreased Increased bat surveillance.

Figure 1. Mammoth Cave National Park guide screening visitors before a cave tour at the park visitor center WNS station. Visitors are asked about prior cave visits and clothing or items that may have been in other caves.

Lysol® in mats was deemed to be off-label use under the US Federal Insecticide, Fungicide, and Rodenticide Act and there was concern for potential contact with skin. From September 2012 through June 2013, the park used only the twelve-foot lengths of plastic outdoor carpet to physically remove spores from the soles of shoes. The carpet was decontaminated daily to kill spores that might accumulate on it. In July 2013 MCNP began using a Woolite® solution in the walkover mats. Woolite® is a common laundry detergent in the United States; both it and Lysol® are products of Reckitt Benckiser LLC. This solution will help clean spores from shoes, it is also deemed safe for contact with people's skin and can be used on footwear.

Intervention for people on caving tours is more intense. Visitors on those tours are required to use park supplied gear that is only used on park. Their shoes undergo a more thorough cleaning than those of people on walking tours.

Although even prior to WNS all 400+ caves in Mammoth Cave National Park were closed to human access except via ranger-led tours, research permits, or special use permits. WNS did cause some changes in access restrictions to caves on the park. Prior to WNS response, colonial bat hibernacula on park were closed in the winter and maternity colonies were closed during the summer to protect bats when they were in sites. In spring 2009, all colonial bat caves on park were closed to access for all activities except those related to WNS and bat research. In May 2015, access restrictions were eased on sites that are known to have WNS or the fungus that causes it.

Figure 2. Mammoth Cave visitors walk over biosecurity mat following their cave tour to clean possible Pd spores from their shoes before they leave the park.

without decontamination. The park continues to require decontamination following cave trips before going to any cave off-park and before visiting any park cave with unknown WNS status.

With over 400,000 people taking cave tours each year, MCNP has a great opportunity to inform people about the importance of bats and the threat posed to them by WNS. Before WNS, information on bats was part of our interpretive message, but since WNS that messaging has increased greatly. People are informed about WNS and bats at the beginning and end of every tour. The post-tour walk over the biosecurity mat provides an important message that WNS is an important threat, and that people have a role in keeping it from spreading. Sometimes visitors have even had the opportunity to see bats with WNS symptoms along tour routes. The park has also participated in numerous media projects on bats and WNS. These have included national and regional television programs, video productions, and print and web media stories.

Additional bat and WNS related messaging became necessary at the park beginning in Spring 2014. WNS caused unusual bat numbers and behavior near toured cave entrances at the park. This led to increased bat-human contacts on cave tours in the Spring 2014, Winter/Spring of 2014-15 and 2015-16. The increases affected both visitors and park staff. Several people required rabies post-exposure inoculations as a result of bat-human contacts. The park assisted by a NPS Disease Outbreak Investigation Team developed a series of responses including improved messaging and increased monitoring for unusually behaving bats. We have not yet experienced elevated levels of bat-human contacts in the Winter/Spring of 2016-17.

When WNS arrived in the northeast United States, many agencies lacked significant baseline data on healthy bat populations. Beginning in 2009, MCNP increased surveillance and monitoring of its bat roosts (both hibernacula and summer roosts) to gather baseline data, detect the arrival of WNS, and to document potential population changes. This monitoring includes biennial hibernation counts, summer emergence counts, and summer acoustic mobile transects. Disease surveillance includes regular entrance checks of bat roosts, targeted winter visits to bat roosts to check for signs of WNS, and cave entrance acoustic monitoring. In 2014 the park added additional monitoring for dead and dying bats along tour routes in response to concerns about bat-human contacts.

Biennial hibernation counts of colonial Myotis sites in 2015 showed significant decreases in several bat species. Preliminary counts indicate little brown bat (Myotis lucifugus) declines slightly above 80%, Indiana bat (Myotis sodalis) declines of nearly 80%, and tricolored bat (Perimyotis subflavus) declines near 70%. Initial results of biennial hibernation counts of the same colonial Myotis sites in 2017 indicate that the trends of decreases in the indicated species have continued. On the other hand, gray bat (Myotis grisescens) and Rafinesque big-eared bat (Corynorhinus rafinesquii) numbers continue to be stable or increasing on park as of this year. Mist netting on several projects suggest that northern long-eared bats, little brown bats, and tricolored bats are greatly decreased on the summer landscape in the park in 2015 and 2016

The park has also supported a wide range of bat and WNS related research by NPS scientists, researchers from other federal agencies, and from academic researchers. Some of these studies have been supported through access to sites, assistance with sample collection, or direct staff assistance in research. Other studies have been funded by the NPS to assist in gathering information needed for management of affected bat species and caves. These studies have included work on such topics as bat physiology; roosting behavior; WNS fungus prevalence and distribution;, decontamination techniques; bat and insect distribution and abundance before and during

WNS outbreak; and bat condition going into hibernation and coming out (pre- and during WNS outbreak).

3. CONCLUSION

WNS and its effects have led to a dynamic management environment for parks with caves and, in particular, for parks with large show cave operations. The need to prevent the spread of WNS tempts managers into simply closing sites to prevent people from coming in contact with the fungus (or to prevent them from introducing it to places it has not previously been found). However, the opportunity to provide strong messaging on bats and the threat that WNS poses to them also provides a drive for managers. At Mammoth Cave, we believe that strong intervention with both visitors and researchers can sufficiently reduce the threat to allow access while protecting bats and caves.

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Nakanai Cave/Karst Country, New Britain, Papua New Guinea: An Anthropological Perspective

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Abstract

Caves have long held the fascination of both scientists and the general populace. In the New Guinea Islands context, archaeological and genetic evidence suggests people have remained relatively isolated since the appearance of Lapita Cultural Complex ~3000 years ago. Cultural trajectories may well have their roots in equally long traditions. Current research in the Pomio District has reported various ethnographic stories that intertwine at least some of the caves with the origins of the local people. The importance of local origin stories is enshrined in the UN Charter for Human Rights which amongst other things specifically includes the right to history (and therefore social and cultural identity) and cannot be under estimated in the PNG context. This paper presents aspects of Nakanai Caves Cultural Heritage Project. The project aims to integrate and document the natural and cultural values for past and present people in the Nakanai Ranges in preparation for a serial nomination to the United Nations World Heritage List. The Pomio area is home to an extensive karst system running across the interior of New Britain, complete with giant canyons and underground caves and rivers. This presentation reports preliminary results from recent fieldwork in Pomio concerning local knowledge and stories surrounding caves. Community knowledge is integrated with archaeological and anthropological evidence thereby linking natural and cultural values in defining the landscape. Two such caves are Pelau-matana and Nut-kovanga. Pelau-matana is a focal point associated with the creation and origin of six local villages. Nut-kovanga was used by the indigenous god as a 'pathway' in a local creation-story. The same god also left behind engravings (at a nearby location) that can still be seen today. These stories are interpreted in terms of the origins of the local people and link them directly to their environment. The paper also discusses transnational companies in the area, which are perceived as a threat to the Nakanai karst system. Of these caves, some are considered sacred and valuable according to various stories and so require special consideration in land, development and tourism management.

Keywords: Caves, Stories, Culture, Conservation, Nakanai, Papua New Guinea.

1. Introduction

In the Pomio District of southeast New Britain in Papua New Guinea (PNG) (Figure 1) lies a region that includes massive limestone karst with equally impressive cave systems. These cave systems are known to the local residents and indeed represent a physical manifestation of specific aspects of their creation stories. The purpose of this paper is to present just two of these caves and the stories associated with them so as to emphasise the importance of these caves to the local land-owners.

The Nakanai Mountains receive 4000-7000 mm of rainfall annually (Bourke and Harwood 2009) and are dominated by volcanoes such as Mt Ulawun and Mt Bamus, covered with primary tropical rainforest and separated by deep dolines and giant canyons that are the conduit for rivers and streams that feed various lakes before crossing the relatively narrow coastal zone to the sea (Hanson *et al* 2009; Gill 2012).

Prior to the nomination of the Nakanai Range to the World Heritage Tentative List, various cave expeditions were carried out within the area. From 1972 to 2012 Australians, French, British to French-Swiss cavers discovered (Gabriel *et al* 2017) some of the most incredible cave systems which have since been proposed to be of universal significance.

Figure 1. Map showing the areas mentioned in the text.

In 2006, Nakanai, Muller Range and Hindenburg Wall were nominated as 'serial site' by the PNG Government to the World Heritage Tentative List as the 'Sublime Karsts of PNG' (whc.unesco.org/en/tentativelists/5064/; Gabriel *et al* 2017). The progress of conservation plans involved meetings with the Conservation and Environment Protection Authority (formerly known as the Department of Environment and Conservation), the National Research Institute, the East New Britain Provincial Government, the Governor of East New Britain, the Tourism Promotion Authority, the Local Level

Government representatives from Pomio, and non-government conservation organisations, as well as local villagers (Gabriel et al 2017).

After the successful serial site nomination, in 2009, scientists from Conservation International and PNG Institute of Biological Research together with local landowners surveyed East New Britain's natural biodiversity. The surveys yielded spectacular finds including a wide range of new species of spiders, frogs, various mammals (rodentia), reptiles, and birds. These incredible discoveries enhanced the conservation potential of the Nakanai area (Richards and Gamui 2011).

In 2013 the Nakanai Cultural Heritage project was conceived with a view to link, develop and facilitate an international awareness and support program that articulates both local and global concepts of universal value for the world heritage nomination of the Nakanai caves. It aims to document and integrate the natural and cultural values of the Nakanai Caves in preparation for the World Heritage Listing bid. Methodologically, this incorporates community knowledge with archaeological and anthropological evidence to link natural and cultural values and define the landscape from a local perspective. This paper describes mythical stories associated with some of these caves in the Pomio District.

2. The Mengen people of south Nakanai

Culture is a set of cognitive and behavioural practices that both combines and separates groups of people. Ordinarily members hold to be true similar ideas drawn from mutual personal experiences and knowledge of histories. In PNG, oral traditions are strong and highly valued. Stories known as 'tumbuna' stories serve as history and include amongst others, notions of group origin(s) and migration/dispersal pathways. The Mengen of Pomio District are one such group from which the following stories were derived. Their stories include sacred places that represent clan knowledge and reflect common identity and inheritance of socio-cultural rules. These places are a physical source of identity and represent unity (Leavesley *et al* 2005). For the Mengen these include; caves, rivers, waterfalls, lakes, sinkholes, rock-shelters and engravings are evident. Of these distinctive features, some have exciting stories that relate and reflect directly to these landscapes.

Contemporary residents combine aspects of traditional culture and modernity. They have mobile phones, and access to the internet. Equally, tradition, especially relating to access to use or ownership of land and ultimate origins is strong. People respect leaders and many communities solve their problems through village leaders, magistrates, the community and the church (Social Mapping Research Project 2005). Other traditional norms and practices remain valuable and are still practiced today in the Mengen societies. These practices include; traditional dances and chores during village gatherings (such as the making of traditional bowls from *luvo* leaves into *raliu* (traditional bowls), *papaitim* (speaking magic by chewing and spitting ginger), garden magic, first female menstruation, male general customary practices of marriage and respect of in-laws and elders *etc*. However, these practises are slowly changing, essentially to suit concepts of development.

3. Cultural significance of caves

In other parts of PNG, caves, such as in Karawari in the Sepik region, were once variously multipurpose ceremonial, burial and hiding grounds. In addition, they were used to perform rites that are purported to increase success in warfare and hunting. The caves are part of a spiritual landscape defined by rituals, stories, objects, and practices that are intimately linked to knowledge about life and ancestors. Importantly, these are places said to be first occupied by the ancestors. Caves and the associated cultural assemblage of practices, beliefs and knowledge are the expression of how the people of this area understand their relationship(s) to place, landscapes and geography (Gabriel and Gorecki 2014).

According to Mengen culture, their natural landscapes are also formed culturally. Knowledge in the form of stories (myths and legends) are passed down from generation to generation (oral traditions) by respected individuals within a clan. The sacred nature of the stories underpins their importance to the Mengen people.

The original version of these stories are inevitably passed down to the current generation in 'tokples' (mother-tongue). We have no avenue to test the verity of the translation from 'tokples' to 'tokpisin' (pidgin language) however, we are extremely confident with the accuracy of the translation from 'tokpisin' to English. We are also aware that some aspects of cultural stories and storytelling require access to other aspects of cultural knowledge. Hence, we are aware of the possibility that there are stories and parts of stories that may be diversely or individually related to the stories that are known but which we do not access. Equally, we also know that these stories reproduced here are not considered privileged knowledge and indeed we explicitly sort and received permission to present them here.

4. Nut-kovanga cave

The Nut-kovanga cave has two adjacent 'mouths' at the foot of a small cliff in the intertidal zone of the Jacquinot Bay, located between the villages of Galue [Galowe] and Bain. This cave is an important part of a local creation-story called Malila (Nutu) (means 'god') told by Patrick Kontorea (Kakaile clan), from Galue village. Patrick is a well-respected elder from his village. The following is an extract from the Malila-creation story told by Patrick in Melanesian pidgin to R. Tsang and S. McIntyre-Tamwoy on 21 February 2017, was translated and recorded. The English interpretation is as follows;

> *"…So the next day, they cut the tree, split it into timber to make a 'galeo' (a shield). While the boys were doing that, Malila walked to 'Nut-kovanga' then to Pelau-matana. From Pelau-matana, he rested at the beach and started drawing on the stone called 'Matapilo'. The rock art depicts a woman and a man. From Matapilo, holding a fishing spear and walking along the shorelines, Malila then carved stones called 'Nut-tetelea' (these exist today in the reef). A conus shell was blown as a call for Nutu during a traditional feast at a village called Longserengreng held by the villagers. He walked through 'Nut-kovanga' and arrived at Longserengreng village to partake in the traditional singsing. When the feast ended, he went into the tunnels (Nut-kovanga cave) and arrived at Sinagolgol (a stone carved into a Mengen traditional shell money)…*
>
> *…Muakale then disappeared (with the flow of water) with the shield. So the parable is Muakale disappeared with all their knowledge. Malila (Nutu) was so angry and went through Nut-kovanga and came out on the other side. He then trav-*

Figure 2. *Interviews with local informants, Palmalmal, Pomio. Photo Courtesy: Susan McIntyre-Tamwoy.*

> *elled up to Sinagolgol. Patangkale and Koianga then started their journey into inland Pomio...*
>
> *…He crossed the water Galue and followed the side of the river up. When he arrived at Basigo, he started to block the river (where it is, there's a huge dam called Nanamepopite). Water Galue dried up. Malila blocked it with trees. The dam is past their old settlement sites and further up. From the dam to Sinagolgol, he travelled through Nut-kovang. He then gets a canoe and taro and pulled to Kalamage. There he planted taro near Marana at Mopuna (these places still exists today)…"*

These excerpts clearly show that Nut-kovanga was used by the indigenous god as a 'pathway' in the local creation-story. From the 'pathway' (Nut-kovanga cave), the same god also left behind engravings (at Matapilo) that can still be seen today. This story was interpreted in terms of the ultimate origins and the migration/dispersal of the Mengen people across the region. Importantly it also serves to link them directly to their environment and the various engravings are symbolic messages in Mengen terms.

5. Pelau-matana cave

A second case study combines an ancestral story anchored to a location between Galue village and Bain village, Jacquinot Bay. Located a few kilometres east of Nut-kovanga is Pelau-matana (Figure 3), also located in the intertidal zone at the foot of a small coastal cliff. In the Mengen language, Pelau-matana means 'ai blo solwara' [in pidgin] or 'lid of the container with seawater'. Nut-kovanga and Pelau-matana cave stories are part and parcel of the local Malila [god] creation-story. The following is a story told in Melanesian pidgin by Iggie Matapia from Malakur village (Lolopuna Ola clan) to R. Tsang and S. McIntyre-Tamwoy on the 16 February 2017, was translated and recorded. The English interpretation is as follows;

Figure 3. *Pelau-matana cave. Photo Courtesy: Jason Kariwiga*

> *"Once upon a time, there lived an old lady with her two grandchildren (described as Nutu/god family). Every day, the grandmother goes to the garden. She brings taro leaves when she comes back home. She uses tree barks (kala, sigilai, guno or gialaunga in Mengen language) to wrap two wraps of taro leaves (one for her and one for her grandchildren). She urinates on her grandchildren's wrap while for her wrap, she would lift the stone where the salt is kept and pours salt on hers. She repeats that every day. Her grandchildren's wrap continuously taste differently from that of their grandmother. However, one day, her grandchildren followed her to the garden. They hid from her. When it was getting dark, quietly, they followed their grandmother. They saw her take the taro leaves. She then wrapped them separately in the tree bark. She urinates on one then lift a stone to get salt water to put in the other wrap. She then leaves for the village with the wraps. When she left, out of curiosity, the grandchildren went and lifted the stone. This allowed the salt water to flow out. At the village, grandmother was surprised and panicked, she ran to the point at Unung (Wunung) (now where Unung river/creek flows out from) then to Galue and grabbed the points trying to contain the salt water but the salt water (now sea) flowed through. She then ran to Pomio and Manginuna and tried to do the same. But again, she couldn't contain the water. She went to Pulpul and Bairaman and tried to do the same. However, it didn't work the third time" (According to Iggie, the stone lid still exists under the sea within Pelau-matana cave).*

This story clearly describes the meaning of the cave name itself as a creation-story associated with spiritual powers. Pelau-matanna is a focal point associated with local creation (whereby it is interpreted as lid of a container of salt water relating to seawater) and once the lid was removed, the salt water flowed out, forming the villages of Unung [Wunung], Galue, Pomio, Manginuna, Pulpul and Bairaman which are all in Jacquinot Bay.

The Pelau-matana cave story points to notions of the origin of a specific series of local villages and therefore is amongst other things, an expression of a claim to access and ownership over those villages providing us with a village creation story.

Taken together the Nut-kovanga and Pelau-matana stories including other rock art sites on cliff faces in rock shelters (e.g. Matapilo, Marana Kepate, etc.) are all related to the local Nutu or god-creation story. They include important notions of ultimate origins, subsequent dispersals and migrations as well as local village origins in stories that directly link these concepts with specific caves thereby explicitly and literally embedding them in the landscape.

6. Conservation Issues

Transnational companies (e.g. logging, mining, and oil palm plantations) (see Gabriel *et al* 2017) are a major threat to the cultural values of Pomio District and PNG as a whole. An example is the recent incident where 'Marana Kepate', a cave with engraved art, in the Nakanai area was threatened by a logging and oil palm company operating under a Special Purpose Agricultural Business Lease (SABL) issued by the PNG government. It was saved by landowners who reacted quickly and invoked PNG cultural heritage legislation.

In addition, according to the Rapid Assessment Program (RAP) Bulletin of Biological Assessment 60, fire is also a threat to the integrity of high-elevation forests in the Nakanai Mountains. Much of the montane forest on the Galowe (Galue) Plateau has been impacted by growth of bamboo following cyclones, and devastating fires during the 1997-1998 El Nino weather pattern. Furthermore, many species documented during the RAP surveys are known to require relatively undisturbed, closed canopy forest for their survival. The principal threat to the survival of these species comes from habitat loss, especially from logging, gardening, and the development of oil palm plantations. Protecting the existing habitats at a range of elevations, or at least major, connected fragments of them, is the most effective way of ensuring the survival of the biodiversity (Richards and Gamui 2011) as well as the natural landscape.

Tourism has not been a major factor in land management to date but this is changing in recent years (see Gabriel *et al* 2017). For example extreme tourism activities although a niche industry are growing in popularity in the area (e.g. the recent 'Red Bull' video on YouTube-Kayaking the Uncharted Beriman River in PNG, https://m.youtube.com/watch?v=-PZIpuAUz7Y).

As a result of the above and concurring with Richards and Gamui (2011), assisting local communities with awareness programs on management plans and using local knowledge will help restrict the impacts of existing logging roads, maximize forest conservation against oil palm, gardens and timber extraction, and awareness on the impacts of bush or man-made fires on Nakanai areas. Nonetheless, the Nakanai area will be further protected if it is declared a World Heritage Site. This will have the added attraction of creating tourism, business and employment opportunities for the communities within the Pomio District, New Britain and PNG as a whole.

7. Conclusion

The massive karst systems, rivers, water falls, engravings, diverse biodiversity including unique cultural landscapes of the Nakanai Range makes it a potential World Heritage Cultural site. These places in the Nakanai area and PNG as a whole are an important aspect of the society's cultural values. Of these landscapes such as caves, some are considered sacred and valuable according to their various traditional stories and so require special consideration in land, development and tourism management.

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Smart Monitoring of Cave Habitats - the VdHK Smartphone App

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Abstract

For several years, the German Speleological Federation, VdHK, has been involved in monitoring cave habitats for European Union (EU) legislation Natura 2000. In Natura 2000, habitats are listed and so are caves which are not open to the public. In a 6 year-period, member states have had to report about the status of habitats to the EU. In Germany this is delegated to the federal states, which is why there is a long history of speleo involvement in some of the German Länder and not in others. In 2010, VdHK started with the first workshop to educate members and to build up a working group about this monitoring process. The outcome was a new form which covers the whole range of habitat structures and cave animals in Germany. This form was presented at the Eurospeleo Congress in Yorkshire, England 2016. Many other federations were interested in it and the European Cave Protection Commission founded a new working group, biospeleology. One of the aims of Natura 2000 is the comparability of data in the European Union, VdHK is happy to share this knowledge. To make it easy and simple, a newly designed smartphone app is now available for every caver involved. The app guides the user through the different structures, negative impacts and species. It is connected to the biospeleological register of the Hesse Federation for Cave and Karst Research and will provide additional information to the normal cave survey.

The app is so easy to handle that the decision was reached at the German working group meeting to use it in every cave, in order to get comparable information about conditions, habitats and species, both now and in the future.

Keywords: cave monitoring, biospeleology, habitat, Natura 2000, smartphone app

1. Introduction

In 1992, the governments of the European Communities adopted legislation Natura 2000 to protect the most seriously threatened habitats and species across Europe. It is a network of nature protection areas in the territory of the European Union and made up of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) designated respectively under the Habitats Directive and Birds Directive. The Habitats Directive obliges member states to monitor the conservation status of listed habitats and species of interest in Europe, over a 6 year period. Caves not open to the public form one of the habitats under protection. For cave animals, only bats are covered in Appendices II and IV. During the setup of Natura 2000 protected areas in Germany, VdHK was unfortunately not very active. The Hesse Federation for Cave and Karst Research did a good job and succeeded in protecting caves in this part of Germany. Based on excellent connections with the authorities, close cooperation in management plans and monitoring were the results. It became a template for Germany. Since 2010 VdHK provides workshops for biospeleology basics and built up a working group to standardize the process of monitoring caves.

2. New EU Habitat Directive Assessment Procedure in Germany

In 2015, a new monitoring form was agreed to at the VdHK working group meeting. Underlying the requirements of Natura 2000, the VdHK form was optimised in relation to caves and karst environments. At the heart of this new assessment procedure is a holistic inventory of the cave habitat type (ecology, fauna, geology). Clearly defined assessment criteria were developed to describe the cave conditions in a comprehensive way, to get an overview of one single cave as well as for the cave habitat in a region as such. To show if a cave gets favourable/good, insufficient or unfavourable/bad status an A, B or C is allocated to each and every subcategory. This summarises into an overall status of the habitat of a single cave together with data from other member states, giving the average status of caves in Europe.

The VdHK form is structured in 3 main categories: habitat structures, species and negative impacts. Nineteen habitat structures have to be qualified to be outstanding (A), good (B), or lacking (C): stagnant or flowing water, humid walls, active dripstones and sinter, shafts, halls, smaller

chambers, fissures, rocks, sediments, organic material, transition zone, dark zone, frost free, constant temperature, height humidity, ventilation and draught protected areas. For each section a guideline is provided to get comparable results.

Species are classified in subtroglophile, eutroglophile, eutroglobiont and endemic. Cave animals are counted by number and species. The higher the amount of a species, the better the status – except for endemic species which immediately leads to a high ranking. As an outcome of decades of sampling in Hesse, a database of cave animals was already in existence and was used to categorise them. For every species found in a German cave, an information sheet was prepared which can be downloaded from the biospleology register. Zoology, characteristics of the species, distribution, ecology and findings can be derived.

For the Natura 2000 monitoring program, animals are captured by hand as well as in barber pitfall traps in different areas of the cave and sent to experts for identification. Bats have to be listed additionally because of the high status of protection, especially the species listed in Habitat Directive Appendix II: *Myotis bechsteinii*, *Myotis dasycneme*, *Myotis emarginatus*, *Rhinolophus hipposideros* and *Barbastella barbastellus*. The diversity of species, their abundance and the habitat itself are taken into account. Overhanging rocks outside caves is the next extra on the list; they are described by flora only, like *Sisymbrio-Asperuginetum procumbentis*. All data of the species is integrated in the biospeleology register of the Hesse Federation for Cave and Karst Research.

Negative impacts are described, including cave tourism in summer or winter, climbing and bouldering, geocaching, fireplaces, soot, closure of the cave, digging, waste, pollutants, intervention of groundwater body, former show cave, abrasion, mining and backfilling. Every topic is defined in detail. In this category the expert itself prescribes the status. A vote of experts is additionally possible in every category.

This new approach was presented in 2015 to the Federal Agency for Nature Conservation (Bundesamt für Naturschutz) and was approved by the federal states except Bavaria. Unfortunately this region is persevering with the old system. VdHK hopes to convince them with the success in other parts of Germany and because of the ease of use which the VdHK members have confirmed. Since 2010, VdHK has provided workshops on biospeleology and the Habitats Directive. To raise awareness on cave biodiversity to the general public, the VdHK has been declaring a cave animal of the year since 2009 as part of the campaign "Nature of the Year" in Germany.

3. VdHK Smartphone App

To keep it simple VdHK decided to offer a web app which precisely represents the described approach. It will be presented at the VdHK annual meeting in June 2017. By opening the website containing the app once, the app can be used on smartphones, tablets, laptops and other computers individually without any further connection to the internet. Data input inside the cave is possible. The app guides the user through the input process, evaluates the data and calculates the final cave rating when requested. Data can be saved locally in several formats, such as pdf or a raw data format, allowing the output to be imported into any kind of database, like the biospeleological register. There is an option to send the collected data by email as well. All in all, the VdHK app can be used as a modern diary for cavers. It allows for a description of the status of a cave in addition to the survey. It serves as an instrument to engage cavers in biospeleology and to show trends.

The link to the VdHK app will be available at www.vdhk.de. To make the usage as simple as possible, there is an option to choose German or English.

4. Conclusion

The new VdHK EU Habitat Directive form covers usage for monitoring and management plans of Natura 2000 as well as environment impact assessment. At it does not embed maps, sharing data should be uncontroversial. In the long run, every German cave shall be evaluated and the data integrated into the regional cave register to provide a comparable status of a cave now and in the future. It is a big step forward for cave protection and an essential addition to the survey.

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Karstcare - Cavers Looking After Caves And Karst

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Abstract

Karstcare is an environmental group set up in 2000, working principally in the Mole Creek Karst National Park in Tasmania. The group is made up of both ASF & non-ASF cavers and Karstcare has given these cavers a very different reason to go underground. To date this group has contributed over 3000 hours to both surface and underground projects. Such projects have included weed eradication, rubbish removal, installation of boot washing stations, track marking and cleaning both tracks and speleothems.

Our aim has been to install good management practices that will pay dividends for many years to come. Some of the work sites are unusual and often difficult to access, requiring an innovative approach to achieve results. A number of these projects are outlined, supported with photos of these caves. This paper summarises the lessons learned, and what can be achieved by a group of motivated cavers.

Keywords: Environment, Cave Management, Volunteers

1. Introduction

Karstcare is a group of active cavers mainly from Northern Tasmania who are interested in contributing to the management of caves in the Mole Creek Karst National Park. Each Karstcare participant is a member of Wildcare, which is the largest incorporated environmental group in Tasmania. Wildcare has existed since 1998 and is a community partner organization with our National Parks Department. Wildcare members work alongside staff of the Conservation and Parks & Wildlife Service (PWS/ Parks). (Wildcare Tasmania n.d.).

Wildcare has its own insurance, regretfully an important necessity in current times. The insurance premium is paid by Wildcare to cover members who are undertaking any Wildcare approved work. Working bees are either proposed by Parks staff themselves, or our own group may propose a project, subject to Parks approval; examples being installation of new track marking, or siting P-hangers for rigging. We work directly under the Parks Office at Mole Creek. Our structure is somewhat casual, with a President, who I prefer to call a co-ordinator, and various volunteers from both within caving clubs and cavers not aligned with a club.

The President's role is to liaise with Parks staff to discuss projects, coordinate volunteers and equipment. He also arranges all administration with Wildcare, such as working bee call-ups and activity notification and ensures proper registration of each volunteer for each activity to ensure insurance cover, and prepares a Job Safety Analysis for most projects. One of the most difficult tasks for the President is the raising of funding for projects. This can be from within the Wildcare organization itself, from various Government-based environmental bodies or even from corporate bodies. Although most of our work is labour-based, funds are required for such things as cleaning equipment, ropes for access, track markers, and protective matting (WildCare Tasmania n.d.).

2. Achievements So Far

2.1. Kubla Khan Cave

Kubla is one of Australia's premier wild caves and is considered by many to be world class. Access is extremely restricted, involving a permit and supervision by an accredited leader. Its 5.5 km length involves considerable vertical skills with outstanding speleothems and some massive chambers.

Cavers contributing to Kubla Khan's management started back in the early 1990's with a proposal from Northern Caverneers Inc to place clay-filled bags over particularly muddy areas and install boot wash stations to minimize mud tracking and erosion. Assistance was also given to Parks staff with gating and since then a huge amount of cleaning the main route has been on-going.

We have installed fixed P-Hanger rig points to limit damage on pitch heads and used the 2005 Australian Speleological Federation (ASF) national conference as an opportunity to conduct mass working bees. Before the conference two children's swimming pools were installed for water storage in preparation for a major cleaning project carried out by conference attendees, each contributing two hours of work whilst undertaking a trip through this magnificent cave. (Wools-Cobb 2006). Now boot-washing stations are positioned throughout Kubla Khan Cave. If used properly, they are an effective method of limiting further mud tracking onto previously cleaned areas. These stations need periodic maintenance to remove accumulated mud and to replenish the water (sometimes from several hundred metres away). Some sections of the route have recently been re-marked to keep cavers to the cleaned areas. A major challenge was the cleaning of the rock-fall down to the huge 18 m high stalagmite known as "The Khan". We used an innovative method for this: instead of carting water in 20 kg loads in backpack sprayers, and getting aching muscles from scrubbing and spraying, we rigged up a siphon hose of 120 m with a spray head. This resulted in much less impact on the cave and cavers and enabled this project to be completed in about one-half of the estimated time (Wools-Cobb 2008) (Fig.1).

Figure 1. Brigida and David B. cleaning the Begum area, Kubla Khan Cave

Figure 2. Paul Darby at boot wash Tailender Cave

Any caver who has visited this cave will have seen a great deal of evidence of our members' contributions. To date a total of 1200 hours of work has been contributed by Karstcare to this cave since 2001. (Wools-Cobb personal records) Management of Kubla Khan is on-going, with areas having been re-cleaned every few years, and boot wash stations serviced.

2.2. Tailender Cave

We have carried out a line survey, instituted track marking and placed some advisory signage and string lines to protect some sensitive areas. We have also undertaken extensive cleaning of the route and installed three boot washing stations (Fig. 2). This time, instead of siphoning we installed a 12 volt pump to bring water up to the work site, as it would have been almost impossible to manhandle backpack sprayers from the water source. Installing p-hanger bolts on the pitch enables safe climbing and tube matting has been laid over some cleaned surfaces. This has proved to be our most difficult project, as to get to the worksite, usually with a big load of matting and cleaning gear required about 400m of crawling. Often our volunteers were quite exhausted before they even started the work! (Wools-Cobb 2008, 2009, 2010).

2.3. Weed reduction: Mersey Hill and Wet Cave Block Revegetation

The Mersey Hill area was purchased by Parks some years ago and has ongoing problems with the weed Spanish Heath. With this block being just above the Mersey River, it was considered that there was a risk that this weed would spread to adjacent areas and downstream.

The Wet Cave Block also has problems with Holly and Sycamores. Three working bees have contributed to the weed eradication on these blocks. The Wet Cave block project is the first time we've been involved in cutting hundreds of trees down in a National Park. Painting poison on plants seems an unusual activity for cavers but we managed to contribute a total of 186 hours to these surface projects. (Wools-Cobb 2006).

PWS, using Karstcare's good reputation managed to gain funding of $27,000 to revegetate three areas of the Mole Creek Valley. Paid labour was employed to plant out native plants in these areas, and since then our Karstcare group has replaced animal barriers to protect these plants, removing them as required. As such plants establish themselves we hope natural seeding will rehabilitate these areas over coming decades. Introduced deer are a problem on one of these blocks, so in conjunction with PWS we are trialing a deer fence and a wallaby fence to see how effective these are before considering extensive fencing. (Plowman 2009, Wools-Cobb 2010, 2011).

2.4. Croesus Cave

Croesus is probably the 'second most' spectacular cave in the Mole Creek area, with a spectacular flowstone feature named "Golden Stairs". At the top of these stairs is a big muddy pool, making it difficult not to track mud onto sections of the stairs. To improve this situation we built a rock walkway from surrounding rocks to prevent picking up mud and tracking it further. We also cleaned this area, and further one-hundred meters upstream. (Wools-Cobb 2003)

We have also worked on a little known upper-section of Croesus, string lining, cleaning the route and carried out a delicate job of cleaning a major speleothem that may have been used as target practice by youth groups with mud balls some years ago. A minor job was also carried out protecting some calcareous sand formations near the entrance of Croesus. (Wools-Cobb 2005)

2.5. Marakoopa Show Cave and Beyond

Some time ago we spent a day removing all "non-cave" material possible from the tourist sections. Apart from minor public litter, many old electrical installations plus other old construction materials were still lying around. In total, four large garbage bags were filled with rubbish and removed. The most interesting find was a very old "Milo-type" tin with candles and a few old-style light globes. Countless broken light globes were also removed. (Wools-Cobb 2007). We have installed some string lines in the "Fireplace section" and plastic matting to limit floor damage. With volunteers from an interstate group, Karstcare arranged for a challenging vertical job of removing invasive ivy from the cliff-face entrance to Marakoopa Show Cave (Wools-Cobb 2007).

2.6. Gunns Plains Show Cave

In July 2008 we were approached by Parks to be involved in the re-wiring and re-lighting project of Gunns Plains Tourist cave. We were given a tight deadline to have the cave "cleaned up" before the re-opening ceremony. This involved removal of old wiring, from sometimes quite exposed places, cleaning up any tourist rubbish and ensuring the pathway was clean. The contractor was so impressed with our efforts that we received a substantial donation. Members have also been involved in the non-tourist section of Gunns Plains Cave with cleaning and matting and on-going maintenance, and re-vegetation around the cave catchment. In this cave we have an on-going lampenflora survey, and have removed old wooden formwork left when concrete paths were laid during the cave's development as a show cave many years ago (Plowman and Wools-Cobb 2008).

2.7. Mapping

Karstcare has also been involved in mapping projects. Within Tasmania, a Cave Access Policy is being determined, and as part of that, PWS required good quality digital maps to be produced, which are seen as an essential tool to identify certain areas and features within a cave for special management considerations. A detailed digital map of the Blackshawl/Pyramid Cave System involved four caving clubs and over 450 hours' work (Wools-Cobb 2014).

2.8. Minor Jobs

Our Karstcare group have been involved in cleaning out two dolines in the Mole Creek area, which past farming practices viewed as a great place to dump rubbish. We have also assisted with water tracing, installing charcoal bags to determine the hydrology of an area containing several caves. In Gunns Plains Cave we have been involved in photo-monitoring of lampenflora.

In Baldocks Cave, an old redundant Show Cave, we have installed a fauna sanctuary near an entrance that is no longer used. This involved string lines, tape & advisory signage. In Lynds Cave and Cyclops Cave, boot wash stations have been installed, and routes cleaned, delineated with string lines and some matting installed to ensure minimal visitor impact in a particularly beautiful part of these caves.

3. Plans For The Future

Karstcare members are always keen to be involved in contributing to better management of caves & karst; we have developed the skills, and experience in managing caves to limit visitor impact. Heavily visited caves will always need cleaning, boot wash stations will always need regular servicing, fixed tapes and ropes need regular replacement.

More recently PWS had acquired some parcels of land with significant caves, which will require careful management. We expect Karstcare to be involved in this management at the earliest opportunity.

It is now time for us to commence removing the clay-filled bags that are showing considerable wear, having been in place for over 25 years in Kubla Khan Cave. We plan to remove most of these, substituting them with good cleaning techniques and where necessary careful placement of natural rock over the clay and mud that they currently cover.

Our guiding principle is to undo previous damage done by cave visitors and assist in managing caves to minimize future damage. Much of our work is tough; it sometimes involves standing in water at about 2°C while scrubbing flowstone with a brush! Many of our sites are difficult to access, but then who better to work in a cave than those who "naturally" feel comfortable in such an environment? Over the past 17 years that Karstcare has been in existence, more than 3100 hours of 'hands-on' work have been contributed to cave and karst management in our area. We believe that we have gained tremendous respect from Parks staff for both our expertise and determination to contribute to caves in an extremely positive way. (Wools-Cobb pers. records)

4. Lessons Learned

Designing, negotiating and funding underground environmental projects is a tremendous amount of work but is particularly rewarding. For every 10 hours spent on carrying out a project, about 2 hours are taken to 'make it happen". Without a great band of volunteers, and our determination to contribute in a positive way, our local parks staff could not possibly complete such environmental projects.

The work of Karstcare has given us a very different reason to go caving. We'd like to think that the caves that we work in are always better off for having us be there.

We've learned things such as:

1. Natural rock is easier to clean than most flowstone
2. Not all mud is from cavers
3. Gravity can be your friend if you can harness it (siphoning)
4. Batteries & pumps can minimize impact on caves and cavers
5. Collapsible backpack sprayers wear badly but are easier to transport than traditional solid fire fighting back packs
6. Wine cask type bladders are good for water transport and storage
7. Child's swimming pools make great water storage tanks
8. Only stainless steel pegs can be used as string-line supports (not aluminum)
9. Laminated signage is best on waterproof paper, waterproof markers and a good surrounding sealed area.
10. Some work sites are harder to get to than the work required when you're there
11. Even the most skeptical caver is surprised by what can be achieved with a scrubbing brush and sprayer. Visiting cavers are usually quite willing to put in a few hours work in return for a great caving experience.
12. If you keep plugging away, Parks staff will eventually be positive about what cavers can contribute.

13. Cavers can influence management with regard to caves. (Wools-Cobb 2012)

5. What Can You Do In Your Area?

It is important to involve speleologists/cavers in cave and karst management, especially as they are often the people who have found the caves, surveyed and documented them. I feel we should not judge either past practices of cavers or past cave managers using today's values. By using the expertise of cavers, managers can undo some past damage and institute good management principles (such as track marking and boot washing stations) to limit future damage to caves. Cavers usually welcome the opportunity to have an input into management decisions. We all care about caves, so with cavers and managers forming a partnership we can work together for the good of caves and karst.

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Cave Climate and Palaeoclimate Records

Heat Waves In Caves: A Useful Tool

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Abstract

This paper will delineate characteristics of heat waves and their role in the study of the cave environment. The influence of the outside temperature on the cave environment is very evident close to the entrance, but is also evident inside the cave, even if attenuated. Data on the propagation of the heat wave are reported for some caves. The parameters of the heat wave, such as amplitude and delay with respect to outside, supply useful data for both the protection of the cave environment and knowledge of the characteristics of the cave itself.

Keywords: Cave climatology, cave environment, heat waves.

1. Introduction

The influence of the outside temperature on the cave environment may occur either through air and water entering the cave or through conduction in the rock layer above the cave itself. The latter mechanism has some practical importance only if the rock layer is relatively thin and there are no other connections between the cave environment and outside. It was suggested the possibility of a record in a cave of an old climatic event (e.g. cold stage of the Pleistocene cold stage: Moore & Nicholas, 1964) with the transmission though a thick rock layer. In this case sometimes it could be rather difficult to distinguish between this process and other sources of disturbance.

The influence of the outside season temperature at the cave entrances has been observed and recorded about one century ago (Bock, 1913; Crestani & Anelli, 1939) but only more recently models were developed to describe the phenomenon (Cigna, 1961; 1967; Badino, 1995; Lismonde, 2002). If the influence quoted above is quite evident and was observed easily, the transmission of the heat wave due to the seasonal temperature deep inside the cave environment was measured more recently only (Cigna & Dini, 1997; Cigna, 2001; 2008).

In this paper the sinusoidal function of the average daily air temperatures outside and inside are compared and the transmission from outside to inside is called heat wave. The delay (days) between the maximum outside and the maximum inside is the travel time of the heat wave.

The identification of the heat waves in different points of a cave may supply interesting information on the cave itself with the use of simple temperature measurements. If such measurements are taken not regularly, a sinusoidal best fit generally provides a reliable function to describe the inside and outside heat waves for their comparison.

2. Experimental results

The heat waves measured in some caves are reported here. Some of them are unpublished while others have already been delivered at previous International Congresses of Speleology. All the data up to now available, both published and unpublished, are reported here with reference to each specific cave. In particular the attenuation of the outside seasonal fluctuation of temperature and velocity of propagation of the heat wave (reported as delay of the maximum) are here listed.

2.1. Frasassi Cave (Italy)

The official name of this cave is Grotta Grande del Vento, and is the most important show cave in Italy with around 200,000 visitors per year. It was discovered in 1972. Previously another cave in the vicinity with a church built inside in 1828 by G. Valadier, was known with the same name as Grotta di Frasassi and reported in many old publications.

The whole karst system is about few tens of kilometres long with one mainly horizontal kilometre accessible to tourists,. In 1989-90 some cracks in the rock in the White Hall (about half a kilometre from the entrance) were monitored to ascertain possible risks of any collapse and instruments were installed. The instruments concerning the rock were installed in holes long about 1.5 m deep. A number of thermometric measurements in air and rock were obtained with thermistors and are here considered for the evaluation of the heat wave. The data are reported in Table 1, where amplitude is calculated on the seasonal daily temperature wave, outside and inside. The few days time shift between the maximum detected by thermistors inside the rock and those in air correspond to the propagation time from the cave atmosphere to the thermistors inside the rock.

As a result of this research the heat wave in the White Hall of the cave was detected with a delay of about 16 days for air and 24 days for the rock, with attenuation to 2.4% in air and

Table 1. Heat waves between outside and the Frasassi Cave

Station	Date of Max Day of the year)	Amplitude		Delay (Days)
		°C	%	
Outside (Fabriano)	July, 22nd	17.5	100	0
CR1, air	August, 7th	0.4	2.5	16
CR2, air	August, 7th	0.5	2.8	16
CR3, air	August, 7th	0.3	1.6	16
CR4, air	August, 7th	0.5	2.8	16
DE1, rock	August, 17th	0.5	2.8	26
DE2, rock	August, 17th	0.6	3.2	26
ST1, rock	August, 14th	0.5	3.0	23
ST2, rock	August, 14th	0.6	3.4	23
ST3, rock	August, 14th	0.6	3.2	23

3.1% in rock of the amplitude observed outside. The relatively short delay is due to the rather large number of visitors in the cave, partiacularly in Summer time, some thousand per day, with a poor management of the door installed in the access tunnel. Therefore the visitors' flow plays an important role by a pumping effect in the heat transfer from outside.

2.2. Grotte di Castellana (Italy)

This cave has been for many years an important show cave with some hundred of thousand visitors per year. In the period from 1958 to 1983 an average increase of about 3°C of air temperature was detected (Cigna & Dini, 1997). Since 1980 an artificial supply of outside air at the dead end was operated for the comfort of visitors (a regrettable solution!). The data of the heat waves are reported in Table 2. Notwithstanding the amplitude of the heat wave, an unusual long delay is attributable to the heat exchange with the rock since the outside air is supplied at the end of a 360 m long section while the air temperatures were measured along the whole passage.

2.3. Grotta di Is Zuddas (Sardinia, Italy)

The cave of "Is Zuddas" was discovered in 1971 by local cavers. Successively a development into a show cave was started in 1980 and tourists started to visit the cave in July 1985 under the management of the "Cooperativa Monte Meana". Air temperature monitoring started in 1990 to control any possible effect due to visitors (Cigna & Sulas, 2000). The cave is mainly horizontal and develops along some branches interconnected with a global length of about 1.5 km, and are visited by some tens of thousands of persons per year; the heat wave data are reported in Table 3.

Since the temperature measurements were not taken systematically the amplitude of the best fit is approximate. Nevertheless it is interesting to observe that the heat wave has a delay between 1 to 2 months in general. In one part of the cave (The Organ) the delay was only one week long and a careful inspection discovered a short connection with outside as confirmed by a smoke release.

2.4. Kartchner Caverns (Arizona, USA)

This cave was discovered in 1974 on the property of Kartchner Family; fourteen years later a bill of the State of Arizona was passed and the creation of James and Lois Kartchner Cavern State Park authorised. After a long and detailed study of the cave, the first section of Kartchner Caverns was opened to the public in November 1999.

An evaluation of the tourist impact reported also data on heat waves in some stations (Cigna, 2001) and the result is summarized in Table 4. The delay of the seasonal outside temperature, i.e. the time of propagation of the heat wave ranges between 1 and 3 months according the station inside the cave and it can be assumed that the heat wave is transmitted through the cave passages through the action of the visitors' flow. In the case of the Echo Passage, which is narrow passage somewhat isolated from the rest of the cave, the detected heat wave has a delay of about 8 months which could be due to the transmission through the ~50m thick overburden above Echo Passage (Jagnow, 1999). Such an occurrence is not common since rarely a cave section is as isolated from the opening to outside. A detailed research should be carried on to confirm this hypothesis.

2.5. Crystal and Fantasy Caves (Bermuda)

These caves open in the same property and are now partly under the sea level. Air and water temperatures were measured weekly; in Crystal cave since October 1998 and in Fantasy Cave since November 2001. The evaluation of the amplitude is indicative only, due to the large error affecting each measurement because values were estimated with an uncertainty of about 0.5°C (Cigna, 2008). The data on the heat waves are reported in Table 5.

The delay of the heat wave propagation in both caves is almost the same for both caves and it can be reasonably assumed

Table 2. Heat wave between outside and the Castellana Cave

Station	Date of Max (Day of the year)	Amplitude		Delay (Days)
		°C	%	
Outside (Bari airport)	July 30th	14.8	100	0
Average value from "Duomo di Milano" to "Grotta Bianca"	August, 25th	2.6	17.6	26

Table 3. Heat waves between outside and the Is Zuddas Cave

Station	Date of Max (Day of the year)	Amplitude		Delay (Days)
		°C	%	
Outside	August, 1st	17.5	100	0
Medusa Hall	September, 15th	0.4	2.0	45
The Organ	August, 8th	1.5	8.6	7
Theatre Hall	September, 30th	0.1	0.4	60
Eccentric Hall	August, 31st	0.1	0.5	30

Table 4. Heat waves between outside and the Kartchner Caverns

Station	Date of Max (Day of the year)	Amplitude		Delay (Days)
		°C	%	
Outside	August, 1st	17.42	100	0
Rotunda	September, 5th	0.36	2.1	35
Cul-de-Sac	September, 30th	0.14	0.8	60
Main Corridor	September, 30th	0.54	3.1	60
Grand Central	September, 30th	0.90	5.2	60
Lower Throne	September, 30th	0.14	0.8	60
Big Room Overlook	September, 3th	0.04	0.2	60
Kartchner Towers	October, 16th	0.14	0.8	76
Jack Rabbit	October, 22nd	0.04	1.1	82
Sharon's Saddle	November, 15th	0.34	2.0	105
Echo Pass. (Start)	March, 28th	0.10	0.6	238

that the transmission occurs through the air along the cave by convection and diffusion processes. The delay of the heat wave propagation in water, on the other hand, is quite different and it is very short in Fantasy cave. Temperature profiles for both caves explain such a difference, since in Fantasy Cave the water temperature is constant from the surface to a depth of 5.5 m while in Crystal Cave a thermocline occurs at a depth of 2.5 m. In both caves a pycnocline was observed around the same depth suggesting a fresh water supply from the water table, while the connection between Fantasy Cave and the sea is closer to the sea surface where the wave and tidal influence prevails (Bermuda Water Consultants Ltd., 2001).

3. Discussion and conclusions.

The heat waves, as they are described here, may provide some interesting information on the connection between a cave and the outside. The delay observed between the respective maxima, that is the propagation time of the heat wave to reach a given point inside a cave, together with the reduction of the wave amplitude are the parameters to be taken into account.

The heat propagation may occur through air, water or rock. In general air plays the most frequent role and in most instances the movement of the air mass is prevalent with respect to simple conduction. Therefore such a process gives precise information on the degree of connection of the cave with the outside, which, for the protection of the show caves' environment, is relevant.

The propagation through water must be distinguished if the water is still or flowing. In the first case it is due mainly to conduction and convection while, if a river is flowing inside the cave, the water flow plays a relevant role in the heat propagation since the water heat capacity (weight) is about 4 times that of air heat. For this reason the river's own characteristics rules the heat transmission and the heat wave from outside may be largely modified by the hydraulic regime. For instance the Grotta di Bossea, Cuneo, Italy, is an interesting example because the amount of the river water flow influences directly the air temperature inside the cave. Since snow is relevant in the catchment area, its melting in springtime increases the water flow with a reduction of the water temperature. Once the water flow decreases to a relatively low level, the temperature both of water and air reach their maxima. Obviously in the case of a cave with a river, the river mainly controls the cave air temperature and the heat wave propagation has little or no meaning.

Table 5. Heat waves between outside and the Crystal and Fantasy Caves.

Station	Date of Max (Day of the year)	Amplitude (%)	Delay (Days)
Outside, surface seawater	August 13th	100	-
Outside, air	August 12th	100	43
Crystal Cave, water	August 13th	22	20
Crystal Cave, air	September 1st	18	40
Fantasy Cave, water	September 22nd	18	5
Fantasy Cave, air	August 18th	22	43

If the water inside the cave is not flowing, as in the case of Bermuda's caves, there are two different heat waves for water and air, the former moving faster on account of the higher thermal conductivity of water.

When annual series of temperatures are available for different branches of a cave it is possible to detect short connections with outside. In Is Zuddas Cave the heat wave delay ranged between 1 to 2 months in four areas of the cave but decreased to 1 week in the only one part where some roots were found confirming the closeness to the exterior.

The propagation through the rock is detectable when the thickness of rock is less than few tens of metre only and the connection through the air is practically absent along the cave. Therefore it is rare and, among many different situations, it was ascertained only in a small passage of the Kartchner Caverns where a long delay of the heat wave together with small amplitude was found.

Badino (2017) developed a theoretical study of the propagation of heat waves in caves. Two models are proposed describing respectively such two kind of the propagation described here. A low pass filter, by considering the cave as a thermal capacitor with a sinusoidal input, describes the case of propagation into the cave, while a diffusive wall model describes the less common case of propagation through the rock. Such models were developed to study the local ipogean thermal insulation using the seasonal temperature variations. The models could perhaps be applied to evaluate quantitatively some more interesting parameters of the heat propagation inside a cave, along the cave itself or, in case of shallow caves very isolated, through the rock between outside and the cave wall. The latter case is uncommon because, in addition for the cave to have no or very little connection with outside, the rock layer must not exceed few tens of metres. Otherwise the heat wave inside the cave is too small to be detected. .

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(Abstract) **A $\delta^{15}N$ and $\delta^{13}C$ guano-derived 1200 year record of hydroclimatic change influenced by the North Atlantic Oscillation: NW Romania**

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Abstract

Cave deposits are among the most valuable continental sources of evidence for long-term climate and environmental change. While late Pleistocene and Holocene speleothems have abundantly been used in paleoclimate reconstructions worldwide, cave guano deposits remain an under-investigated archive of climate variability and vegetation dynamics. $\delta^{13}C$ and $\delta^{15}N$ analysis was completed on a 287 cm long guano core recovered from Măgurici Cave (NW Romania) with the intent of characterizing past changes in local hydroclimate and vegetation dynamics. Two hiatuses were found in the ~1,200-year old guano at AD 1079-1131 and AD 1310-1654. The second hiatus corresponds with the first half of the Little Ice Age (LIA). $\delta^{13}C$ values indicate that no C4 plants existed in the region since AD 800, therefore the isotopic values are interpreted to reflect past water availability in the C3 vegetation community. The $\delta^{15}N$ values of guano are correlated with $\delta^{13}C$ values of the same core, indicating that both nitrogen and carbon isotopic data represent variations in wet/dry conditions. The 4‰ increase in $\delta^{13}C$ values (1‰ decrease in $\delta^{15}N$ values) between AD 850 and 1300 indicates that the climate was trending towards drier conditions leading up to the LIA. Variation of 1-2‰ in both $\delta^{15}N$ and $\delta^{13}C$ between AD 1650 and 1900 suggests that there were changes between relatively wet and dry periods. This interval is punctuated by the driest period in the record at AD 1920. In addition, it was determined that the North Atlantic Oscillation has an influence on precipitation in the region, and therefore also on the carbon and nitrogen isotopic composition of the guano. Lower $\delta^{15}N$ and higher $\delta^{13}C$ values (drier conditions) occur during positive phases of the North Atlantic Oscillation, when colder and drier winters are expected in southern Europe. These findings indicate that $\delta^{15}N$ and $\delta^{13}C$ values of cave guano can be used to investigate the role of large-scale atmospheric circulation patterns, which control precipitation and temperature variation in the cave region. Our results have strong implications for the interpretation of climate variability in the region as recorded by the guano deposit within the Măgurici Cave, which is more than 1,000 years old.

Sourcing Carbon Dioxide Gas In Karst Systems

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Abstract

Recent studies have demonstrated that caves may act as significant reservoir of CO_2 gas on an annual scale and may be acting as sinks for atmospheric CH_4 on a daily scale, which provides evidence that the subterranean atmosphere of karst systems may play a key role in regulating greenhouse gases in the atmosphere. In this study, we have measured CO_2 variability and carbon isotope composition of subterranean air in karst environments. The cave sites cover a spectrum of local climates (oceanic and continental), bedrock lithology, cave microclimatic conditions, ventilation pattern, geomorphological and speleogenesis types (epigenic and hypogenic caves). The potential mechanisms involved on the CO_2 dynamic of either soil or geogenic-derived CO_2 in subterranean atmospheres are discussed. The atmospheric air that is inhaled into dynamically ventilated epigenic caves then return to the lower troposphere as CO_2-enriched air, during periods with higher ventilation. The first samples obtained in an active hypogenic cave (Vapor cave) exemplify the potential releasing of CO_2 along the faults and in the fractures occurring in the carbonate rocks and its significant influence on the conditions of the adjacent soil and local atmosphere at exterior.

Keywords: carbon dioxide, methane, caves, carbon isotopes, karst, subsoil.

1. Introduction

The increasing concentration of greenhouse gases (GHGs) in the atmosphere and its relationship to the Earth's climate are deserving a special scientific attention focused on the identification and characterization of all possible sources, reservoirs and sinks of GHGs, in order to calculate more accurately the carbon greenhouse gases budget, mainly CO_2 and CH_4 (Ciais *et al.* 2013 and references therein). The subterranean atmospheres are key locations to be considered regarding the balance of atmospheric carbon. Karst settings are reported to cover between 12 and 25% of the land surface of the Earth mainly linked to outcrops of carbonates (Ford and Williams 2007). These areas are potentially capable of harboring underground air masses (e.g. caves) that are periodically renewed by interaction with the atmospheric boundary layer and directly influence their physicochemical properties.

Some previous tracing studies employing carbon isotopes (Frisia *et al.*, 2011; Garcia-Anton *et al.*, 2014 and 2017; among others) or an analytical approach addressing CO_2 fluxes (Cuezva *et al.*, 2011; Corinne *et al.*, 2013), have demonstrated that the deep soil air CO_2 is the main source of this gas in cave air in near-surface cavities (generally formed under an epigenic context). CO_2 air in some deeper caves results from the interaction of cave ventilation with a reservoir of CO_2-enriched ground air formed by the decay of organic matter washed down into the deeper unsaturated zone (Mattey *et al.* 2016) and held within the smaller voids and fissures of the bedrock-surrounding cave.

Caves formed by specific hydrogeochemical mechanisms of hypogene speleogenesis and their interaction, e.g. hydrothermal, sulfuric acid, mixing corrosion, dissolution of evaporites, dissolution in mixed sulfate-carbonate sequences (Klimchouck *et al.*, 2014; Chavez and Reehling, 2016) can harbour subterranean atmospheres with a distinctive gas composition with presence of abiotic CO_2 gas (formed by chemical reactions which do not directly involve organic matter), which are frequently mixtures of multiple sources. This composition results from the current activity or residual signs of some processes as degassing from CO_2-rich groundwater or deep-sourced (geothermal) CO_2.

The pathways and mechanisms that control the fluxes of CO_2 among atmosphere, soil and subsurface reservoirs in karst terrains have not been characterised to date from an overall view, i.e. including at the same time diverse geological, tectonic and hydrogeological environments in the data analysis process. Here, we put forward some general insights concerning the GHGs behaviour in the upper vadose zone of karst terrains, based on climatic and gas composition monitoring combined with geochemical tracing using the stable carbon isotopic signature ($\delta^{13}C$) of CO_2. This study contributes with new data and findings to define and characterize the biotic and abiotic processes that regulate the CO_2 dynamic in near-surface epigenetic and hypogenic caves and assess their interaction with the external atmosphere.

2. Sites, materials and methodology

Fieldwork based on tracking gases has been deployed in sites were authors maintain a comprehensive cave monitoring and sampling networks in place for air analysis of soil and subsurface. Here it is only presented four of the most outstanding cave sites that summarize a wide range of processes that regulate the consumption and storage of CO_2 and CH_4. Ojo Guareña cave (northern Spain) is a highly ventilated cave with large daily and climate-driven oscillations of CO_2 levels (680–1900 ppm/day) (Fernandez-Cortes *et al.*, 2015). Castañar cave (central Spain) is a low-energy and quite isolated cave with very high thermal stability and poorly ventilated at daily scale (Fernandez-Cortes *et al.*, 2011). Pech Merle cave (southern France) is an example of cave atmosphere enriched in soil-derived CO_2 (1.4–2.8%) and depleted in O_2 (<19.5%), with clear evidences of stability of its underground microclimate since last two decades (Bourges *et al.*, 2014). Vapor cave (southeastern Spain) represents a particular case of chasm developed in a karstic area of active faulting with evidence of geogenic sources for CO_2 and CH_4, hydro-thermalism (38–43 °C), hypoxic conditions (O_2 ranging 17–18%), related to upwelling flow in or from the zone of fluid-geodynamic influence (Perez-Lopez *et al.*, 2016).

Spot air sampling was conducted in a predefined network of points spatially distributed inside each cave and exterior atmosphere. Soil air collection was also conducted at sites located vertically above each cave at a depth of 50 cm, near the bedrock–soil interface. Air samples were collected into 1 L Tedlar bags with lock valves and using a micro-diaphragm gas pump. Samples were obtained on a bi-monthly basis in Ojo Guareña and Castañar cave during more than annual cycle. Pech Merle and Vapor cave were sampled under, at least, two different meteorological seasons.

Bag samples were analyzed using a CRDS analyzer model G2201-i (Picarro Inc., Santa Clara, CA, USA) belonging to the National Museum of Natural Sciences (Spanish Research Council). The device was calibrated before each analysis session using synthetic gases with known concentrations. Further details about the methodological procedures can be found in Fernandez-Cortes *et al.* (2015). CO_2 mole fractions of samples were also measured independently in the greenhouse gas laboratory at Royal Holloway University of London with a Picarro G1301 CRDS analyzer, calibrated against the NOAA reference gases. The carbon isotopic ratio ($\delta^{13}C$-CO_2) of bag samples was measured in the RHUL lab in triplicate to high precision (±0.05‰) by continuous flow gas chromatography isotope ratio mass spectrometry (CF GC-IRMS) (Fisher *et al.* 2006).

3. Results and Discussion

Figure 1 summarizes some prevailing processes once the dataset of gas concentrations (CO_2) and its carbon isotopic ratio were analyzed for the studied caves. The extrapolation down to the X-axis of the keeling functions (colored lines of Figure 1) gives the $\delta^{13}C$ for the CO2 sources at each cave site (-26.16‰ at Ojo Guareña, -26.19‰ at Castañar, -23.08‰ at Pech Merle). These $\delta^{13}C$-CO_2 data confirm that CO_2 in shallow caves (Castañar and Ojo Guareña) results from from mixing atmospheric air and CO_2 produced by microbial respiration in soils containing organic material from C3 vegetation (around -27‰ according to Amundson *et al.*, 1998, in contrast to the observed $\delta^{13}C$ values for C4 vegetation; approximately -14%, O'Leary, 1988).

The $\delta^{13}C$ of the CO_2 source in Pech Merle is heavier than other caves despite of the woodland vegetation with a C3 pathway is predominant on the surface. This suggests that ground air is influenced by the decay of organic material washed down into the deep soil and unsaturated zone and it could be another important CO_2 source of this cave.The organic matter from soil can transported by infiltration of water through fractures and voids in the vadose zone immediate below the deepest layers of soil. The microbial decomposition of this organic matter leached from the soil produces air enriched in CO_2 and, undoubtedly, with a different isotopic composition from the CO_2 generated directly by modern-day soil. This CO_2 with a heavier $\delta^{13}C$ can then enter the cave through diffusion via cracks and fissures in the bedrock. Mattey *et al.* (2016) have also described this additional CO_2 source in Gibraltar caves and it seems to be also responsible for the high accumulation of this gas in Pech Merle, which is favoured by the prevailing low air renewal of this cave site. The high CO_2 concentration in Pech Merle (ranging 1.5–2.7%) determines the tendency to hypoxic conditions of the cave atmosphere due to a mole-to-mole replacement of O_2 by CO_2 in air (O_2 levels ranging 17.9–19.5%)".

The grey-shaded area in Figure 1 show the air-mixing model in shallow epigenic caves (e.g. Ojo Guareña and Castañar) between background atmosphere and a theoretical composition of pure CO_2 produced by microbial respiration in soil. The black-solid straight lines of the mixing area are labeled as % of pure additional CO_2 from soil remaining in the cave air and soil air. As the distance of the cave air samples from the y-intercept of the Keeling models increases, there is greater ventilation and greater influence of the external atmosphere. Conversely, when CO_2 concentration is high and $\delta^{13}C[CO_2]$ tends toward the y-intercept, the gas enters by diffusion and has a mainly edaphic origin. Cave air in highly ventilated sited as Ojo Guareña is well mixed with background atmosphere and the remaining soil-derived CO_2 is usually below 5% with a marked seasonal variation, except for air samples collect during summer months (from July to early September) when this percentage is above 10%. By contrast, air of poor-ventilated cave as Castañar the remaining soil-derived CO_2 is usually above 10%.

The black-solid curved arrows in Figure 1 show the kinetic fractionation trajectory of soil CO_2 due to its upwards diffusion to open atmosphere, modelled by a Rayleigh-type distillation process with a fractionation coefficient of 4.4‰ (based on the theoretical mass-dependent fractionation between $^{12}CO_2$ and $^{13}CO_2$ during diffusion, according to Camarda *et al.*, 2007). The Rayleigh equation is an exponential relation that describes the partitioning of isotopes between two reservoirs as one-reservoir decreases in size, in this case the CO_2 content in soil air. Each curve arrow starts from a soil air with a different percentage of remaining pure CO_2 produced by respiration in soil, i.e.; theoretical source of CO_2 (2% CO_2 and -27‰ $\delta^{13}CO_2$), 20% remaining and 50% remaining, from the lower to upper arrow respectively. As an example, the upper curve arrow is labelled with the fraction of CO_2 remaining after Rayleigh fractionation associate to the diffusion process. Some cave air samples from Ojo Guareña and Castañar fit well to these diffusion curves, i.e. CO_2 of cave air tends to be heavier while its concentration almost no change, which could indicate a slight diffusion of this gas from the monitored areas of this cave to deepest or nearby locations of the vadose zone.

A distinctive case is represented by the air samples from Vapor cave, where the high concentration of CO_2 and its heavier $\delta^{13}C$-CO2 (5.97‰ on average) result from a deep source of CO_2 in cave-air. The hypogene speleogenesis and the current

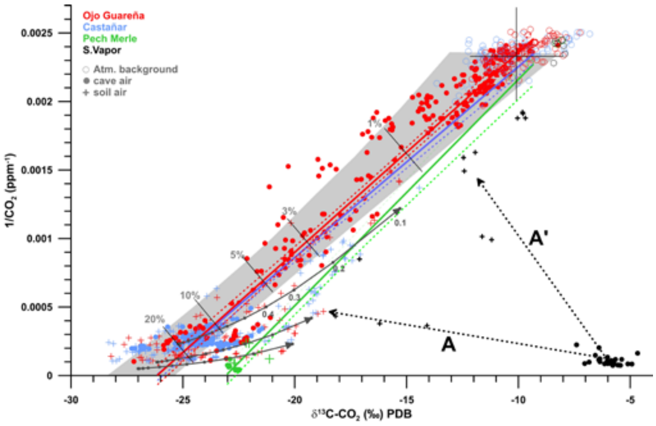

Figure 1. Keeling plot of 1/CO_2 versus $\delta^{13}C$-CO_2 considering three air reservoirs: (1) background atmosphere, (2) cave air and (3) soil air (see legend). The average composition of the background atmosphere for the 4 fieldwork sites is indicated by the crosshair. The colored continous lines indicate the keeling functions the three-component mixture (atm, cave and soil) and almost it does not differ from the two-component functions (atm-soil and atm-cave); R^2=0.95 (Ojo Guareña), R^2=0.94 (Castañar), R^2=0.99 (Pech Merle). Dotted lines show the 95% confidence intervals for each Keeling function. See text for further data interpretation and discussion.

gas exchange processes are controlled by the upwelling air flow from the zone of fluid-geodynamic influence associated to an active fault with frequent microseisms (Perez-Lopez *et al*., 2015). The $\delta^{13}CO_2$ values in air are also consonant with those measured in the CO_2-rich thermal waters of the aquifer spatially associated to the active fault (between -8.1 and -3.8‰, according to Ceron *et al*., 1998). Therefore, degassing from CO_2-rich groundwater and deep-sourced geothermal CO_2 are the prevailing process responsible of the high abundance of CO_2 and its heavier carbon isotopic composition, which is clearly distinguishable from the epigenetic caves where the isotopically light endmember CO_2 is soil-derived. The upwelling flow of geogenic gases in this cave has a clear influence on the $\delta^{13}C$-CO_2 of the soil air above the cave and, to a lesser extent, on the local atmosphere. This effect is noticeable in both the soil air well-mixed with open atmosphere and the soil air mixture with a higher percentage of remaining pure CO_2 produced by respiration in soil (arrows A' and A in Figure 1, respectively). The soil air in Vapor cave sometimes have lower CO_2 values than the other caves, despite the input of geothermal CO_2. There is an intense upward flux of CO_2 from soil to atmosphere, likely higher than other sites with deeper and wetter soils. Consequently, the soil CO_2 at Vapor cave results from a mixing between atmosphere and the composition of geogenic CO_2 coming from the subterranean atmosphere.

Pending to a full comparative analysis of $\delta^{13}CO_2$ and other isotopes (D/H for CH_4 and $^3He/^4He$) of air samples from Vapor cave, the obtained results ($\delta^{13}CO_2$ ranging from -4.5 to 7.5‰) indicate that the likely source is a mantle-rooted CO_2, i.e. a mantle-derived CO_2 flux. Similar carbon isotopic ratios have been described for soil air samples from hydrothermal areas within wider volcanic regions (Wen *et al*., 2016) and magma-derived CO_2 emissions (Zhang *et al*., 2016). Other previous studies in hydrothermal sites have describe some wider ranges carbon isotope composition of CO_2, e.g. from -2.4 to -7.8‰ in submarine hydrothermal vents (Botz *et al*., 1999) or -1.0 to -9.1‰ in hot springs (Yokoyama *et al*., 1999). Taking these $\delta^{13}CO_2$ values as references, the higher $\delta^{13}CO_2$ may indicate the addition of CO_2 directly from volcanic sources (Mazot *et al*., 2014) or from underlying sedimentary rocks containing more marine carbonate minerals, i.e. CO_2 is produced mainly by thermal decarbonation (Cinti *et al*., 2014). On the contrary, the lighter $\delta^{13}CO_2$ suggest a likely contamination by crustal organic sediments (Zhang *et al*., 2014).

4. Conclusions

In an attempt to understand the GHGs dynamics in karst systems, we have carried out a pooled analysis of data of abundance and carbon isotopic composition of CO_2 in air from different cave sites with distinctive and opposite environmental conditions. The CO_2 dynamic within the upper vadose zone of karst (accumulation, mixing with background atmosphere or mobilization by diffusion) changes seasonally depending on the air-exchange rate with the external atmosphere, which involves substantial variations on the gas abundances and their carbon isotopic signal. In general, results provide evidence that atmospheric air that is inhaled into dynamically ventilated epigenic caves (at daily or seasonally scale) can then return to the lower troposphere as CO_2-enriched air. CO_2 depletion by mixing cave air with background atmosphere prevails during periods and subterranean sites with higher ventilation. On the contrary, when air renewal is hindered the CO_2 of cave air can be mobilized by diffusion to nearby air voids of the vadose zone. In contrast, the first samples obtained in an active hypogenic cave (Vapor cave) exemplify the potential releasing of CO_2 along the faults and in the fractures occurring in the carbonate rocks, which can be an important source in the seismically active areas. The role of subterranean air of karst as sink or source of CO_2 can vary seasonally and it may have a significant influence on the conditions of the adjacent soil and local atmosphere at exterior.

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Reconstruction of lapse rates during the Pleistocene-Holocene transition from Swiss stalagmites by noble gases analysis

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We present the results of an application of ‹Combined Vacuum Crushing and Sieving (CVCS)› system (e.g., crushing samples to defined grain size in vacuum) for the first time to stalagmites grown in cold climates during the last glacial-interglacial transition, but at different altitudes.

Recently, concentrations of dissolved atmospheric noble gases in fluid inclusions of stalagmites were used to reconstruct past ambient cave temperatures, the annual mean temperature and hydrological conditions when the water was trapped (Brennwald, *et al.* 2013; Vogel, *et al.* 2013a, b). To reconstruct temperatures from noble gases (noble gas temperature: NGT) in water-filled inclusions, we processed samples from Swiss stalagmites M6 from Milandre cave (400 m.a.s.l) and GEF1 from Grotte aux Fées cave (895 m.a.s.l) covering the climatic transitions Allerød–Younger Dryas–Holocene.

1. Water content

The amount of water extracted per unit mass of calcite fabric (e.g., 'water yield': WT) was shown to be a measure of the total water content. The data shows that the WT systematically changes with $\delta^{18}O_{calcite}$ of the calcite. We therefore conclude that WT records can be linked to changes in drip rates [3] and thus can be used to track changes of past precipitation, even in cold regions.

2. Noble gases

Noble gas analysis shows that the annual mean temperatures in Milandre cave were 2.2±2.0 °C during the late Allerød and dropped to 0±2 °C at the Younger Dryas. Such temperatures close to 0 °C indicate conditions near to the freezing point of water during the first part of the Younger Dryas. However, one late Holocene sample gave a cave temperature of 8.7±1.4 °C, agreeing generally with present day annual mean temperature. The annual mean temperature of 5.7±1.3 °C from GEF1 was determined for the early Holocene. The observed data show systematic variations with sample elevation, e.g., higher temperature from lower altitude and vice versa. Combining the isotopic composition of water in fluid inclusions ($\delta^{18}O_{water}$, δD_{water}) and the NGTs allows determination of the $\delta^{18}O$-T relation ('lapse rate') in the past, as both $\delta^{18}O$ and T scale with altitude. This calibration is key as paleo-temperatures are often reconstructed from $\delta^{18}O$ and δD data by implicitly assuming that the modern $\Delta(\delta^{18}O_{water}, \delta D_{water})$-$\Delta T$ relation is also valid for the past. Our study makes an argument that noble gas analysis in stalagmites can also be a new route to address this fundamental hypothesis of past climate reconstruction.

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Extreme Seasonal Fluctuations Of Carbon Dioxide In The Cave Atmosphere Of Cova De Sa Font (Sa Dragonera Islet, Balearic Islands, Spain)

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Abstract

Cova de sa Font (also known as Cova des Moro) is a small cave situated in the north of Sa Dragonera, a 4 km long islet in the Balearic archipelago (Spain) separated from Mallorca by a 800 m sea channel. Sa Dragonera is mainly constituted of Jurassic limestones, which were subjected to Alpine overthrusting as a part of the Serra de Tramuntana mountain range of Mallorca. Tectonic conditioning explains its elongated SW-NE shape, as well as the striking differences between the gentle slopes descending toward SE and the high cliffs that form the whole NW side of the island (where outstands the highest summit of Na Pòpia, 360 m above sea level). Cova de sa Font is located at an elevation of 25 m a.s.l. and consists of a wide descending chamber with lower extensions occupied by several sea-level pools of freshwater. The easy access to the water table through the cave was well known by Mediterranean-sailors in ancient times as evidenced by the presence of pottery fragments dated from the 4th century BC to the Middle Ages.

Extreme seasonal oscillations of carbon dioxide were reported previously at Cova de sa Font using scattered data. More recently, a set of periodic measurements collected over an annual cycle ‑ from March 2014 to March 2015 ‑ has provided a better understanding of the concentration of CO_2 in the cave atmosphere. Data from March to June showed a slow and sustained increase of carbon dioxide content (from near 1,000 to 54,000 ppm) and it continued increasing until reach a long stabilization with high CO_2 values (over 90,000 ppm) from August to October. This period of extremely high CO_2 values abruptly finished in November driven by a fast removal of the air confined in the cave, and later CO_2 values fell below 1,000 ppm during winter months. Due to the extreme variations of carbon dioxide and radon contents in the cave atmosphere, Cova de sa Font and Sa Dragonera islet could be implemented as useful natural monitoring-sites for further research focus on CO_2 exchanges between caves and cracks in the vadose zone and the whole karst ecosystem.

Keywords: carbon dioxide, cave atmosphere, ground air, radon, vadose zone, Western Mediterranean.

1. Introduction

Carbon dioxide is a crucial matter for discussion in cave and karst sciences. A wide range of quite diverse speleological topics are closely related to the research on the CO_2 amounts, distribution, fluxes and reservoirs existing in the subterranean environments; among these topics, speleothem research (Fairchild and Baker 2012), cave ecology (Howarth and Stone 1990), caver safety (James *et al.* 1975) and speleogenesis (Wood 1985) can be highlighted. A detailed historical overview of CO_2 measurements carried out in caves up to the eighties is available in Renault (1985). Recent interest on cave-air CO_2 is mainly focused on carbon budgets in karst systems (McDonough *et al.* 2016), show-caves monitoring and management (Liñán *et al.* 2008), conservation issues associated with wall cave paintings (Bourges *et al.* 2014) and the use of speleothems for paleoclimatic reconstruction (Baldini *et al.* 2008).

Caves affected by high CO_2 concentrations are found occasionally on Mallorca island. Ginés *et al.* (1987) reported eight caves and shafts with CO_2 values over 2.5% in their study on the annual cycle of Cova de les Rodes. A realistic estimation, based on the approximately three thousand caves currently documented in Mallorca, and the neighbouring islets of Cabrera and Sa Dragonera, would suggest that near 1% of the explored caves have more than 3% of CO_2 content, at least during the warmer months of the year. Cova de sa Font, in Sa Dragonera, is an outstanding case study.

1.1. Sa Dragonera islet: a special karst site

Close to the western end of Mallorca – the main territory within the Balearic archipelago (Spain) – is Sa Dragonera, a small island separated from Mallorca by a 800 m wide sea channel. The islet is a 4 km long ridge, mainly comprised of Jurassic limestones and dolomites, which were subjected to Alpine overthrusting as a part of the Serra de Tramuntana mountain range of Mallorca. This tectonic trend explains the island's elongated SW-NE shape, as well as the remarkable differences between the gentle slopes descending toward SE and the high cliffs that form the whole NW side of the island. Its maximum elevation is Na Pòpia summit, 360 m a.s.l. The mean annual temperature is approximately 17 ºC and the very irregular annual rainfall is about 350 mm (1950-1980 average).

Due to its insular position and steep relief, Sa Dragonera is a particular case of telogenetic coastal karst, mostly developed on the Mesozoic carbonate rocks. In spite of the lack of specific hydrogeological studies, a deep vadose zone is assumed across the whole island, from the top of the ridge to the water

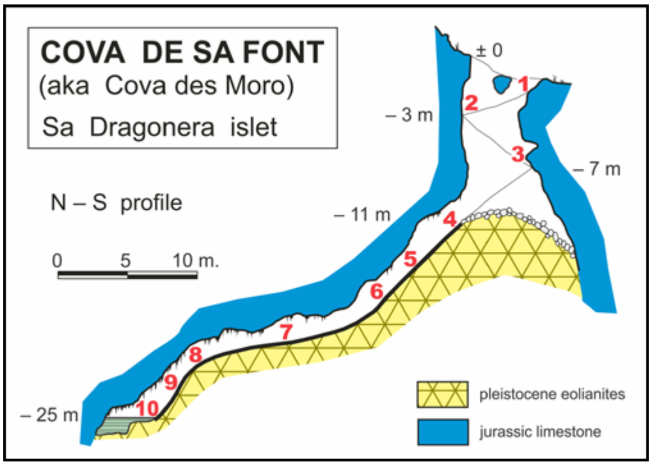

Figure 1. Longitudinal cave profile and measurement stations.

table. Regardless of the origin of seasonal CO_2 enrichment in Cova de sa Font, it is assumed that the ventilation of the vadose zone in Sa Dragonera – over large expanses of slanted exokarst surfaces and cliffs – is a key factor to explain the distribution of CO_2 in its caves and fissures. In this respect, evident similarities to the karst of Gibraltar (Mattey *et al.* 2016) must be outlined, although the amount of rainfall in Sa Dragonera is noticeably lower. Today the island remains uninhabited and is protected as a Natural Park by the environmental department of *Consell de Mallorca* (local insular authority).

2. Cova de sa Font: a significant cave site

Located not far from the small bight of Cala Lledó, Cova de sa Font (also known as Cova des Moro) is a karst cave that opens 25 m above the sea level. The cave consists of a simple main chamber, approximately 35 m wide and 18 m deep, connected to the surface through a vertical shaft less than 8 m in depth (figure 1). Only a few small extensions are found at the upper part of the chamber. At sea level, its lowermost section is occupied by several shallow pools of freshwater, the surface of which oscillates with the tides. The descending floor of the chamber has a smooth and nearly conical appearance, and was formed of sand material from littoral dunes deposited during the Middle Pleistocene through the vertical entrance of the cave.

Periodic observations demonstrated a seasonal pattern of high carbon dioxide concentrations, as reported by Ginés and Ginés (2010) in their description and comments on the main features of Cova de sa Font cave site (rough estimations over 5% in summer). After the measurements performed on 23 April (0.07%), 4 July (4.2%) and 11 October 2013 (6.2%), a program of measurements was undertaken in 2014, taking into account the high amount of CO_2 and the relatively easy access for sampling. After the 2014 field program, a final measurement was undertaken on 4 April 2015 (0.07%). Air temperature fluctuated between 17 °C and 18 °C in the inner part of the cave.

2.1. Carbon dioxide content over 2014

Ten stations for the measurement of CO_2 were allocated along the path that runs through the main chamber of the cave, from the almost vertical entrance to its deeper extensions. These are occupied by several small sea-level pools of freshwater, corresponding to the water table. Stations 1 to 3 were sited in the entrance section of Cova de sa Font, while stations 4 to 10 monitored the inner section of the cave (figure 1). The station 10 was situated at -25 m, just beside the main sea-level pool. Differences in elevation between the stations can be roughly estimated around 2.5 m. The vertical distribution and spacing at regular intervals between the measurement stations was planned in order to obtain information on the main characteristics of the air column at different points along the shortest transect, from the surface to the sea-level pool. In this way it would be possible to gain an insight into the gradients, homogeneity or abrupt changes on CO_2 content and air density that could be observed eventually close to the soil-epikarst or in the immediate vicinity of the surface of phreatic waters.

Cave-air CO_2 concentration was measured using a portable non-dispersive infrared gas analyzer with a range of 0-10% in volume (SenseAir Alarm, SenseAir, Sweden). During the summer months, due to the dangerous amount of CO_2 (over 6%), measurements only could be carried out with the aid of light diver's breathing equipment.

Table 1 summarizes over one hundred CO_2 measurements collected during more than 13 sampling trips. Periodic measurements were made approximately once per month, but

Table 1. Carbon dioxide measurements in Cova de sa Font during 2014.

CO_2 (%)													
stations	**18 Mar**	**13 Apr**	**26 Apr**	**25 May**	**22 Jun**	**5 Jul**	**20 Jul**	**23 Aug**	**20 Sept**	**18 Oct**	**1 Nov**	**22 Nov**	**16 Dec**
1	0.04	-	0.04	0.04	0.04	0.04	0.05	0.05	0.05	-	0.04	0.06	0.05
2	-	-	0.06	0.08	1.20	-	1.10	-	1.20	-	1.20	0.13	0.06
3	0.07	0.06	0.08	1.15	2.07	0.74	1.56	1.69	1.79	1.69	1.66	0.14	0.07
4	-	0.13	0.13	1.51	5.37	6.91	7.94	8.92	9.21	9.05	9.11	0.25	0.09
5	-	0.13	0.13	1.53	5.42	6.98	7.98	8.95	9.18	9.10	9.06	0.26	0.09
6	-	0.12	0.12	1.53	5.42	7.00	8.05	9.03	9.24	9.18	9.17	0.24	0.09
7	0.08	0.11	0.12	1.53	5.42	7.03	7.98	-	9.24	-	9.14	0.39	0.09
8	0.08	0.11	0.11	1.53	5.42	-	7.96	9.03	9.24	-	9.12	1.13	0.08
9	-	0.13	0.12	1.54	5.44	-	7.96	-	9.20	-	9.14	5.50	0.09
10	0.09	0.11	0.11	1.54	5.44	-	8.10	9.05	9.30	-	9.14	6.21	0.09

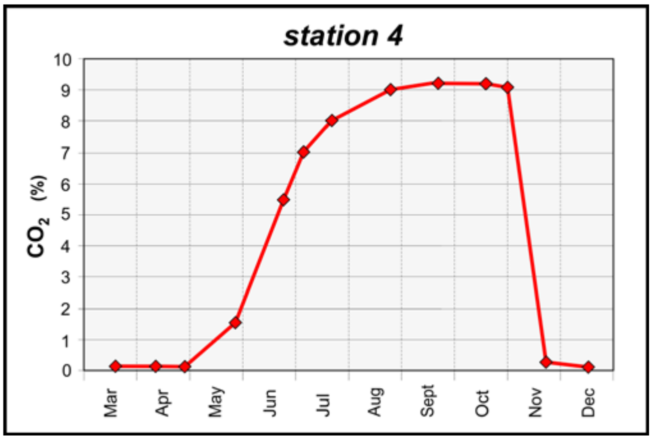

Figure 2. Carbon dioxide fluctuations in the inner section of Cova de sa Font (station 4) during 2014.

some additional sampling was performed with the aim of provide evidence for the crucial moments of expected increases and decreases of CO_2 concentrations, namely during April, July, October and November. On the other hand, it must to be emphasized that strongly homogeneous values were obtained repeatedly all along the inner section of the cave (stations 4 to 10; coefficient of variation: less than 1% from May to October). The only exception were the data of 22 November 2014, which reflect a particular snapshot in the sequence of the removal of confined-air occurring after the end of the warm season.

Figure 2 shows the pattern of extreme seasonal changes of CO_2 affecting the inner section of Cova de sa Font from March to December 2014. A general trend is evident: values lower than 0.1% were found all through the cave from December to March, showing a negligible increase through April; a progressive increase in the cave-air CO_2 occurred from May to July (up to 8%); it followed a long stabilization from August to October with values around 9%; and finally an abrupt decrease in the CO_2 content was recorded during November, until reaching again the typical winter values. What stands out in this graph is the sigmoid shape that characterizes the curve between 26 April and 20 September 2014. Diffusion of CO_2 coming from the cracks that surrounds the cave – after cave ventilation ceases due to the start of the warm season – could be a tentative explanation for this particular pattern.

Seasonal changes of CO_2 contents were consistent with the high values in radon levels reported in the same stations by Dumitru *et al.* (2015). An average value of 714 Bq.m^{-3} was recorded all along the cave (from station 3 to station 10) through the winter season. During the warm season, between July and October 2013, the radon levels increased till average values of 2,810 Bq.m^{-3}, including the lesser values of 2,100 Bq.m^{-3} measured at station 3, which is located in the entrance section of the cave at a depth of -7 m.

3. Discussion and conclusions

The seasonal fluctuations of carbon dioxide in Cova de sa Font show a similar pattern to that found in most of the caves reported in the available literature, with low values during winter and a substantial increase of CO_2 concentrations during the warmer months. This trend is mainly controlled by cave ventilation, because denser cold air incoming from

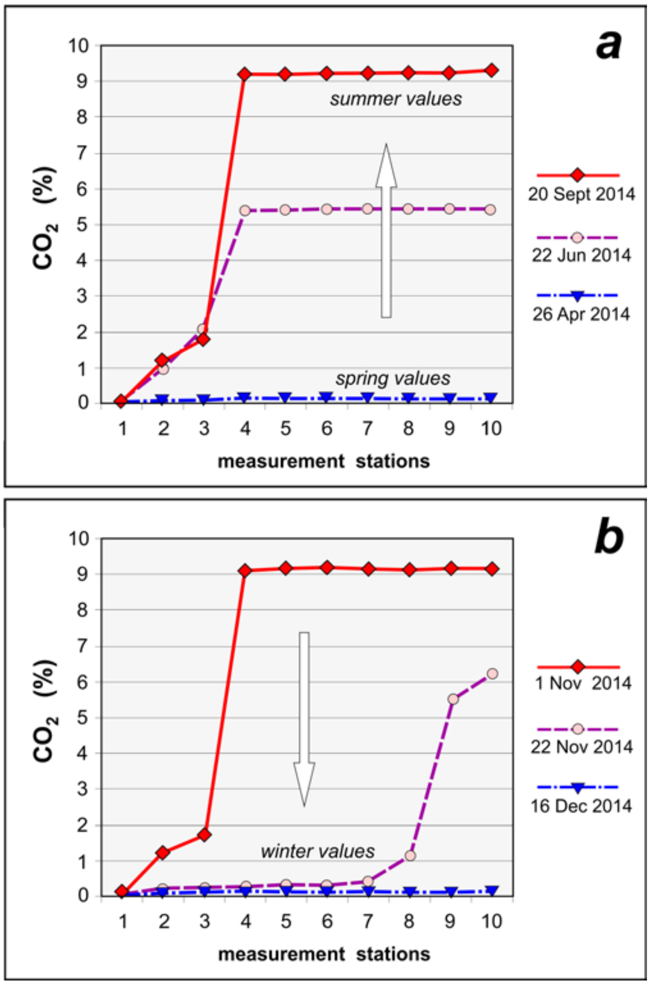

Figure 3. Seasonal changes of carbon dioxide along the air column profile at Cova de sa Font.
a: rising trend of CO_2 concentrations through the warmer months;
b: confined air renewal from 1 November to 16 December 2014.

the surface enhances the renewal of cave air until its cessation when the increase on outside temperatures blocks the air circulation. What is really significant in Cova de sa Font is the large amount of CO_2 contained into the cave atmosphere in absence of direct ventilation, as demonstrated by the values over 9% recorded from August to 1 November 2014. It is also worth to outline that no CO_2 gentle gradients were observed from the water table upwards, nor from the soil-epikarst downwards, during the warmer months (see values from stations 4 to 10 in table 1).

Air column profiles are shown in figure 3a to illustrate the gradual development of a sort of gaseous pycnocline as soon as the cave ventilation stops and the substantial CO_2 enrichment of the air confined in the cave begins. The increase in CO_2 values affecting the inner section of the cave from May to August 2014 is probably caused by strong density differences with respect to the buoyant air above, all over the entrance section, inducing the formation of the cave-air pycnocline between stations 3 and 4, at around -8.5 m. Once established, the pycnocline remained stable during the warm months, with only minor fluctuations lesser than 1 m in amplitude until the end of October. Figure 3b shows the air column profiles corresponding to the sequence of cave air ventilation occurred between 1 November and 16 December 2014; note the apparent remnants of the former gaseous pycnocline on the graph corresponding to 22 November 2014.

The very high levels of carbon dioxide recorded in Cova de sa Font are difficult to reconcile with whatever kind of CO_2 migration from the thin and impoverished soil, under the conditions of semi-arid Mediterranean climate that characterizes the islet of Sa Dragonera. Conversely, the presence of the gaseous pycnocline, at a shallow depth of -8.5 m, suggests that the rising in CO_2 content could be produced at the inner section of the cave as a result of the continuous release of CO_2-rich air coming from the network of small cracks that surrounds the cave, in absence of efficient cave ventilation. Limited ventilation causes the strong differences in buoyancy observed between the inner cave atmosphere and the entrance air – according to their well-differentiated air compositions (Sánchez-Cañete *et al.* 2013) – as well as the gradual pycnocline development. On the other hand, repeated measurements carried out just over the sea-level pools, yield no evidence of any cave-air gradient close to the water table (see figure 3 and table 1), ruling out degassing from phreatic waters as the main source of CO_2 in this cave.

The background of periodic measurements collected along the cave, including the extreme seasonal changes observed during 2014, seems to be in agreement with the existence of a significant storage of "ground air carbon dioxide" in the vadose zone (Atkinson 1977). This source could be able to generate the seasonal rising of the CO2 contents by diffusion and advection through the surrounding network of small cracks, when the cave ventilation is interrupted during warmer months. The karst of Sa Dragonera islet, and especially the Cova de sa Font site, would allow to check some aspects of the "ground air" model postulated by Atkinson (1977), developed by Wood and Petraitis (1984), and lately reformulated by Mattey et al. (2016). Furthermore, as suggested regarding the similar steep topography of Gibraltar (Mattey *et al.* 2016), the location of Cova de sa Font in the lower part of Sa Dragonera islet would account for descending ground air outflow in summer, which likely could contribute to achieve the outstanding high CO2 values reported in the cave.

Acknowledgements

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(Abstract) Experiments on short-time human impact on the cave environment: Monitoring Grønligrotta Show Cave, Rana, North Norway

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Abstract

Grønligrotta (UTM zone 33 466098 7366716) is the only commercial tourist cave with infrastructure and regular visits in Norway. The cave is situated some 250 m a.s.l. in a valley wall some 60 km from the coastline. It has two present-day entrances and an active stream flowing through it. Mean annual temperature is about 2.5 °C. Tourism has prevailed for almost 120 years. Today, the cave has walkways made of concrete and201-Gringdheim wood with electric light. In the summer season (June-August), guided tours are run hourly, counting from ca. 5 to 70 people. Under the Cavemonitor project, two locations in the cave were instrumented with "intelligent" data loggers, yielding high-frequency data during and after visits. Logged parameters are CO_2, temperature, relative humidity, in addition to radon strip detectors. We suggest that half-life is a useful parameter for characterizing the decay of human emissions (thermal and chemical). In order to quantify and disentangle the response characteristics of the cave passages on human presence, a series of controlled experiments are performed on human impact on the ventilation response of the site. The previous loggers are supplied by continuous radon loggers and logging anamometers. The work will commence in January 2017.

(Abstract) Microclimate Monitoring At Rei Do Mato Cave, Sete Lagoas, Minas Gerais, Brazil: Preliminary Results

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Keywords: Climate monitoring; Rei do Mato Cave, Minas Gerais.

The study of karst areas in Brazil began in the nineteenth century by the Danish naturalist Peter W. Lund with his research in the State of Minas Gerais. In the twentieth century, the study of such regions, especially its caves, was initiated in the 1960s with the exchange of European researchers in partnership with Brazilian ones at the University of Ouro Preto (UFOP). This cooperation enabled the creation of the Brazilian Speleology Society (SBE) in 1969. Since then, Speleology started to develop and in 1980s, Brazilian karst areas also began to be studied. However, there has been very few studies of cave microclimate, especially for those used for tourism.

This research was conducted continuously to demonstrate in a period of 9 months (from June, 2014 to February 2015), the role and function of microclimatic monitoring in the Gruta Rei do Mato Natural State Monument, in Sete Lagoas, Minas Gerais. This was to stress the importance of this type of monitoring in caves opened for tourism.

Five data loggers (Testo 175H) were installed along the 220 metres of catwalk opened for tourism, and programed to record temperature and humidity data each ten minutes. Temperature was recorded with ±0.4 °C accuracy, and 0.1 °C resolution, and humidity was recorded with ±2% accuracy, and 0.1% resolution. To analyse such a large amount of data which are both dynamic and non-linear, and to predict probable impacts caused by tourism, the authors used an artificial neural network, tested many times to improve its results.

At the start of the research high air humidity and a tendency of temperature stabilization while moving towards the end of the cave is observed. From all the sensors, the biggest variation of temperature and humidity were recorded at the station located closest to the entrance (approximately 80 metres); this is most likely due to outside climatic conditions. Initial data shows that, although one can see increase of temperature and decrease of humidity, the cave tends to show a stable behaviour. Comparing it with the visitor numbers registered (maximum of 45), the impacts were not great.

A second phase of the research will analyse what happened to the cave climate with data colleted over 24 months that should help managers to better understand the cave carrying capacity.

This is, basically, the first step to analyze the cave climate with the aim to eventually provide information to plan carrying capacity"

(Abstract) **Peculiar CO_2 values in a Hungarian cave with lower and upper entrances**

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Abstract

Between January of 2013 and April of 2016 we measured the CO_2 level in Béke Cave every month.

An artificial entrance was opened in 1953 in the upper part of main passage. Another was opened in 1966, which is also an artificial exit near to the end point of the cave, 68 m under the entrance. From 1968, the air went into the cave across the lower exit in winter, and went out across the upper entrance in summer. After the discovery until 2013, we never measured high CO_2 level, which was always under 1%.

In March 2013, this value started to rise, and in the summer of 2013 it was higher than 3% in the middle of the cave. Since downward from the upper entrance we found higher and higher values, we did not go to the lower part of the cave: we supposed there would be 5-6% CO_2. At the end of 2013, the CO_2 value fell below 1% again (in the middle of the cave). However, in the spring of 2014 it started to rise again, and in July it was already above 3%! We were at the lower exit (which is out of use), but we could not go into the cave, because the artificial tunnel was under water. In January 2015, the CO_2 value was again under 1%, and we tried to take a full crossing tour. We could not reach the Giant Hall at the end of the cave, because in the stream we found a new syphon, where the water reached the ceiling. In the summer of 2016 we measured more than 3% CO_2 again, and in January 2016 it was again under 1%.

We suppose that after a big cave-flood in the spring of 2013 the Margitics syphon at the end of the cave filled up with sediment. The water closed the exit behind the syphon, and created a new syphon in the main passage. Therefore, there was no chance the air move across the exit. In summer, in the vegetation period, the stream and the seeping water across the roof bring in abundant CO_2, which accumulates in the lower part of the cave. In winter, the air comes across the invisible cracks into the lower part of the cave and transports the CO_2 from the cave across the upper entrance. In spring the process starts from the beginning.

Speleogenesis in Stockyard Gully National Park and Beekeepers Nature Reserve, Western Australia

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Abstract

Stockyard Gully National Park and Beekeepers Nature Reserve are protected limestone areas in southwest Western Australia. The limestone is a young cemented carbonate coastal dune system (aeolianite), deposited during several Pleistocene interglacial episodes due to migration under the influence of strong south to southwesterly winds.

Field work, combined with mineralogical, chemical, stable isotope analysis and uranium-thorium (U/Th) and optically stimulated luminescence (OSL) dating, enabled a detailed insight into the repetitive glacial and interglacial climatic periods over the past 500 ka. The syngenetic karst of these areas, in particular the limestone exposures and speleothems within the caves, proved especially useful in determining the environmental history of the area.

Deposition of the carbonate aeolianites occurred during interglacial episodes. The higher effective rainfall during the transition from interglacial to glacial episodes resulted in aeolianite dissolution and karstification. During the colder climates and less effective rainfall of the glacial periods, no carbonate sand deposition occurred; instead laminated terrestrial microbialite and/or laminar calcrete precipitated, followed by palaeosol formation. These cyclic events are imprinted in the stratigraphy exposed in the cave walls, and include buried pinnacle karst and ancient soil horizons. Speleothem deposition occurred around 3 ka and is now very limited, evidence of climate variability in the Holocene.

Caves in Stockyard Gully National Park and Beekeepers Nature Reserve, combined with the spectacular geological and floral diversity of the area, have therefore outstanding scientific value. It is important to know their characteristics and behaviour to help preserve these fragile systems and also provide the basis for recovery due to human-related pressure on these areas. Soil erosion, collapse of underground cavities and formation of sinkholes requires the involvement of aeolianite research to gather relevant data for better long-term effective environmental management.

Keywords: karst, cave, aeolianite, palaeoclimate, geomorphology, Western Australia

1. Regional Setting And Methods

Southwestern Western Australia has a spectacular syngenetic karst cave development within the Pleistocene Tamala Limestone along the coast (Bastian 1964; Jennings 1968; Grimes 2006). The Tamala Limestone is a predominantly cemented Pleistocene calcareous coastal dune system, defining it as aeolianite (aeolian calcarenite), and stretches for more than 1000 km along the southwest Western Australian coast.

An extensive limestone outcrop about 260 km north of Perth is protected partly as Stockyard Gully National Park and partly as Beekeepers Nature Reserve (Fig. 1). The climate is Mediterranean with hot and dry summers, and mild and wet winters. The average annual rainfall in the nearby town of Eneabba is ~490 mm and mean annual temperature ~21 °C (Bureau of Meteorology 2016). Syngenetic karst (i.e. karst formed more or less simultaneously with the sediment lithification; Jennings 1968) has developed in the research area with caves, collapse dolines and pinnacles as prominent features.

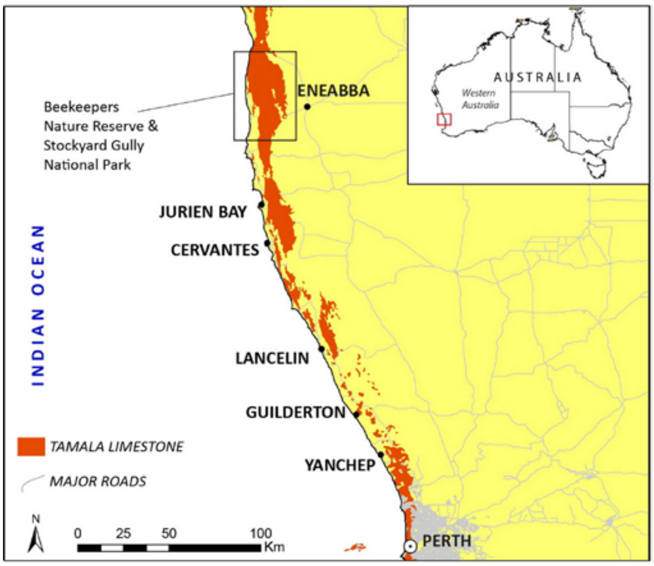

Figure 1. Location map of Stockyard Gully National Park and Beekeepers Nature Reserve.

The most outstanding feature is the Stockyard Gully cave system. The entrance is a blind valley (Fig. 2B) where non-karstic allogenic water flows (at present ephemerally) into the karst landscape. The system is largely collapsed and consequently numerous collapse dolines are present (Figs. 2A & 2C), along with a karst dry valley. The walls of these features offer excellent exposures of the limestone stratigraphy, that correlates well with the overall aeolianite deposition of the Tamala Limestone elsewhere north of Perth (Lipar & Webb 2014; Lipar *et al.* 2017).

This study is based on detailed field work which included exploration of the caves and mapping of the characteristics of the Tamala Limestone. Rock samples were collected and examined in thin section for mineralogy and texture. Additional mineral composition was determined by X-ray powder diffraction (XRD) analysis at La Trobe University. Flowstone was dated by the uranium-thorium (U/Th) method at the University of Melbourne and the University of Queensland, while aeolianite samples were dated by the optically stimulated luminescence (OSL) method at Victoria University of Wellington, New Zealand. Limestone samples were additionally analysed for $\delta^{13}C$ isotopes at the University of Melbourne.

2. Caves In Aeolianite

The aeolianite in the research area shows characteristic dune cross-bedding inclined up to 45° towards the north to north-east, intersected by layers of calcrete/microbialite and unconsolidated or weakly consolidated palaeosols (Fig. 2). In places a karst surface developed beneath the palaeosol, expressed as a weathered uneven surface with solutional voids filled with soil material. The aeolianites are fine to coarse grained and well-sorted, containing variable amounts of carbonate, quartz and feldspar. The presence of meniscus and pendant cement indicates that the lithification of the carbonate dunes occurred in a meteoric environment (vadose zone).

Cyclic deposition of aeolianite occurred during interglacial periods of marine isotope stage (MIS) 7 (Pinnacles Desert Member), 9 (Stockyard Gully Member), 11 (Nambung Member), and possibly 13 (White Desert Member) (Table 1) (Lipar & Webb 2014). Individual members have different aragonite / high-mg calcite / low-mg calcite ratios. The aeolianite shows a progressive reduction with age in aragonite and high-Mg calcite content and a corresponding increase in low-Mg calcite content, indicating that carbonate material from each depositional cycle was a fresh derivate from the ocean and not reworked from older aeolianites. Whole rock carbon and oxygen isotopic values become lighter with age due to more extensive diagenesis (Gardner 1983; Beier 1987), and are sufficiently distinctive that they can be used to differentiate some members of the Tamala Limestone. Each Tamala Limestone member also has a characteristic palaeo-surface, helping to distinguish one member from another. In addition, aeolianite from the Stockyard Gully Member was dated by the OSL method as 313 ± 44 ka (MIS 9).

The ages of aeolianites in the research area suggest that speleogenesis commenced at least in late MIS 13 (around 500 ka ago) and continued with the deposition of younger limestone up to the present. The collapse dolines are amongst the

Table 1. Stratigraphy of the Tamala Limestone in the research area.

	TIME OF AEOLIANITE DEPOSITION:	STRATIGRAPHY:	KARSTIFICATION:	MICROBIALITES:	CALCRETE:	PALAEOSOL:
PLEISTOCENE	MIS 7	PINNACLES DESERT MEMBER	High level of karstification incl. pinnacle karst and solution pipes	Abundant up to ~30 cm wide microbialites	Some amount of calcreted rock	/ (recent soil)
	MIS 9	STOCKYARD GULLY MEMBER	No karstification	No microbialites	Extensive up to 40 cm thick laminar calcrete	Loose but mostly cemented reddish up to 1 m thick palaeosol
	MIS 11	NAMBUNG MEMBER	High level of karstification	Abundant up to 2 m wide microbialites	Minor amount of calcrete	Mostly loose and up to 50 cm thick palaeosol
	MIS ≥13	WHITE DESERT MEMBER	Minor level of karst voids where microbialites were deposited, otherwise unknown	Some microbialites up to 10 cm wide	Some amount of calcreted rock	Cemented up to 50 cm thick palaeosol

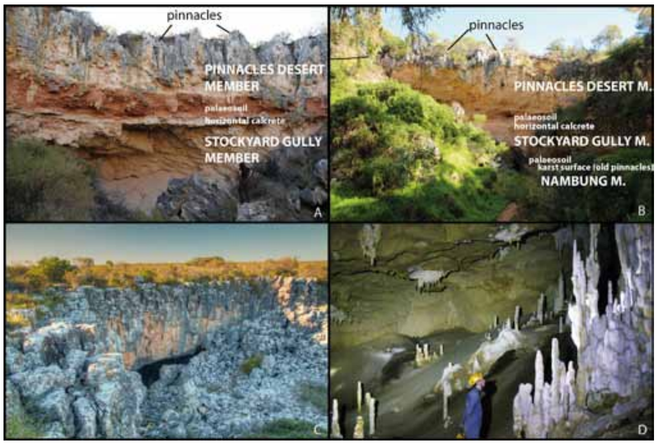

Figure 2. Rock exposures in the research area. (A) Stratigraphy of the collapse doline entrance of the Beekeepers Cave; (B) Stratigraphy of the end of the blind valley of the Stockyard Gully system; (C) collapse doline entrance of the Weelawadgi Cave; (D) flowstone formations in lower sections of the Weelawadgi Cave.

younger features, formed after the youngest member of the Tamala Limestone was cemented and pinnacles on its surface had formed, i.e., around 100 ka or younger (see Lipar & Webb (2015) for pinnacle formation).

Aeolianite deposition occurred predominantly during highstands (interglacial periods), in accordance with deposition of aeolianites elsewhere in Australia (e.g., Hearty & O'Leary 2008; Murray-Wallace *et al.* 2001, Murray-Wallace 2002; Lipar *et al.* 2015). It was due to migration of coastal dunes under the influence of strong south to southwesterly winds, as evident from cross-bedding. Rainfall was insufficient to support vegetation cover on the dunes, and so was probably limited or seasonal. Aeolianite deposition did not occur during the last interglacial, and this probably reflects high precipitation during the peak interglacial so the dunes were vegetated and stabilised at that time.

After the peak of the interglacial periods the calcareous dunes were covered by vegetation and limestone dissolution occurred. The transition from interglacial to glacial climates was therefore characterised by higher effective rainfall, which was probably due to decreased evaporation caused by the reduction in average temperature, reinforced by the on-going offshore presence of the warm water of the south-flowing Leeuwin Current. However, no karstification occurred during the MIS 9-8 transition (i.e., palaeo-surface of Stockyard Gully Member is not karstified (Fig. 2A)), indicating a relatively dry phase and contrasting with the other phases.

During glacial periods there was a shift to colder climates with less effective rainfall and no dune formation. Instead laminated microbialite deposition occurred in karst voids and/or laminar calcrete formed, followed by palaeosol formation. The thickest microbialites formed during MIS 10, suggesting that MIS 10 was wetter or less seasonal than other glacial periods. In contrast, a massive hardpan calcrete and relatively thick palaeosol were deposited during MIS 8, showing that the glacial climate at this time was relatively dry.

2.1. Speleothems

Speleothems are relatively scarce in the main Stockyard Gully cave system, but are more abundant in Weelawadgi Cave located ~15 km to the north. The entrance to the cave is a collapse doline followed by collapse passages and then a linear stream cave. The lower sections of the cave contain abundant stalactites, stalagmites, columns and flowstone sheets. A sample of a broken stalagmite, composed entirely of a low-Mg calcite, gave an age of 3.1 ± 0.2 ka (U/Th; 2σ uncertainty). A second stalagmite sample from the entrance of the cave could not be dated precisely as it had a very low U/Th ratio, so there is uncertainty in the assumptions for detrital correction (Zhao *et al.* 2009). This sample was probably deposited under disequilibrium conditions due to evaporative effects.

It appears that the latest major speleothem deposition in the research region occurred relatively recently in the Holocene at ~ 3 ka. At present, speleothem growth is relatively retarded due to the semiarid conditions, so the extensive deposition 3.1 ka ago may indicate a short period of relatively wetter conditions. Flowstone at Cape Range (850 km north) is older than ~ 6 ka (Denniston *et al.* 2013), and at Margaret River (450 km south) speleothems are still actively growing (Treble et al. 2008), reflecting the southwards increase in rainfall (at present from ~490 mm at Eneabba to ~1000 mm at Cape Leeuwin). This is also indicative of the variability of the Holocene climate in southwestern Western Australia (Churchill 1968, Kendrick 1977, Semeniuk 1986, Treble *et al.* 2008, Gouramanis *et al.* 2012, Lipar *et al.* 2017), although more data is needed to define a general pattern for southwestern Western Australia due to the size of the area.

3. Conclusion

In order to understand present day climate changes and predict the future climate, it is necessary to fully understand the past climate. Limestone exposures and speleothems within the caves proved especially useful in determining the time of speleogenesis as well as the overall environmental history of the Stockyard Gully National Park and Beekeepers Nature Reserve. This area confirms and improves proposed palaeoclimate interpretations provided by other studies.

Acknowledgement

We wish to thank Western Australian Speleological Group (Inc.) for the agreement to use their reference sources and for organising and leading cave trips required for this research. A permit to conduct research in national parks as well as to enter certain caves or cave passages was obtained from the Western Australia Department of Parks and Wildlife. The research was carried out whilst the senior author was supported by a La Trobe University Postgraduate Research Scholarship and Australian Speleological Federation Karst Conservation Fund.

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(Abstract) **Timing of Pliocene sea-level high-stands in western Mediterranean using U-Pb ages of cave deposits from Mallorca Island**

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Abstract

The magnitude of sea-level rise in the coming centuries due to anthropogenic climate change ranks high and remains a pressing societal problem. Even if temperatures were stabilized, according to different mitigation scenarios for greenhouse gas emissions, the retreat of land ice will increasingly contribute to future sea-level rise. Accurate long-term sea-level change projections are plagued, among other factors, by uncertainties related to sensitivity of ice sheets to future changes in atmospheric CO_2 and temperature. One way to refine these predictions is to gain better understanding on sea-level behavior during periods when Earth's climate was warmer than today. A possible yet imperfect analogue is the Pliocene epoch when global temperatures and atmospheric CO_2 reached levels similar to those projected for the end of this century. Arguably, the best studied interval of the Pliocene, both in terms of climate modeling and sea-level reconstructions is the mid-Pliocene Warm Period between 3.26 and 3.02 Ma. However, the current knowledge of the Pliocene global mean sea level by the scientific community remains very incomplete, mainly because of the difficulties of gaining direct and precisely dated sea-level markers for this relatively remote time period.

Mallorca Island is regarded as a tectonically stable site from which previously estimated paleo-relative sea-level (RSL) using phreatic overgrowths on speleothems (POS) appear to closely follow the eustatic sea-level (ESL) reconstructions. Some POS are positioned 20 m or more above present sea level (mapsl), consist of aragonite, and are beyond uranium-series limits.

Here we present the first direct U-Pb isochron ages of POS from caves of the Cap Vermell area. We obtained relative sea-level estimates for four distinctive POS horizons situated at elevations between 22.5 and 30.5 mapsl. The lower POS has an age of 3.35 ± 0.16 Ma indicating a highstand attained during marine isotope stage MG3. The next two are situated at 23.5 and 25 mapsl and returned ages of 3.31 ± 0.09 and 4.07 ± 0.23 Ma, respectively. The peak Pliocene sea level reached ~30.5 ± 0.75 mapsl at 3.5 ± 0.14 Ma. Our absolute ages imply full deglaciation of the Greenland and West Antarctic ice sheets, and varying contributions from the East Antarctic Ice Sheet. However, precise paleo-ESL estimates using the POS-derived Mallorcan paleo-RSL data is challenged by difficulties in assessing reliably the effects of glacial isostatic adjustment, and especially, the earth dynamic topography.

High-resolution examination of drought and pluvial events in southwestern USA stalagmites

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Abstract

We examine Holocene-aged stalagmites from the Guadalupe Mountains, New Mexico USA that exhibit highly resolved layering with the goal of identifying drought and pluvial events at an annual to decadal resolution. These stalagmites exhibit annual banding defined by fluid inclusions that represents the average growth of the stalagmite, and aragonite layers and growth hiatuses that represent drier periods. Growth hiatuses are commonly associated with aragonite layers or dark magnesium-rich silicates and produce easily resolved variability in grayscale and stable isotope time-series. Clear layers (free of fluid inclusions) of calcite that are millimeters in thickness and represent years to 10s of years of growth are in contrast with annual banded zones and growth hiatuses but also produce strong variability that is difficult to interpret. The concern is that some clear layers that yield overall greater grayscale values and stable isotope time-series variability that could be interpreted to represent pluvial-like conditions might instead be an expression of drier climatic conditions. Our study examines the layering types using grayscale and carbon and oxygen stable isotope time-series tied to a high-resolution uranium-series chronology. Our preliminary results suggest that the clear calcite layers represent drought, not pluvial, conditions.

Keywords: stalagmite, annual banding, fluid inclusions, hiatus, aragonite

1. Introduction

Research using stalagmites as a source of paleoclimate records has rose impressively over the last two decades. Paleoclimate records require accurate chronologies. Early research demonstrated potential for accurate high resolution studies (Thompson et al., 1974), and significant advances in uranium-series dating (Edwards *et al*., 1986; Cheng *et al*., 2013) provided researchers with the tools needed to construct extremely important high-resolution speleothem-based paleoclimate records. Oxygen stable isotope time-series tied to a uranium-series chronology have produced globally important records. However, with very accurate chronologies come the possibility to make interpretations regarding climate change at an annual to decadal scale via examination of stalagmite growth (i.e., mineral and fluid inclusion assemblages). For example, what type of stalagmite growth is characteristic of normal, drought, and pluvial conditions? More specific interpretations of Holocene climate history could be possible given these capabilities to characterize the stalagmite growth. It is likely that these characterizations will be site specific, and change from region to region. Here we examine examples of speleothem growth types from cave zones near large entrances and discuss what these represent with regards to climate, similar to what Frisia (2015) proposed.

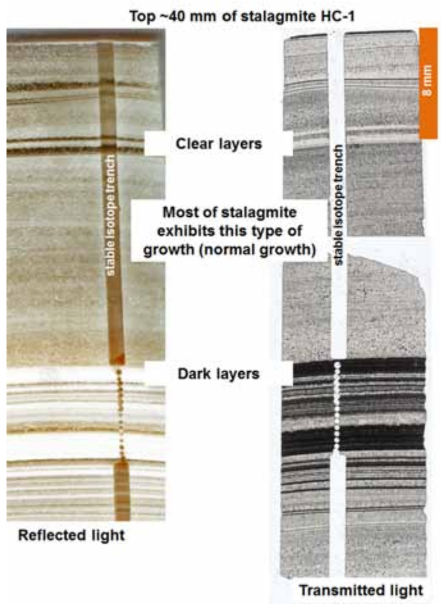

Figure 1. Example of stalagmite growth types in stalagmite HC-1, Hidden Caver, Guadalupe Mountains, New Mexico. When observed with visible light, growth is expressed differently in reflected and transmitted light. Note that the aragonite layers are white in reflected light and dark in transmitted light.

2. Results and Discussion

Layering defined by fluid inclusions in calcite as annual banding seems to represent the normal growth history of some stalagmites from several caves in the Guadalupe Mountains of New Mexico, USA. There is much variation in the way that this growth develops (Fig. 1). The normal growth of a stalagmite could be defined as representative of the normal climatic conditions. Stalagmite growth expressed as aragonite or non-growth expressed as aragonite-defined hiatuses represents distinct periods of drought (Fig. 2) and are consistent with Type L layering of Railsback *et al*. (2013). The annual banding, aragonite layers, and hiatuses seem distinctly tied to normal, pluvial, and drought type climate. However, some stalagmite growth is expressed as clear layers of calcite that represent years to decades of growth and are less well understood. Are they formed by pluvial periods, or are they expressions of mild droughts? Stalagmites HC-1 and PD-3 from Hidden and Pink Dragon caves exhibit examples of these dif-

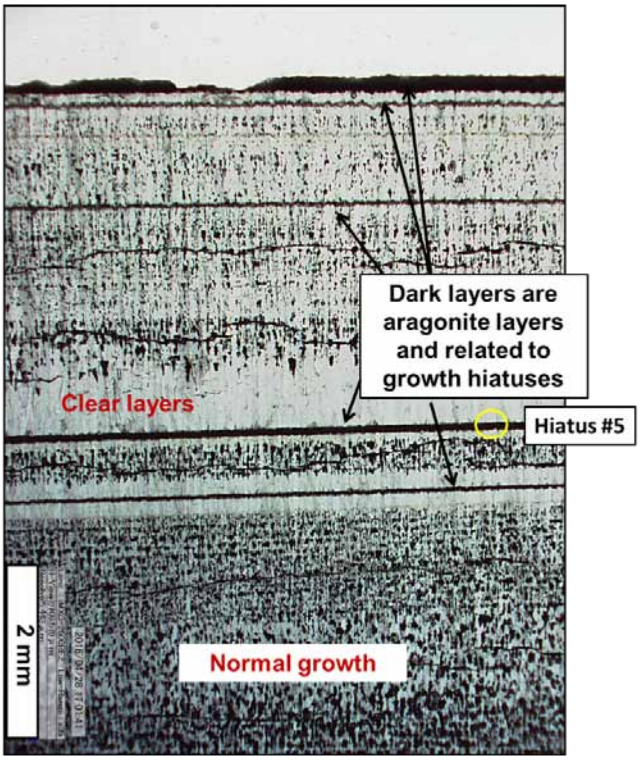

Figure 2. Optical thin sections are a good and inexpensive method for studying stalagmite growth. The top 7 mm of stalagmite HC-1 growth is exhibited in transmitted light and shows different types of growth such as dark aragonite layers that define brief hiatuses, fluid inclusion-rich calcite layers that define what most of the growth in this stalagmite looks like (normal growth), and clear layers that seem to indicate mild drought conditions. The yellow oval shows an aragonite layer (hiatus #4) examined using scanning electron microscopy and shown in Figure 3.

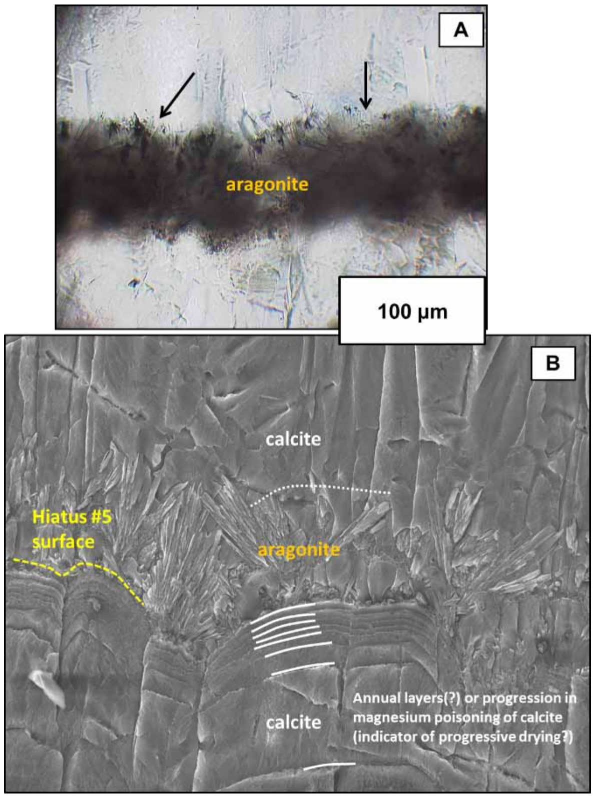

Figure 3. This aragonite layer is interpreted as a brief hiatus. (A) The thin section shows an aragonite layer (hiatus #5) that is about 0.1 mm thick, and the image shows aragonite crystals protruding from the layer. (B) A SEM image distinctly shows that this layer consists of aragonite, but also seems to show poisoning of calcite growth prior to aragonite nucleation and growth. The slowing and cessation of growth is probably equivalent to several years of normal stalagmite growth.

ferent expressions of stalagmite growth that are interpreted to be tied to climatic changes.

Stalagmite HC-1 normal and dark layers. In stalagmite HC-1, normal growth is defined as most of the stalagmite growth (Fig. 1). This growth exhibits annual banding defined by fluid inclusions (Fig. 2). Drought-type growth is exhibited as dark layers in transmitted-light images. These dark layers are clearly hiatus-like layers defined by a change from normal calcite growth to layers of aragonite growth (Fig. 2). Uranium-series chronology for HC-1 published in Asmerom *et al.* (2013) show that these layers represent slow growth and growth hiatuses. In Figure 3, scanning electron microscopy (SEM) shows one of these aragonite layers. The SEM image seems to show poisoning of calcite growth due to increasing Mg concentrations possibly resulting in progressively thinner layers (annual bands?) until at a very brief hiatus surface, aragonite crystals nucleate and grow. Stalagmite growth then returns to normal calcite. We interpret this growth hiatus to be defined mostly by slowing growth of calcite and eventually aragonite, which forms a white layer in reflected-light and dark layer in transmitted-light optical micrographs. Mg-silicate materials, observed in a longer hiatus (~4000 years) of another stalagmite, also produced a dark layer in transmitted light. Subtle variations of grayscale of fluid-inclusion-defined calcite banding (normal growth in stalagmite HC-1) are likely related to equally subtle differences in climatic conditions. Examples of fluid inclusions are exhibited in Figure 4a. These differences can be measured using grayscale histograms and quantitatively analyzed given the chronology is tightly controlled (Fig. 5). These grayscale histograms represent a high-resolution history of the stalagmite growth, but they are difficult to interpret.

Stalagmite HC-1 clear layers. A more perplexing expression of stalagmite growth exhibited in these Holocene stalagmites from caves of the Guadalupe Mountains are clear layers of calcite (Figs. 1 & 2). These layers are void of fluid inclusions, but sometimes have within them layers characteristic of growth hiatuses like those nicely exhibited in Figure 2. Stable isotope values over these layers seem to show heavier values usually representative of drier conditions (Lachniet, 2009), but not always heavier. Stable isotope values also distinctly show higher values for the dark layers that we interpret to be drier conditions/growth hiatuses (Figure 5). Within some of these clear layers are faint banding that seem to be very thin annual bands, or dark aragonite layers, both of which would support drier conditions (Figure 4b).

Annual bands are probably evidence of two-season stalagmite growth primarily due to monsoonal conditions in the summer in the southwestern United States, where seasonal differences in precipitation are distinct. Without this wet-season versus dry-season growth, distinct banding may not occur. So it is possible that the clear layers represent absence of stalagmite growth during the monsoon, which would indicate drier conditions. Or it may be that stalagmite growth

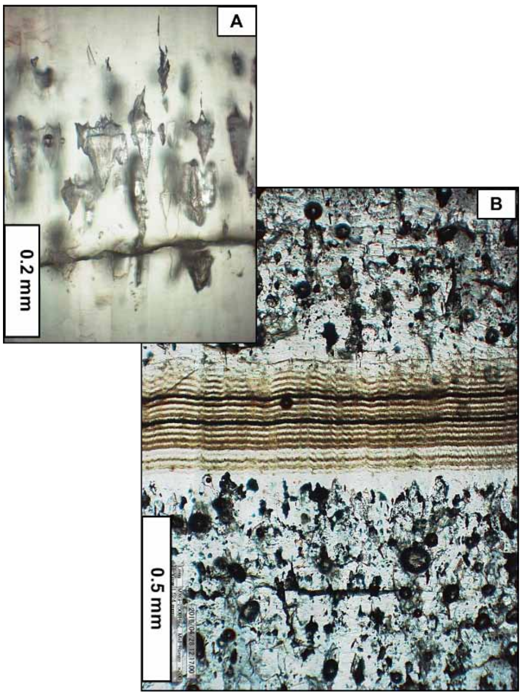

Figure 4. *(A) Typical fluid inclusion forms in stalagmitic calcite exhibited by stalagmites from the Guadalupe Mountains. (B) A clear layer (clear of these fluid inclusions) that exhibits numerous bands of growth, interpreted to be annual bands. In this example, the growth rate above and below this clear layer is approximately 40 µm/year, and 20 µm/year within the clear layer with the assumption that these layers are annual bands. In addition, two of these bands are distinctly darker than the others, suggesting that these may be brief hiatuses.*

is too slow to accommodate development of inclusions. Both scenarios are evidence of drier climatic conditions.

Stalagmite HC-1 pluvial growth layers. Pluvial conditions are less obvious and can be represented by thicker annual banding (Polyak and Asmerom, 2001; Asmerom *et al.*, 2013). However, do pluvial periods cause layering with increased or reduced density of fluid inclusions? The more pluvial periods should ideally produce lower stable isotope values (Lachniet, 2009). In Figure 5, the grayer areas below AD 588 overall seem to yield slightly lower oxygen stable isotope values, but the distinctly darker layers within these grayer areas yield spikes in oxygen isotope values. Grayscale histograms cannot accurately measure differences in color or organic abundances in the calcite that might help define subtly wetter or drier climatic conditions. We suspect that the subtly grayer values represent wetter conditions, but the sharply grayer bands represent drier conditions. Further examination of grayscale histograms at high resolution and in comparison to stable isotope values should help resolve how pluvial growth is represented.

3. Summary

A paleoclimatic interpretation from stalagmite HC-1, not the purpose of this paper, can be achieved by examining the growth of the stalagmite at a high resolution. The combination of normal growth, variations in the normal growth, aragonite and growth hiatuses, clear layers, and high-resolution chronologies provide opportunities to make very detailed climate change interpretations from these Guadalupe Mountains stalagmites. Our examination of stalagmite HC-1 seems

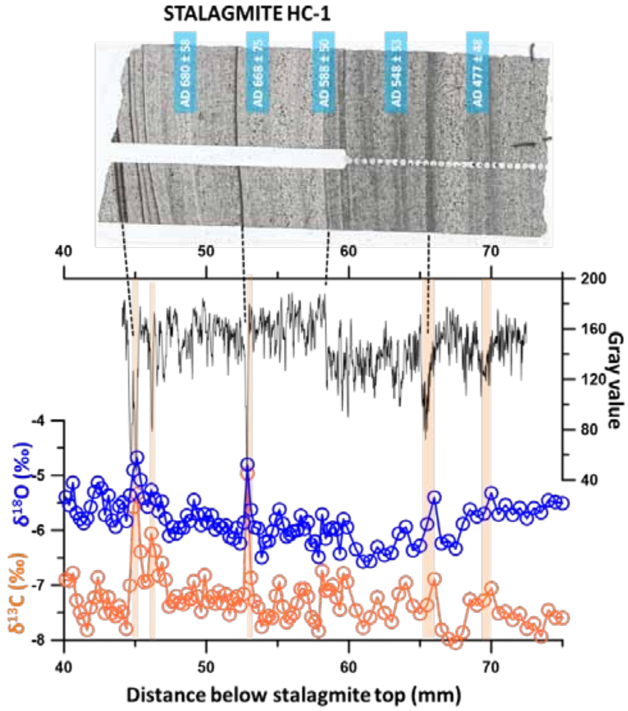

Figure 5. *Comparison of transmitted light image, grayscale of that image, and carbon and oxygen stable isotope values of the mid-section of stalagmite HC-1. Note the dark layers have higher stable isotope values. The five dates are uranium-series ages.*

to indicate that changes in stalagmite growth preserves frequency of drought better than frequency of pluvial conditions, at least until we better understand how growth from pluvial conditions is expressed. Never-the-less, the stable isotope and grayscale time-series presented here can produce important spectral results expressed as periodicities during the Middle to Late Holocene that relate to important climate drivers such as the El Niño/Southern Oscillation, the Pacific Decadal Oscillation, and solar oscillations. Regardless of how well characterized the stalagmite growth is, these important interpretations are only as robust as the stalagmite chronology.

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(Abstract) **Microclimate Monitoring At Gruta Da Lapinha (Lapinha Cave), Sumidouro State Park, Minas Gerais, Brazil: Preliminary Results**

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Keywords: Climate monitoring; Lapinha Cave, Minas Gerais.

Karst landscapes and their caves are considered fragile environments in which tourism must be conducted carefully. Regarding show caves, many factors must be taken into consideration; one of them is the understanding of their climate.

The Lapinha Cave (Gruta da Lapinha) is located at the Sumidouro State Park, South-Center of Minas Gerais State (Brazil), and is considered one of the many important findings of the Danish Naturalist, Peter Wilhelm Lund in the nineteenth century. Opened for tourism since 1965, little has been investigated about its microclimate and the impacts of tourism on it. Therefore, this research was conducted continuously for a period of 31 months (from March, 2014 to November 2016) to demonstrate the role and function of microclimatic monitoring in the cave, stressing the importance of this type of monitoring in caves opened for tourism.

Five data loggers (Testo 175H) were installed along the 511 meters of the tourist path, and programed to record temperature and humidity data each 10 minutes. To analyze such a large amount of data which are dynamic and non-linear, and to predict probable impacts caused by tourism, the authors used an artificial neural network. This was tested many times to improve its results.

Initial data shows that, although sometimes it is possible to observe some minor impacts, the cave tends to quickly return to its steady state, probably due to the airflow provided by the openings, which help to lower its temperature after visits.

The neural network is being used as a statistical tool to allow analysis with multiple variables, correlating them with each other and verifying their importance in the possible changes of temperature and relative humidity of the air inside the cave. By establishing the parameters of the neural network to be tested, if a significant relationship is found between the number of visitors and changes in temperature and relative humidity recorded by the sensors, a prediction of the maximum number of visitors supported by the cave could be determined without significant changes in the climatic variables observed. The research is the first step to analyse the cave climate with the aim to eventually provide information to plan carrying capacity.

(Abstract) How convective cave ventilation affects speleothem growth

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Abstract

Interpreting speleothem d^{13}C records for robust palaeo-environmental reconstructions has often relied on correlation with other proxy records rather than an independent process-derived d^{13}C interpretation. We have taken the process path to d^{13}C speleothem interpretation by conducting multi-year continuous monitoring of external weather, soil and cave functional parameters, but particularly cave trace gases. CO_2 in cave air of the growing speleothem controls speleothem growth through dissolution in drip waters via the 3-phase chemical equilibrium

$$2HCO_3^- (aq) + Ca^{2+}(aq) \hat{U} \; CaCO_3 (s) + CO_2(g) + H_2O \qquad \text{Eqn 1.}$$

A response time of drip water pH to changes in cave CO_2 of less than 10 minutes demonstrates the expected chemical equilibrium (Eqn 1). Imposition of an exogenous source of high CO_2, from overlying karst soil, on the speleothem chemical equilibrium inhibits speleothem growth and may cause partial speleothem dissolution. Convective cave ventilation driven by external temperature contrast with the cave temperature is dominant in our study of Chifley Cave, Jenolan, NSW, Australia. In summer karst soil gas and air from above is drawn into Chifley Cave and in winter from the lower cave entrance. Seasonal bi-directional cave ventilation with different CO_2 sources and concentrations directly links external temperature and high cave CO_2 to speleothem growth. The karst soil source of CO_2 (plant and microbial respiration) is temperature and soil moisture dependent, further accentuating the potential for seasonal speleothem growth bias. The strength and direction of convective cave ventilation is also dependent on external temperature. These 3 mechanisms link external temperature to speleothem d^{13}C.

Continuous measurement of three independent gas tracers Rn, N_2O and d^{13}C – CO_2 confirms a summer karst soil gas origin of high CO_2, to over 10,000 ppm in Chifley Cave. Winter air-flow in the opposite direction with low ambient CO_2 shows a comparatively small addition of CO_2 with a d^{13}C – CO_2 isotopic label consistent with equilibrium speleothem growth, establishing a seasonal speleothem growth bias mechanism for convectively ventilated caves.

Cave Mineralogy

Secondary Minerals From Italian Sulfuric Acid Caves

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Abstract

Italy is a country hosting a large number of hypogenic sulfuric acid (SAS) speleogenesis caves, mostly located along the Apennine chain, but also in Campania (along the coastline of Capo Palinuro), Apulia (along the coastline of Santa Cesarea Terme) and Sicily.

Besides the typical morphologies related to their special geochemical origin (cupolas, replacement pockets, bubble trails, etc), these caves often host abundant secondary mineral deposits, mainly gypsum, being the result of the interaction between the sulfuric acid and the carbonate host rock. Native sulfur deposits are also well visible on the ceiling and roof, and peculiar sulfuric acid minerals such as jarosite, alunite, and other sulfates like copiapite, pickeringite, tschermigite, tamarugite (probably related to the weathering of native clay minerals) have been found in those caves.

The presence of typical SAS minerals, together with the morphologies, testifies the influence of rising acidic waters, that likely interact with the deep-seated Triassic evaporite deposits (along the Apennine chain), with volcanic sources or hydrothermal springs in the Tyrrhenian sea (in Campania) and with marine waters that infiltrate on the sea bottom and rise through deep faults (in Apulia). This paper describes the secondary minerals discovered in several caves, and discusses their origin and possible use in reconstructing the evolution of these cave systems.

Keywords: sulfates; speleogenesis; hypogenic caves; cave mineralogy

1. Introduction

Hypogene caves are widespread around the world and together with epigenic caves represent the most important types of karst systems (Klimchouk 2007). Despite the fact they can evolve in different lithologies (carbonates, evaporites and clastic rocks with soluble cement) and geological settings, they present similar cave patterns and the morphological features of rising flow (Klimchouk 2009). Because of the fact they are climate-independent and do not rely on infiltrating surface waters, the most famous and largest hypogene cave systems have been found in dry regions (*e.g.* Carlsbad caverns and Lechuguilla in the Guadalupe Mountains in New Mexico, Toca da Boa Vista and Toca da Barriguda in Bahia in Brazil, etc). In these areas hypogene cave systems can be preserved after their exhumation thanks to the dry weather conditions, with subduing secondary processes (*e.g.* epigenic infiltration, deposition of speleothems), which can cover the original hypogenic features (Klimchouk *et al.* 2016). Several types of hypogene caves are well known, such as sulfuric acid (SAS) caves, thermal limestone caves and intrastratal caves in gypsum (Klimchouk 2009). In Italy all these types of hypogene caves (Galdenzi and Menichetti 1995; De Waele *et al.* 2014) are documented, but here we focus in particular on sulfuric acid caves that are abundant especially along the Apennine Chain, in the Southeast Apulian foreland and in Sicily. Differently from sulfuric acid caves in the Guadalupe Mountains (Hose and Macalady 2006), along the Appennine chain the H_2S source is mostly related to deep-seated upper Triassic evaporites called "Anidriti di Burano Formation." (Martinis and Pieri 1964; Ciarapica *et al.* 1987) cropping out in several regions of Italy including Emilia-Romagna, Tuscany, Latium, Umbria, Marche, Apulia (Gargano), and also in Greece and Albania (Martinis and Pieri 1964).

We collected and analyzed samples coming from several sulfuric acid environments reported in Figure 1, in particular from Porretta Terme thermal spa underground tunnels (Emilia-Romagna), Monte Cucco and Faggeto Tondo caves (Umbria), Montecchio cave (Tuscany), Cavallone and Bove caves (Abruzzo), Cerchiara di Calabria and Cassano allo Ionio Caves (Calabria), Santa Cesarea Terme caves (Apulia), and Acqua Fitusa cave (Sicily).

2. Geological setting

Most SAS caves are located along the Apennine chain, where deep-rooted faults allow groundwaters to rise from depth. In many cases these rising fluids are rich in H_2S, and more or less thermal. Porretta Terme (Emilia Romagna), Cassano allo Ionio-Cerchiara di Calabria (Calabria), and Santa Cesarea Terme (Apulia) represent commercially exploited spas and thermal baths. Montecchio hosts a thermal lake at -100 m, Acqua Fitusa is related to a nearby thermal sulfuric spring, Monte Cucco, Faggeto Tondo, Cavallone and Bove caves are high up in the mountains and no longer directly related to thermal rising waters.

Porretta Terme spa is located in the Tuscan-Emilian Apennines and develops in the "Porretta Terme Formation.", in particular in the arenitic member called "Arenarie di Suvi-

Figure 1. Location of the caves object of this study. From the N to the S are reported: Porretta Terme caves in Emilia Romagna, Monte Cucco and Faggeto Tondo caves in Umbria, Montecchio cave in Tuscany, Cavallone and Bove caves in Abruzzo, Cerchiara di Calabria and Cassano allo Ionio caves in Calabria, Santa Cesarea Terme caves in Apulia, Acqua Fitusa cave in Sicily.

ana" characterized by Oligocene lithic arenites with a vertical stratification due to Apenninic tectonic movements (ISPRA). Several sulfuric thermal springs have been encountered in an artificial tunnel network realised in the XIX century. These old underground environments are similar to caves, and host a wide variety of secondary mineral deposits.

Monte Cucco and Faggeto Tondo caves are located in the Umbro-Marche Apennines in a fold-and-thrust belt dominated by Jurassic carbonate rocks of the "Calcare Massiccio Formation." (Pialli *et al.* 1998). Both caves are part of a huge sulfuric acid cave system, uplifted high above the present base level and now abandoned by the sulfuric waters. The cave is intersected by epigenic vadose shafts and hosts several active passages, unrelated to its hypogenic origin. Several fossil conduits still host a variety of secondary minerals related to SAS speleogenesis.

Montecchio Cave is situated in southern Tuscany, and is hosted in the massive Jurassic limestone of the "Calcare Massiccio Formation.", and in Lower-Jurassic well-bedded cherty limestone of the "Calcare selcifero di Limano" (Piccini *et al.* 2015). It is composed of several cave levels, the lowest of which (-100 m from the entrance) still hosts a thermal sulfuric acid pool.

Cavallone and Bove caves are located in the central Apennines, in the Majella National Park of Abruzzo, mainly characterized by fossiliferous marine limestones deposited during upper Cretaceous at the bottom of a tropical sea. The Majella massif is composed of an anticline fold structure (Patacca *et al.* 1992). Both caves are uplifted trunks of a huge SAS cave system now partly dismantled by surface erosion, but still holding evident signs of its speleogenetic past.

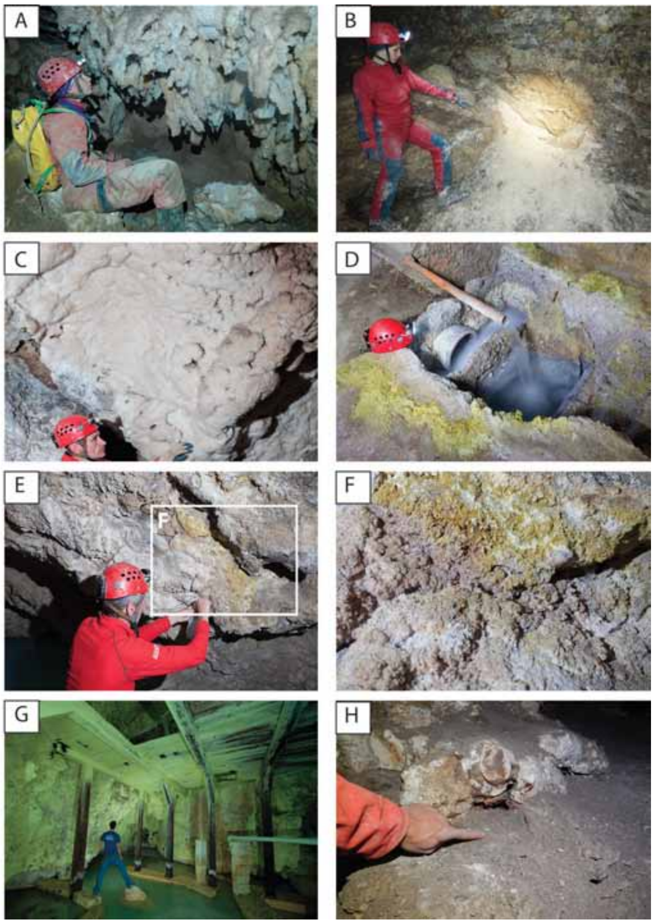

Figure 2. SAS minerals in several caves in Italy; A) Gypsum deposits in Faggeto Tondo cave (credits: J.De Waele); B) Alunite deposits in Cavallone cave (credits: M. Nagostinis); C) Gypsum in Sant'Angelo Cave in Cassano allo Ionio (credits: O. Lacarbonara); D) The yellow deposits are characterized by copiapite, tamarugite and pickeringite and are located in "Sorgente N°3" in Cassano allo Ionio (credits: O. Lacarbonara); E and F) The yellow deposits are characterized by copiapite and tschermigite and are located in Ninfee cave in Cerchiara di Calabria (credits: O. Lacarbonara); G) Sulfur deposits covering walls and ceiling in Gattulla cave at Santa Cesarea Terme (credits: M. Vattano); H) Gypsum deposits in Acqua Fitusa (credits: M. Vattano).

Cerchiara di Calabria and Cassano allo Ionio caves are located in the southern Apennines and develop in biogenic calcarenites of the "Cerchiara Formation." of Lower Miocene age (Selli 1957) and in Triassic dark-grey dolostone (Selli 1962), respectively. The underground karst network is composed of various caves and cave levels carved along the former sulfuric base level. The lowest level still contains active sulfuric water streams, used in the local spas.

Santa Cesarea Terme caves are located in the south-eastern Apulian foreland. They develop in micritic limestones and dolostones called "Calcari di Altamura" of Upper Cretaceous age (Azzaroli 1967). The four caves, all of modest dimensions, are carved at sea level and all have a direct access to the sea. Sulfuric thermal waters rise from the final parts of the caves where they meet seawater.

Acqua Fitusa cave is located in the eastern sector of the Sicani Mountains, in San Giovanni in Gemini, Sicily. It forms in the breccia member of the Upper Cretaceous known as "Crisanti Formation.", characterized by conglomerates and calcarenites with rudists and benthic foraminifera (Catalano *et al.* 2013).

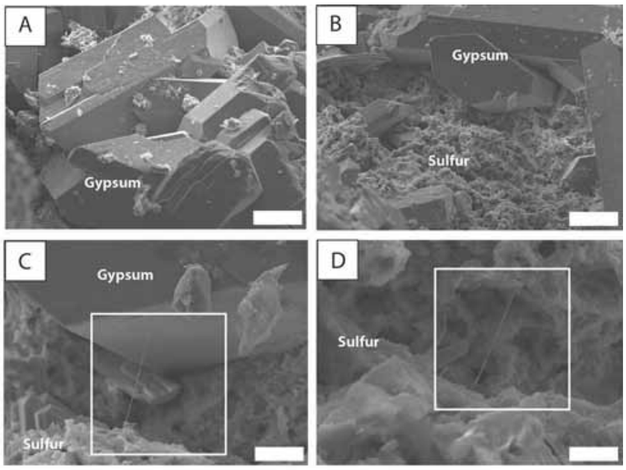

Figure 3. SEM images of gypsum and sulfur from Santa Cesarea caves; A) Gypsum crystals, the bar is 100 µm; B) Gypsum and sulfur crystals, the bar is 100 µm; C) In the white square it is possible to observe a filamentous structure between a gypsum crystal and sulfur minerals, the bar is 20 µm; D) In the white square it is possible to observe a filament in sulfur deposits, the bar is 10 µm.

Acqua Fitusa is a marvellous example of a sulfuric water table cave (De Waele *et al.* 2016), now disconnected from the active spring below.

3. Results

The collected samples have been analyzed using XRD methodology in Genova and Modena-Reggio Emilia Universities. Some preliminary analyses with Scanning Electron Microscope have been done in the laboratory of Bologna University.

In the following table (Table 1) the eleven SAS minerals found in these sulfuric acid environments are listed. These minerals generally occur as crusts or microcrystalline powdery deposits of pale white to yellowish and orange color. Larger crystals have also been found occasionally (mainly gypsum and sulfur) (Fig. 2).

Gypsum is derived from the typical reaction of sulfuric acid with pure limestone (calcite), producing also CO_2 (Galdenzi and Maruoka 2003). Sulfur is instead formed in extremely acidic conditions with the intermediation of micro-organisms. SEM images (Fig.3) from gypsum and sulfur deposits of Santa Cesarea Terme caves are shown below. Using a high magnification (20 µm and 10 µm) it is possible to observe microbial filaments (Fig.3C and D).

All the other sulfates, on the other hand, are all weathering products of sulfuric acid with the host rock, mainly Mg, Al, Fe, K, and Na - containing clay minerals. Among these, the K-jarosite and in particular alunite-group minerals are of extreme interest, because they allow to date the cave-forming process using the radioactive decay of the K-Ar chain (Polyak *et al.* 1998). Barite, found only in minor amounts in the Monte Cucco cave, might hint to a thermal origin, while fluorite in Faggeto Tondo cave clearly points to very acid and thermal conditions in the initial stages of cave development, before SAS speleogenesis became the dominant process (Forti *et al.* 1989).

4. Concluding remarks

In this study we report the results of mineralogical studies on secondary cave minerals formed by the interaction of sulfuric acid with the host rock. A total of 15 SAS caves have been visited and minerals have been collected. Also the artificial tunnels of a sulfuric thermal spa have been investigated.

Eleven minerals have been identified, most of which are sulfates (9), while native sulfur has been found in three locations and fluorite in only one cave. Besides the well-known SAS minerals (gypsum, jarosite, alunite), also less common minerals such as copiapite, tamarugite, tschermigite and pickeringite have been discovered. Copiapite-group minerals, besides volcanic caves close to fumarolic activity (Hill and Forti 1996), have been observed in mine environments and in particular in inactive mines of massive sulfide deposits in California (Jamienson *et al.*, 2005) and in Sardinia (Bini *et al.* 1986; De Waele and Forti 2005; Ara *et al.* 2013). It has also been reported from one sulfuric acid cave, Carlsbad Caverns (Mosch and Polyak 1996). Tamarugite and pickeringite have previously been described in relation with fumarolic activity in volcanic caves (Hill and Forti 1996), and in two sulfuric acid environments as well, Diana Cave in Romania (Puşcaş *et al.* 2013) and Aghia Paraskevi in Greece (Lazaridis *et al.* 2011). Tschermigite deposits have been discovered in thermal sulfidic serpents cave in France by Audra and Hobléa (2007) in association with alunogen and jurbanite, and in Lone

Table 1. The eleven secondary SAS minerals in the studied caves: PT = Porretta Terme, MC = Monte Cucco, FT = Faggeto Tondo, MT = Montecchio, CB = Cavallone-Bove; CC = Cerchiara di Calabria-Cassano allo Ionio, SCT = Santa Cesarea Terme, AF = Acqua Fitusa.

SAS Minerals	Chemical formula	PT	MC	FT	MT	CB	CC	SCT	AF
Gypsum	$CaSO_4\ 2H_2O$	x	x	x	x	x	x	x	x
K-Jarosite	$KFe(SO_4)_2(OH)_6$	x	x	x	x	x	x	x	
Sulfur	S^0	x		x				x	
Alunite	$KAl_3(SO_4)_2(OH)_6$		x		x	x			
Barite	$BaSO_4$		x						
Fluorite	CaF_2			x					
Natroalunite	$NaAl_3(SO_4)_2(OH)_6$					x			
Copiapite	$Fe^{2+}Fe^{3+}_4(SO_4)_6(OH)_2$ *$20H_2O$						x		
Pickeringite	$MgAl_2(SO_4)_4$*$22H_2O$						x		
Tamarugite	$NaAl(SO_4)_2$ *$6H_2O$						x		
Tschermigite	$(NH_4)Al(SO_4)_2$ *$12H_2O$						x		

Creek Fall Cave in eastern Transvaal, where it derives from pyrite oxidation and decay of guano, in the presence of clays (Martini 1983).

Some of these minerals can allow in the future to date the cave-forming process, with the possibility to constrain the formation of the very old caves of Cavallone and Bove, and maybe also Monte Cucco.

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SEM images were performed at the University of Bologna with the assistance of Prof. Giorgio Gasparotto.

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Secondary minerals from halite caves in the Atacama Desert (Chile)

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Abstract

In the past 15 years several expeditions by French, American and especially Italian cavers have surveyed over 15 km of salt cave passages in the Cordillera de la Sal, close to San Pedro de Atacama village (Atacama Desert, Northern Chile). Over 50 caves have been explored up to now at an elevation around 2,500 m asl. These karst systems are characterized by in-cave temperature of around 17 °C and a relative humidity always very low, with a maximum of 15%. This extreme aridity is due to the severe conditions of the area with only a couple millimeters annual rainfall and several years without rain. Currently the rare precipitation events are enough to allow the dissolution of the salt rock and crusts, and the deepening of underground meandering river passages. Moreover, after the sporadic rain events, the water penetrating the cave's host rock along fractures and bedding plains leads to the dissolution of primary minerals and allows the formation of seeping brines with dissolved salts. Both these processes selectively add solutes to the incoming undersaturated rainwater. The evaporation of these resulting salt-rich fluids at the cave atmosphere interface causes secondary minerals to precipitate.

Mineral samples have been collected in eight caves, and include stalactites, flowstones, precipitates that form crusts in the streambeds and at the groundwater seeps, parietal coatings, earthy masses from the cave floors and efflorescence salts on ceiling rock outcrops. Most secondary deposits are composed of halite, but also other halides, carbonates, sulphates, nitrates, phosphates, and silicates have been discovered. Among the sixteen observed minerals, antarcticite, leonite, darapskite, blödite, atacamite and anhydrite are worth mentioning. The peculiar climate (extremely arid) and the very special environment dominated by NaCl and $CaSO_4$, allow the crystallization primarily of halite. Atacamite was found where local enrichment in Cu (of hydrothermal origin) occurs, and antarcticite precipitates by the final evaporation of SO_4-depleted brine (after early precipitation of anhydrite). Among sulphates, the metals necessary for the formation of these mineral species (magnesium, potassium, sulphate) derive from the cave sediments while nitrates are supplied by bird guano. Salt mineral precipitation is controlled by the temperature dependence solubility of the species in saline water, so that different secondary minerals were observed.

Keywords: salt karst, sulphates, halides, speleothems, minerogenesis

1. Introduction

Few regions worldwide characterized by an extremely arid climate, host salt caves in which halite survives over time. Among hypersaline desert areas, the central Atacama is one of the driest (Houston and Hartley 2003). Despite the scarcity of rainfall in this area, there are several solution caves in the Oligocene-Miocene evaporites of the Cordillera de la Sal, close to San Pedro de Atacama. Following the first cave exploration of the early 1990s (Salomon 1995), in this area almost 50 caves have been discovered, explored and surveyed for a total development of over 15 km (Fryer 1995; Sesiano 1998, 2006, 2007, 2009; Padovan 2015). Only recently the evaporite karst of Atacama has been the subject of scientific research (De Waele *et al.* 2009a, b, c, d; De Waele & Forti 2010; De Waele *et al.* 2017) describing eight cave minerals in the previously explored caves whereas the last sampling campaign in November 2015 enabled to investigate newly discovered caves on the higher part of the Cordillera (Padovan 2015). In this paper we refer to the sixteen known cave minerals from the Atacama region and the very special conditions that allowed their formation, following the recently published more detailed report of these mineralogical studies (De Waele *et al.* 2017).

2. Caves in the Cordillera de la Sal

The Cordillera de la Sal is a NE-SW elongated fold- and thrust belt a couple of km wide and over 100 km long, located near the San Pedro de Atacama village (2,446 m a.s.l.) in the Pre-Andean depression at about 150 km east from the Pacific coast of South America (Fig. 1).

From a geological point of view the Cordillera is composed of an over 1,800-m thick sequence of Tertiary continental sediments of the Paciencia Group, a package of alluvial conglomerates. These sediments interfinger with the San Pedro Formation, a series of fine-grained clastic sediments including some 20 to 60 m thick interbedded salt units (Wilkes and Görler 1994) where more than 50 caves are known, several of which are over 2 km long.

Cave microclimate conditions are characterized by in-cave temperatures ranging between 15-18 °C, depending on

Figure 1. The Cordillera de la Sal anticline and the investigated caves: 1. Chulacao Cave; 2. Lechuza del Campanario Cave; 3. Parede de Vidrios Cave; 4. Zorro Andina Cave; 5. Vicuña Seca Cave; 6. Arco de la Paciencia Cave; 7. Ventanas Cave; 8. Cressi Cave system.

altitude, cave depth below the surface, and size/number of their openings. Cave relative humidity is always very low (between 10-15%) enforced by the constant airflow through the entire cave length. The long periods of extreme dryness favours evaporation on cave walls, except during rare rain events. Sometimes decades can pass between one rain event and another. Secondary minerals and speleothems have been sampled in eight caves (Fig. 1).

3. Methods

Secondary minerals sampled for this study include stalactites, flowstones, precipitates that form crusts in the streambeds and at the groundwater seeps, coatings along the cave walls, earthy masses from the cave floors and efflorescence salts on ceiling rock outcrops. Cave mineral and speleothem samples were collected during two expeditions (2009 and 2015) with a knife or a geological hammer using small plastic containers or sampling bags. Mineral phases were determined by combining X-ray diffraction data with semi-quantitative chemical analyses. Details on the methods used can be found in De Waele *et al.* (2017).

4. Cave minerals

Mineralogical analyses have revealed a great variety of secondary deposits for the Atacama salt caves, much more than in any other salt karst area of the World (Hill and Forti 1997; Filippi *et al.* 2011). Sixteen mineral species have been identified (Table 1, Fig. 2-3), six of which are quite rare for cave environments (antarcticite being a new cave mineral). Most secondary mineral phases are composed of halite but other minerals have been observed occasionally, such as other halides, sulphates, phosphates, nitrates, carbonates, and silicates.

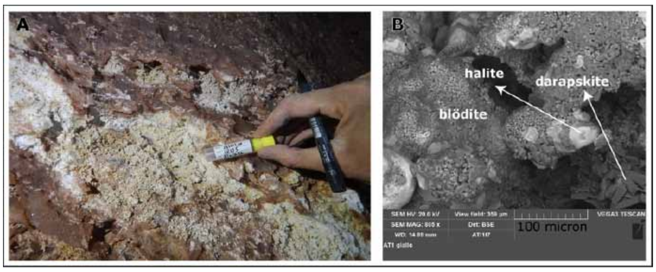

Figure 2. Sulphates of Atacama halite caves: A. Anhydrite powders in a pocket in Arco de la Paciencia Cave (photo Marco Vattano, La Venta Esplorazioni Geografiche); B. The association darapskite, blödite, and halite from the Cressi cave system (SEM photo, Genova University).

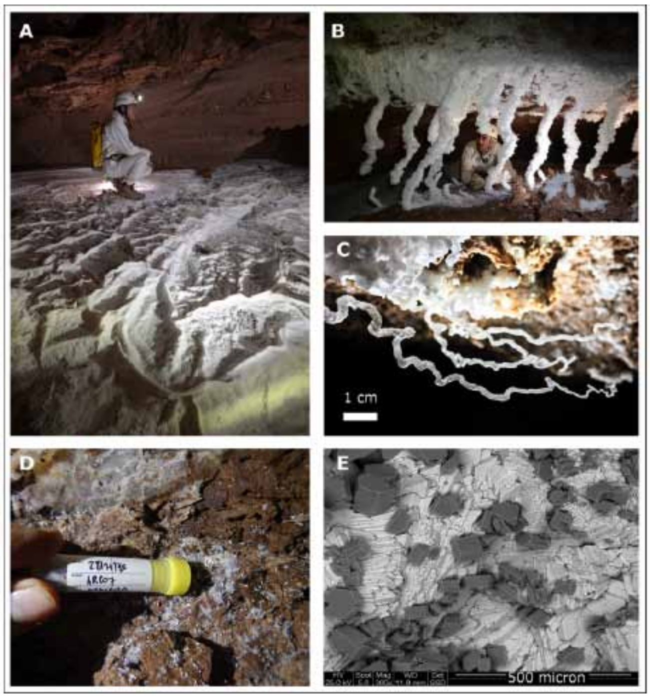

Figure 3. Halogenides of the Atacama desert caves: A. The typical white halite crust covering the cave river floors (Cressi Cave system) (photo Marco Vattano, La Venta Esplorazioni Geografiche); B. Bend halite columns in Cressi Cave system (photo Marco Vattano, La Venta Esplorazioni Geografiche); C. A 20 cm long halite helictite (Arco de la Paciencia Cave (photo Riccardo De Luca, La Venta Esplorazioni Geografiche); D. Antarcticite needles on the marly interbed in Arco de la Paciencia Cave (photo Marco Vattano, La Venta Esplorazioni Geografiche); E. Atacamite crystals on aragonite, Chulacao Cave (Sem image, Modena and Reggio Emilia University).

Most of the secondary minerals found in the salt caves of Atacama are derived from the evaporation of brines (i.e, halite, gypsum, antarcticite, darapskite, blödite, leonite), or from the dehydration of gypsum (bassanite, anhydrite) induced by the hot, arid climate of the area. Halite occurs as crusts (Fig. 3A), white stalactites in euhedral cubic crystals, poorly crystalline trays, bent columns (Fig. 3B), rims, blisters, helictites (Fig. 3C) and cottonballs (Filippi *et al.* 2011). In few spots, also the very rare cave minerals atacamite and antarcticite (Fig. 3D) have been found. In a sample collected close to the southern entrance of Mina de Chulacao Cave, atacamite has been detected as rounded aggregates of emerald to dark green crystals and crystalline crusts on the cave walls, associated with small, thin, white to pale-green aragonite crusts (Fig. 3E). In the Arco de la Paciencia Cave, antarcticite, occurs as efflorescences of acicular crystal aggregates protruding out-ward from a marly interbedded layer on the cave walls (Fig. 3D). The genetic mechanism that has allowed the formation of this mineral in the karst environment, such as Atacama, is far more complex than the extreme evaporation of the hypersaline lakes of the other locations known in the world. In fact, in this cave antarcticite has not crystallised in evaporated pools, but on a dry cave wall. The mineral seems to have formed starting from capillary water seeping out from the fine-grained sediments, probably following exceptional rain and/or snow events that occurred some months before its discovery.

Gypsum, bassanite and anhydrite have commonly been found in the caves and at the surface (De Waele and Forti 2010). Anhydrite forms relatively pure white, fine powders filling fractures and dissolution pockets far from the entrance in the Arco de la Paciencia (Fig. 2A), Vicuña Seca and Ventanas caves. Leonite occurs together with antarcticite in Arco de la Paciencia Cave, but also in the yellowish crusts over dry lakes in the Cressi Cave system, together with other sulphates (blödite and darapskite) and halite (Fig. 2B). This is the third leonite occurrence in a cave, after Tausoare Cave in Romania (Onac *et al.* 2001) and Wooltana Cave in Australia (Snow *et al.* 2014). The leonite-blödite-darapskite paragenesis has been identified in the Cressi Cave system, upstream of a large salt lake; blödite and leonite probably precipitate during dehydration of lake water from a magnesium and potassium sulphate mixture, whereas the formation of darapskite is controlled by nitrogen that in Atacama it is supplied by urine and guano or recycled from cement in the sediments.

In the Parede de Vidrios Cave, biphosphammite, a very soluble mineral, has been preserved together with guanine, another rare cave mineral formed during the early stages of the mineralization of guano and/or bird droppings, already reported from desert caves in Chile, Western Australia and Mexico (Bridge 1974; Forti *et al.* 2004). Bird droppings and pellets can be seen close to the cave entrances, and these organic products have transformed into these crystalline species.. Moreover, Cl-apatite traces found in Arco de la Paciencia Cave are probably related to minor amounts of phosphates (bones) brought into the cave.

In a karst pocket close to the entrance of Chulacao Cave, authigenic Na-clinoptilolite has been found, which is a typical zeolite of alkaline saline lakes (Mason and Sand 1960; Gottardi and Galli 1985; Coombs *et al.* 1997). Clinoptilolite is probably

Table 1. Cave minerals identified in Atacama caves: Ch - Mina de Chulacao; Lec – Lechuza de Campanario; Pav – Parede de Vidrios; Zra – Zorro Andina; Arc – Arco de la Paciencia; Vs - Vicuña Seca; Vent – Ventanas; Cre – Cressi Cave system.

Cave	Mineral	Nominal chemical formula	Occurrence
All	Halite	$NaCl$	Ubiquitous as speleothem, sometimes present also as small euhedral ice-luster millimetric crystals
Arc	Antarcticite	$CaCl_2 \cdot 6H_2O$	White, ephemerous, millimeter-long curls on clay-marly substrate
Ch	Atacamite	$Cu_2Cl(OH)_3$	In globular aggregates of emerald green radial elongated crystals or, rarely, as millimetric veins of euhedral crystals
Ch	Aragonite	$CaCO_3$	Crusts up to 5 mm thick of vitreous luster transparent to pale-blue or light-green tabular prismatic crystals
Ch, Zra, Cre, Arc, Vent, Vs	Anhydrite	$CaSO_4$	Small lens-shaped aggregates of milky white fibres over euhedral partially corroded gypsum crystals, or white powders filling fractures or solution pockets.
Zra	Bassanite	$2CaSO_4 \cdot H_2O$	Rare very small fibres inside an earthy material in corrosion pockets on the surface of gypsum crystals
All	Gypsum	$CaSO_4 \cdot 2H_2O$	Transparent centimeter-sized, euhedral crystals, partially transformed into bassanite and anhydrite
Cre, Arc	Barite	$BaSO_4$	Small micrometric inclusions in halite, not visible with naked eye
Cre	Celestine	SrSO4	Small micrometric prismatic crystals in halite, not visible with naked eye
Cre	Blödite	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	Granular material in the yellowish crusts on dried out cave pools
Arc, Cre	Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	Small amounts together with antarcticite, not visible with naked eye.
Cre	Darapskite	$Na_3(NO_3)(SO_4) \cdot H_2O$	Small submillimetric laminar crystals in yellowish crusts on dried out cave pools
Arc	Cl-Apatite	$Ca_5(PO_4)_3[Cl]$	Traces in some samples
Pav	Biphosphammite	$(NH_4, K)H_2PO_4$	Thin small pale yellow layered fibres
Pav	Guanine	$C_5H_3(NH_2)N_4O$	Earthy, silky-luster milky white to pale pink crusts
Ch	Clinoptilolite	$Na_4K_{1.5}Ca_{0.5}(Al_{6.5}Si_{29.5}O_{72}) \cdot 20H_2O$	Small whitish to pale-pink earthy grains with a few euhedral crystals always strongly associated with halite

a more common phase in evaporites, indicting greater aridity and reflecting the high level of Na in the saline brine.

5. Conclusions

A total of sixteen secondary minerals have been described as occurring in the salt caves of Atacama, including very rare minerals (atacamite, darapskite, blödite, and leonite) and the occurrence of antarcticite, a new cave mineral. An unknown calcium-strontium chloride mineral has also been found, but unfortunately its deliquescent behaviour and small quantity have not allowed for its detailed classification and description.

Most of the Atacama minerals are highly soluble in water. However, the extremely dry climate of the area permits the formation and permanence of these sometimes very rare mineral assemblages. Salt mineral precipitation is controlled by the temperature-dependent solubility of the species in saline water, so that different secondary minerals occur. Processes that drive the crystallization of these phases include the action of thermal fluid-rock interactions and the loss of water through evaporation. Atacamite and aragonite formed from slightly hydrothermal solutions rising along a fault plane in Chulacao Cave.

The other salt minerals in these caves precipitated by evaporative processes during the persistent dry conditions of the Atacama Desert. In fact, the water penetrating along fractures after sporadic rain events causes the dissolution of primary minerals in the host rock, and the slow evaporation of these salt-rich seeping fluids at the cave interface produces speleothems, salt efflorescences and crustal precipitation. Detailed conceptual models for the formation of some of these minerals (i.e. antarcticite, anhydrite, and the blödite-darapskite-leonite association) have been proposed recently (De Waele *et al.* 2017) for this extreme karst environment. It is worth emphasizing that the Atacama salt caves are potential analogues for the study of hygroscopic salts in the Martian subsurface.

Acknowledgements

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Mineral- and fine-grain sedimentology of the Reingardslia karst, Rana, North Norway.

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Abstract

The classical marble karst of Reingardslia is developed in a marble zone stretching some 2.5 km EW with an altitude range of 400 m. The karst is forested with birch, spruce and pine. It hosts one of the longest cave systems in the country with an aggregate length approaching 9 km. The caves consist of phreatic passages with relatively minor vadose development connected into combinations of linear and labyrinthic geometry. Lower levels are active and individual caves are separated by sumps. Passage cross-sections vary from body size to 73 m^2. The karst was re-mapped and studied in the period 2015-2016, with emphasis on structural speleology, paleohydraulics and mineralization. Here, we report the formation of fine-grained (clay) sediments and secondary mineralization. For its latitude (mean annual surface temperature about 2.5 °C), calcite speleothems (stalactites, stalagmites and flowstone) are abundant in space and time. Previous speleothem dating puts speleogenesis beyond MIS 17 (> 750 kyr). Sulphate mineralization (selenite, jarosite) is common and stems from pyrite and sulphide inclusions in the marble and adjacent mica schist. Fe-oxides (goethite) have presumably the same origin. Rarer occurrences of hydrated carbonates (e.g. hydromagnesite) are in accord with the sub-arctic environment. In restricted locations, calcite speleothems (stalactites) are destroyed from seepage water dissolving their roots so they come loose off the rock ceiling. Tentatively, we may link this change in water chemistry to local surface pollution rather than a general change in forest quality. Fine-grained sediments are of glacigenic origin, forming clay deposits, So far we have not detected advanced weathering products that may represent pre-glacial relicts.

Keywords: Cave mineralization, Fine-grained sediments, Jarosite, Illite, Gypsum, Iron oxide

1. Introduction

Deposits in glacially altered terrains are usually never older than the last few glacial events. Caves, which are protected locations, are important sources of information about the paleoclimate (e.g. Valen et al., 1997). Previous speleothem dating puts speleogenesis beyond MIS 17 (> 750 kyr) (Lauritzen et al., 1990). Caves are natural low-temperature laboratories where rare and unstable minerals are formed, and they are therefore very vulnerable (Hill & Forti, 1997; Lauritzen, 2010). There have been documented 255 official cave minerals, where some were first found and other only exist in caves (Hill & Forti, 1997). Difference in chemical, physical and biological factors determines the formation of different types of minerals. Temperature, relative humidity, partial pressure of CO_2, bacteria, water chemistry, fluid flow rate and geography are the most important factors for the secondary mineralization inside the cave. In addition to the occurrence of rare secondary minerals there are also sediment sequences that include fine-grained sediments such as the clay mineral illite. Clay and silt will usually deposit under stagnant water conditions, which can occur during glacial damming or in back-flooding areas of the cave (Valen et al., 1997). This article will focus on cave mineralization and fine-grained sedimentology in a cold-climate cave system. The caves are situated in Reingardslia in the Rana county, northern Norway. In these areas, the processes are much slower regarding mineralization and speleothem growth.

1.1. Geographic and geomorphic setting

The Reingardsli cave system (UTM zone 33 4630 7360) is situated approximately 400 m a.s.l. on the eastern side of the valley Røvassdalen (Fig. 1), in Rana county, northern Norway. The closest glacier in the area is Svartisen ice cap, which is located around 20 km north from the cave system. The cave system consists of four caves; *Larshullet, Lapphullet,* *Olavsgrotten and Persgrotten*, with an aggregate length approaching 9 km. They are all believed to be hydrologically connected, and Olavgrotten and *Persgrotten* have been linked by surveying. On the western side of the valley Røvassdalen there are several other caves, among them *Grønligrotta* and *Setergrotta*. The caves from the western side of the valley and the caves on the eastern side are all situated in the typical Norwegian *stripe karst* (Horn, 1947). This is a marble zone stretching approximately 2.5 km EW with an altitude range of 400 m. The caves are formed in calcite marble adjacent to mica schist. The caves consist mainly of phreatic passages with relatively minor vadose development connected to combinations of linear and labyrinthine geometry. Most of the cave system is dry, but lower levels are active. Passage cross-sections vary from body size to 73 m^2.

Figure 1. Map showing the location of the Reingardsli cave system. The four red marks represent the approximate location of the entrance to the four caves (Kartverket, 2016).

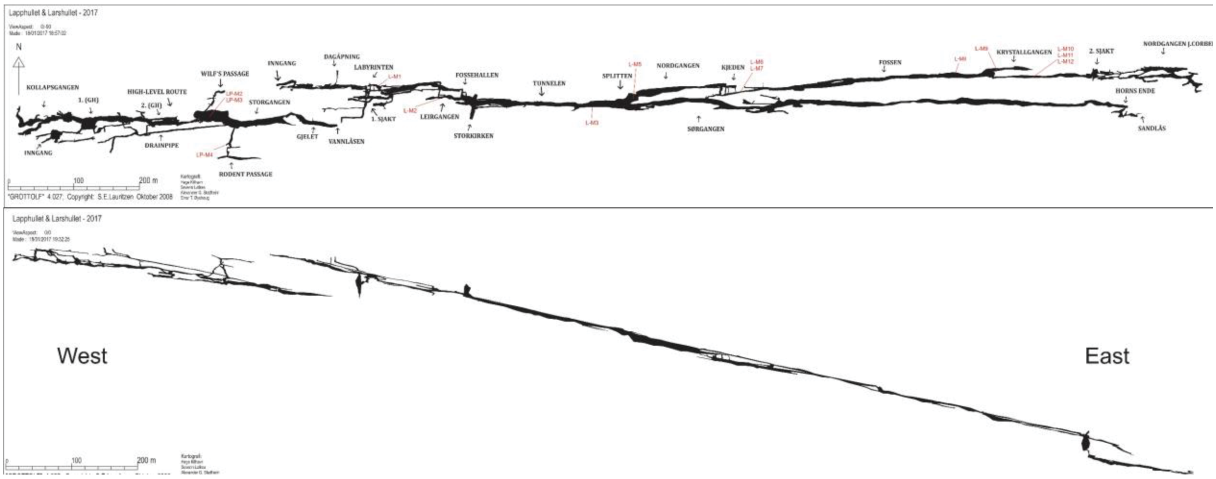

Figure 2. Map showing two of the caves, Larshullet and Lapphullet. The upper figure shows how the two caves from a bird's perspective. The lower figure shows how the two caves are situated in a cross-section.

2. Material and methods

The material in this article is samples collected from the Reingardsli cave system. So far we have identified four types of minerals, and one clay mineral. Calcite is represented in sample LP-M4, L-M1, L-M3 and PO-1.24, gypsum is represented in sample LP-M3, L-M6, L-M7, L-M8, L-M10, L-M11 and L-M12, whereas jarosite is present in sample L-M7, L-M11, L-M12 and PO-1.23, and the iron oxide is found in LP-M2, L-M6 and PO-1.24. Figure 2 shows the approximate position for the samples from *Larshullet* and *Lapphullet*. The clay mineral, illite is represented in sample L-M2, L-M5, L-M9 and H-M1, where the three first ones are from *Larshullet*, shown in Figure 2.

2.1. X-ray diffractometry (XRD)

Standard XRD techniques were applied on a Bruker D-8 instrument, mineral databases and the clay mineral protocol of Poppe et al. (2000). Particularly, the **clay** samples were isolated by sedimentation and decantation to separate silt and clay. The clay fractions of the samples were then treated for removal of organic matter (30% H_2O_2). Clay mineral identification followed standard protocols of successive treatments with ethylene glycol, and with heat (400 °C and 550 °C) (Poppe et al., 2000). The **mineral** samples were also prepared following the procedures of Poppe et al. (2000). A small amount of the mineral was crushed with mortar and pestle, then 2-3 drops of methanol was added to the sample and mixed. A pipette was then used to disperse the sample on a glass slide.

2.2. Scanning electron microscopy (SEM)

Standard SEM techniques and EDX spot and area analyses were applied (Swapp, 2016) on a Zeiss Supra 55VP SEM microscope, the KV range is from 100 V to 30 kV. Samples were coated with iridium or palladium/gold in the standard way.

3. Results and discussion

Calcite – $CaCO_3$

Calcite, the most widespread mineral in the caves, was identified from its XRD pattern (Fig. 3a and 4f). Calcite is present in samples LP-M4, L-M1, L-M3 and PO-1.24. Sample LP-M4 is the very common speleothem called Moonmilk. It came from *Lapphullet*, in a passage approximately 300 m from the entrance (Fig. 2). The passage is called Rodent Passage and stretches up towards the surface. The Moonmilk is spread out on big parts of the floor and the walls in this passage. The Moonmilk has a milky white colour and consists a mass of microscopic crystals, mainly calcite, and water. The Moonmilk is also present in *Olavsgrotta* (not shown on map). L-M1 and L-M3 are collected from *Larshullet*, one of them from the passages called Labyrinten, and the other from a passage called Tunnelen (Fig. 2). L-M1 and L-M3 are present as crystals precipitated on the floor (and some in fractures on the ceiling). Moonmilk consists of either carbonates or sulfates (Hill & Forti, 1986; Onac & Lauritzen, 1995). So far calcite is the only mineral that has been detected in the Moonmilk. Sample PO-1.24 is collected from a stalactite on the wall in *Persgrotta* (not shown on map). This calcite has a brown to reddish colour, the colour is due to iron oxide (Fig. 4f). Calcite mineral from sample L-M1 and L-M3 can possibly be of anthropogenic origin, from carbide dumping during touristic visits in the past.

Gypsum – $CaSO_4{\cdot}2H_2O$

Gypsum is one of the most common minerals in the cave system, it occurs both on the floor, walls and ceilings in the cave. Gypsum occurs as acicular crystals (up to 2 cm long) and some as more compact crystal masses. Gypsum is associated with both jarosite and iron oxide. Gypsum is identified by its XRD pattern, crystal habit and composition on SEM (Fig. 3b, 3d, 4b, 4c, 4d and 5b). It is present in samples LP-M3, L-M6, L-M7, L-M8, L-M10, L-M11 and L-M12. Sample LP-M3 is situated in *Lapphullet,* on a collapse block in a big collapsed passage approximately 300 m from the entrance (Fig. 2). The other samples mentioned above came from *Larshullet,* mostly in the large passage named Nordgangen (Fig. 2). Some specimens were collected from collapse blocks, while others were efflorescence on the cave walls and ceiling. Gypsum is quite common in the caves, with the largest occurrences on clay and cave walls in the lower part of Nordgangen.

Jarosite – $(K,Na,H_3O)Fe_3(SO_4)_2(OH)_6$

The mineral jarosite was identified by its XRD pattern, crystal habit and chemical composition under SEM (Fig. 3c, 3d, 4a, 4b and 5a). Jarosite is present in samples L-M7, L-M11, L-M12 and PO-1.23. It occurs both on walls, ceiling and on collapse blocks. The mineral occurs as bright yellow-orange masses as pure jarosite intermixed with gypsum. Sample PO-1.23 is

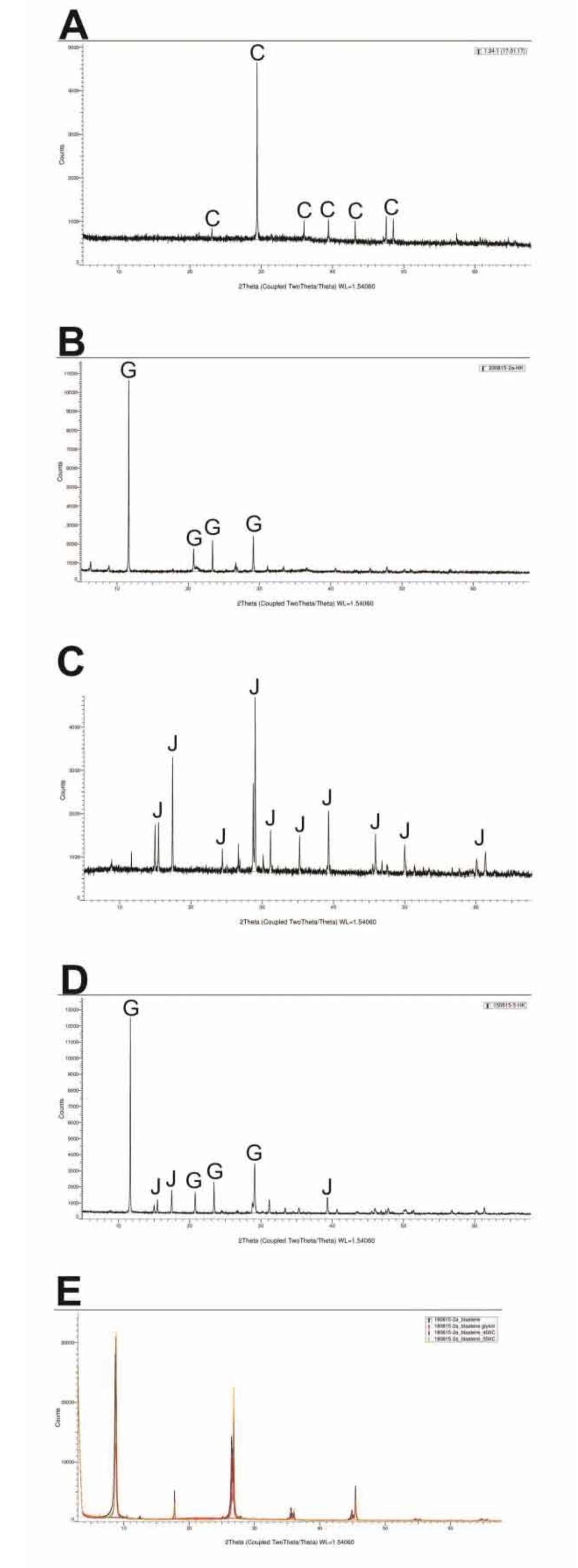

Figure 3. XRD analysis of A) calcite, B) gypsum, C) jarosite, D) gypsum and jarosite, and E) illite. The minerals were prepared following the standard protocols of Poppe et al. (2000). C=calcite, G=gypsum, J=jarosite.

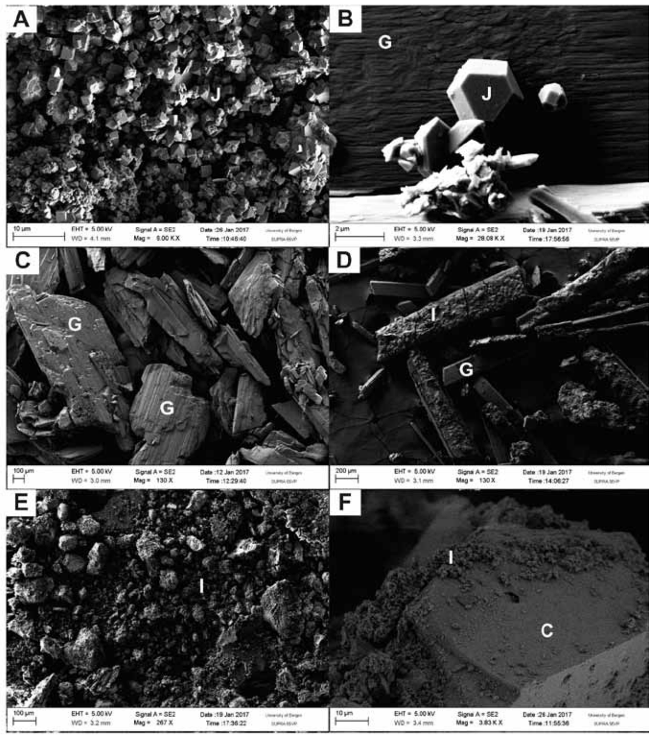

Figure 4. SEM image of different minerals found in the Reingardsli cave system. A) jarosite, B) jarosite that is growing on to the gypsum crystals, C) gypsum, D) gypsum crystals covered in iron oxide, E) iron oxide, F) calcite with iron oxide. J=jarosite, G=gypsum, I=iron oxide, C=calcite.

collected from *Persgrotta* (not shown on map) on a collapse block on the floor, and is pure jarosite. Sample L-M7, L-M11 and L-M12 is found in *Larshullet*, in the passage Nordgangen (Fig. 2). Jarosite in these 3 samples is found together with gypsum, some on the wall in the cave and others on collapse blocks. The gypsum needles have a yellow colour, and SEM shows that jarosite is growing on to the gypsum crystals, like a coating (Fig. 4b). Jarosite has a trigonal-pyramidal shape and symmetry. This is the first documentation of crystalline jarosite in Norwegian caves. Jarosite originates from sulphate mineralization, which is formed by oxidation of pyrite and sulphide inclusions in the marble and adjacent mica schist. Chemical analysis (EDX on SEM) suggests an excess of oxygen. In jarosite, $(K,Na,H_3O)Fe_3(SO_4)_2(OH)_6$, H_3O^+ can substitute for some of the alkali metals, which may account for the oxygen excess. Another explanation could be hydration of water.

Iron oxide

Iron oxide in caves (Fe_xO_y+nH_2O) are often XRD amorphous, and were therefore mainly identified on SEM with EDX and by chemical treatment by acid and dithionite (Fig. 4d, 4e, 4f, 5c). In *Persgrotta* (not shown on map) there is at least one sample of iron oxide (PO-1.24), existing as a coating on a stalactite with a brown to reddish colour. Iron oxides are also present in *Lapphullet* and *Larshullet* at sample LP-M2 and L-M6. Sample LP-M2 is situated on the same block as some gypsum crystals; macroscopically the sample forms a dark-red coating on the block. L-M6 is from *Larshullet* on a collapse block on the floor. The iron oxide in this sample is coating on to gypsum crystals and give them a dark reddish-brown colour. The chemical analysis from SEM-EDX gives a series of different amount of oxygen compared to iron. Therefore it is

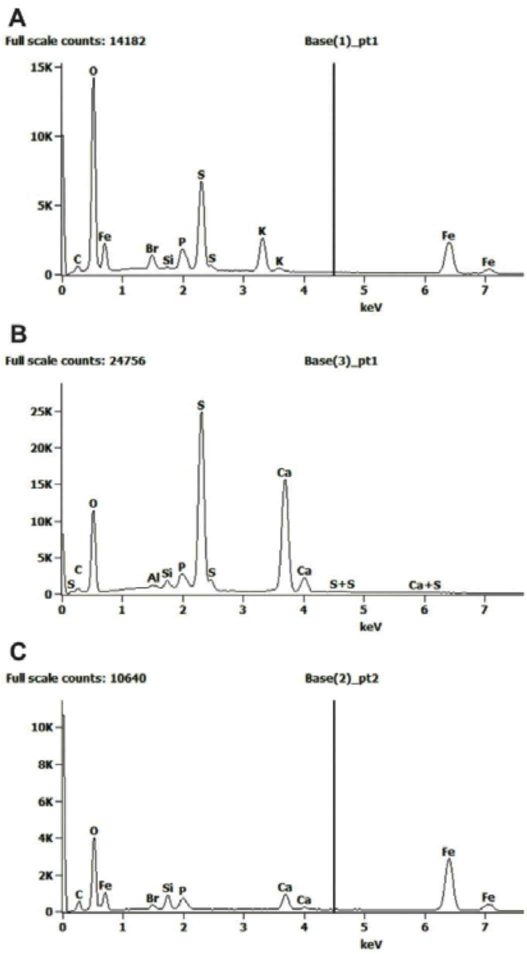

Figure 5. Chemical analyses from SEM. A) jarosite, B) gypsum, and C) iron oxide.

difficult to identify which type of iron oxide the samples could be, Al could indicate trivalent iron. Further analysis by IR or RAMAN spectroscopy is required. The iron oxide could also stem from pyrite or iron oxide impregnations in the overlying mica schist, transported by seepage and percolation waters.

Clay minerals – illite

There are several depositions of apparently glacial clay throughout the whole cave system. Far down in *Larshullet* the walls and ceiling of the passages are covered in clay. There are also several deposits of a 5-10 cm thick layer of clay in the lower passage of Nordgangen (Fig. 2). The clay that covers the walls and ceiling is named "flood clay" and is found from the deepest part of the cave and all the way up until the passage Tunnelen. Another clay deposit is the "blue clay". This differs from the other deposits with its blue, almost metallic colour. There are 4 samples of this clay, and the mineralogy is identified as predominantly illite by XRD (Fig. 3e). Three of the samples are found in *Larshullet* (L-M2, L-M5 and L-M9) and one, H-M1, is from another cave in the area, *Hammernesgrotta*. All the samples are found in vicinity of either a fracture or a collapse. They occur as cones of deposit on top of the existing bed of sediments or marble.

4. Conclusion

In the Reingardsli cave system there are different types of secondary minerals and fine-grained sediments. There are occurrences of calcite in all four caves, present as stalagmite, stalactite, flowstone, pool crystals and Moonmilk. Gypsum is also quite common in the cave system, it occurs as single, acicular crystals and as compact crystals masses. Gypsum is also associated with the rare cave mineral jarosite and iron oxides. Jarosite and iron oxides are less common, most probably stemming from pyrite and sulphide oxidation. Fine-grained, water-laid sediments as clay deposits are found in all four caves, mostly consisting of the clay mineral illite. However further analyses are to be done during the period 2017-2018, regarding more detailed identification of the minerals (testing the present hypotheses), and there are more samples yet to be analysed.

Acknowledgement

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(Abstract) **Adipocere as a Group IX cave mineral and precursor for calcification on bone**

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Abstract

Adipocere ("Leichenwachs") consists of Ca- and Mg- salts ("soaps") of long-chained fatty acids and derive from degradation of animal tissues in wet and Ca-rich environments. It has a waxy or soapy consistence and may attach to bone long after proteinaceous matter has decayed away. The fatty acid components are commonly myristic (C-14), palmitic (C-16) and stearic (C-18) acids (Ubelaker et al. 2011). The material may form in caves on decaying carcasses below pit-fall traps or in scavenger middens. Both natural and synthetic material display XRD-crystallinity (Berner 1968, Science), and may therefore be advocated as an organic (cave) mineral (Group IX), on the same level as guano-derived minerals. Moreover, adipocere is regarded as a trigger or precursor for calcium carbonate precipitates, concretions (sensu Berner), and crusts. Such specs are quite common on bone material from animals with a significant fat-reserve, like bears. At a later stage, adipocere may become completely converted to carbonate through oxidation, forming a kind of "pseudomorphs" on bone. Occurrence, spectroscopic and morphological characteristics will be presented.

(Abstract) **Ikaite in old and newly formed ice deposit of Scărișoara Ice Cave, Romania**

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Abstract

The complex interactions occurring between CO_2, natural carbonate materials, and water play a central role on the carbon cycle. Rising atmospheric CO_2, concentrations over the past century have led to a major concern about the long-term fate of anthropogenic CO_2,. Carbonate minerals (mainly calcite, aragonite, and dolomite) form the greatest proportion of the mineral carbon reservoir. In addition, amorphous calcium carbonate, vaterite, monohydrocalcite ($CaCO_3{\cdot}H_2O$), and ikaite ($CaCO_3{\cdot}6H_2O$) are of considerable interest due to their role as precursors of stable carbonate minerals. Of these anhydrous and hydrated polymorphs of calcium carbonate, ikaite, $CaCO_3{\cdot}6H_2O$, is a rare mineral phase that forms in a variety of environments, but only at temperatures below 4°C. Ikaite was first reported in a cave environment from Scărișoara Ice Cave and later identified in a handful of other perennial or seasonal cave ice deposits. Here, we provide additional mineralogical, spectroscopic, and isotopic data on ikaite samples recovered from the Holocene-age ice block as well as from newly formed and melting ice speleothems in Scărișoara Cave.

Two morphologically different types of ikaite were positively identified and characterized by means of X-ray diffraction, Raman spectroscopy, stable isotopic composition, and environmental scanning electron microscope studies: 1) platy crystals (< 670 µm across) forming patchy white-yellowish powdery accumulations within certain ice layers and at the surface of the ice block and speleothems, and 2) rosette-shaped glendonite (calcite pseudomorphs after ikaite) aggregates up to 4.7 cm in length. Glendonite samples were found protruding out from a melting ice tongue in the Great Reservation.

The high $\delta^{13}C$ (0 to +11‰) and $\delta^{18}O$ (–2 to –6‰) values for type 1 ikaite are typical for cryogenic carbonates in Scărișoara Ice Cave and elsewhere. It forms by rapid water freezing accompanied by a sudden kinetic CO_2 degassing from a pool of dissolved inorganic carbon that begins with $\delta^{13}C$ values typical of karst waters (~ –12‰). Type 2 ikaite (glendonite) has almost identical $\delta^{13}C$ values (~ –11.5‰), implying that the source of dissolved inorganic carbon derives from both biogenic and lithogenic CO_2 by dissolution of limestone by carbonic acid in which half of the DIC derives from limestone ($\delta 13C_{CO2}$ = ~ 0‰), and half derives from biogenic CO_2 ($\delta^{13}C_{CaCO3}$ = ~ –26‰). These results represent a starting point to further explore paleoclimatic and paleoenvironmental implications the presence of ikaite in perennial ice cave accumulations might have.

Fe-oxide filaments interpreted as fossil bacteria in byproducts of hypogene speleogenesis

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Abstract

Hypogene speleogenesis involving CO_2 and H_2SO_4 produce byproducts that serve as direct evidence of the speleogenetic processes. Filaments of Fe-oxide have been interpreted as fossil microbes and are relatively common in these byproducts. This type of hypogene speleogenesis is becoming important towards landscape evolution science; and greater understanding of hypogene speleogenesis will improve the practical application to landscape evolution studies. Here we examine speleogenetic byproducts containing Fe-oxide filaments that we interpret as fossil bacteria and discuss the physical context of their occurrence with respect to speleogenesis. Using x-ray and electron diffraction, the Fe-oxide has been identified as goethite. Samples include the 'Rusticles' from Lechuguilla Cave, and cave mammillaries from Grand Canyon. The rusticles are deposits of Fe-oxide minerals coated with mammillary layers of calcite. They are associated with a pool basin containing a thick deposit of dolomitized cave rafts, and are likely related to hypogene speleogenesis. Cave mammillaries of Grand Canyon are also late stage hypogene speleogenesis byproducts. The Fe-oxide filaments are primarily located in the inner areas of these mammillary coatings. Scanning electron microscope images of etched samples of a Rusticles stalactite shows that the Fe-oxide filaments consist of 1-3 µm-sized Fe-oxide goethite crystals that radiate around the filament form, which is ~8 µm in diameter. Thin section micrographs show a possible central tube, supported by SEM images, but the inner tube is irregularly shaped and mostly filled in with Fe-oxide material. Similar Fe-oxide filaments occur in Grand Canyon mammillaries. In a mammillary deposit formed in a basalt vug, Fe-oxide filaments occur in a reaction zone between Fe-rich crystals of the basalt and the mammillary growth. In this boundary, the Fe-oxide filaments have etched and replaced the Fe-rich crystals in the basalt. A relatively thick Mn-bearing Fe-oxide layer coated by mammillary calcite in another Grand Canyon cave also exhibits abundant Fe-oxide filaments. SEM and optical imaging show these are smooth and beaded-like textures. The Fe-oxide filament occurrences associated with cave mammillaries, suggest the filaments formed primarily in shallow phreatic conditions; however, somewhat deeper than the mammillary calcite was forming. The occurrences are related to shallow hypogene speleogenesis, but deeper phreatic or vadose examples probably exist.

Keywords: Fossil Bacteria, Hypogene Speleogenesis, Cave Mammillaries, Fe-oxide filaments, goethite

1. Introduction

Hypogene speleogenesis has two connotations described by Dublyansky (2014); 1) a geochemical emphasis, and 2) a hydrogeological emphasis. Palmer (2000) defines geochemical hypogene speleogenesis as caves formed aggressively at depth independent of surface-derived acidity. A hydrogeological definition of hypogene speleogenesis focusses less on the particular dissolutional mechanisms, and more on the source of groundwater and its systematic transport and distribution mechanism (Klimchouk, 2007). The deposition of mineral and mineraloid byproducts of hypogene speleogenesis (Provencio and Polyak, 2001) allow speleologists to use hypogene speleogenesis as a scientific tool for purposes beyond speleology. For example, some of these minerals and mineraloids are dateable and contain elements that yield stable and unstable isotope results that ultimately provide important information about the geologic history of the region that hosts these hypogene caves (Polyak *et al.*, 2014). Canyon incision and landscape evolution histories have been worked out using isotopic results retrieved from these byproduct materials (Polyak *et al.*, 2008; Polyak *et al.*, 2013; Hill and Polyak, 2014; Decker *et al.*, 2015). Many of the caves in the western United States are hypogene caves that have a geochemical imprint. Of these, most of the research has focused on caves in the Guadalupe Mountains of southeastern New Mexico and west Texas, and caves in Grand Canyon, Arizona. Because of the speleogenetic byproducts in these caves, the emphasis has been on the geochemical aspect of speleogenesis, and the hydrogeological aspect of speleogenesis is intimately linked and well-defined by the geochemical aspect. Both are pertinent to interpretations made regarding incision and landscape evolution histories, but the geochemical aspect provides the integration of all aspects of hypogene speleogenesis in these types of caves. Our study examines Fe-oxide filaments in mammillary calcite from caves in the Guadalupe Mountains and Grand Canyon. Fe-oxide and other filaments have been noted in other studies in materials that are likely speleogenetic byproducts of hypogene speleogenesis (Davis *et al.*, 2000; Provencio and Polyak, 2001; Palmer and Palmer, 2012). Fe-oxide filaments in caves are not restricted to hypogene speleogenesis, but in this setting they are preserved in mammillary calcite and in other materials considered hypogene speleogenetic. As part of an effort to further characterize speleogenetic byproducts we examine Fe-oxide filaments in mammillary calcite from caves of the Guadalupe Mountains and Grand Canyon. These filaments are interpreted to be fossilized bacteria. Characterization of speleogenetic byproducts is essential if these materials are going to be used effectively as a scientific tool.

2. Materials and Results

Samples consist of Fe-oxide filaments directly beneath or encased in mammillary calcite in Lechuguilla Cave (the Rusticles), and several caves from Grand Canyon; also mammillary calcite filling voids in basalt on the Hualapai Plateau, Grand Canyon. These deposits are interpreted to be speleogenetic byproducts.

The Rusticles filaments, Lechuguilla Cave. A segment of Rusticles 'stalactite' collected in 1994 was studied by Provencio

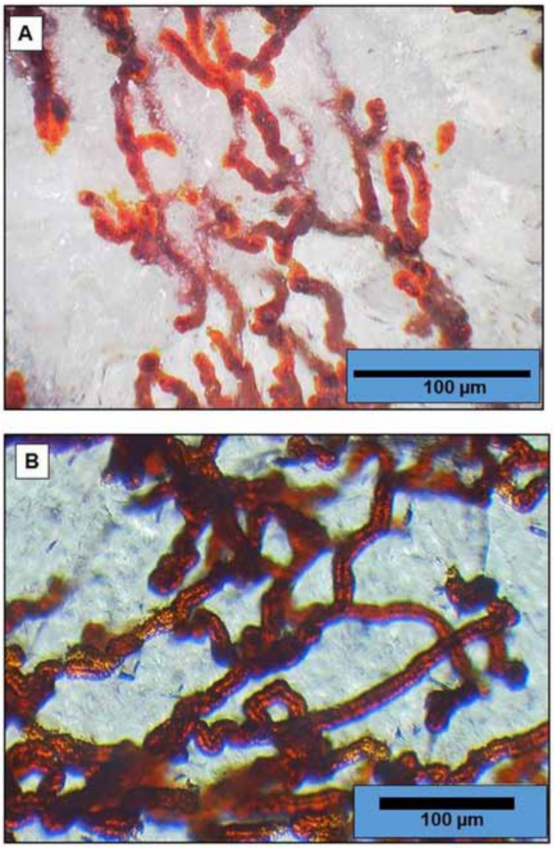

Figure 1. Optical thin section images of Rusticles filaments showing the erratic character of growth. (A) Image collected using reflected light shows Fe-oxide color of the filaments relative to the surrounding clear calcite. (B) Image collected using transmitted light shows a dark interior that is interpreted as a central tube within the filaments.

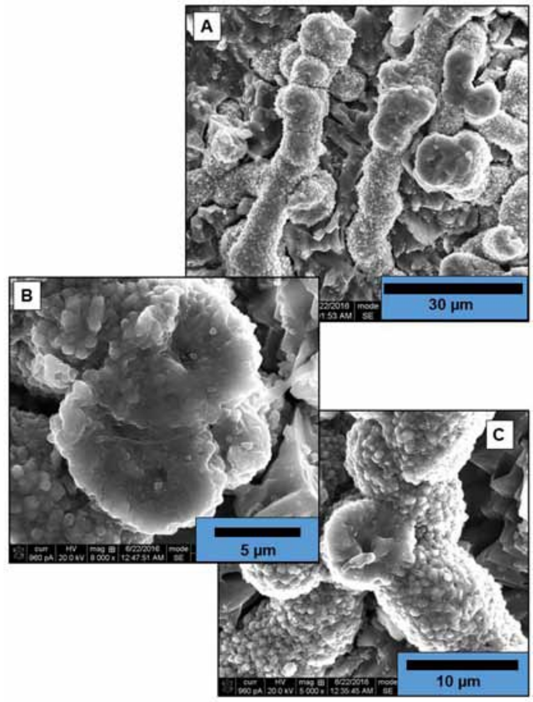

Figure 2. Scanning electron microscopic images of the Rusticles filaments encased in calcite. The surface of this sample was lightly etched with 1% nitric acid to enhance the structure of the filaments. (A) The Rusticles filaments are roughly 5-10 µm in diameter and have a rough crystalline exterior. (B) Close-up of Rusticle filament cross-section showing what appears to be a central tube less than one micrometer in diameter. Note the faint radiating structure of goethite crystals around the center. Energy dispersive spectroscopy measured only Fe and oxygen in this region. As in (B), (C) nicely shows the goethite crystal terminations.

and Polyak (2001), and other pieces of these Fe-oxide stalactites were studied by Davis *et al.* (1990), and both studies suggested a phreatic microbial origin. The Fe-oxide stalactites have a central tube much like a drip stone stalactite, but the tube varies greatly in diameter. The Fe-oxide filaments within these stalactites are encased in calcite (Figure 1), and the calcite is interpreted to be a mammillary coating (Palmer and Palmer, 2012), not drip stone. The thin section and SEM images suggest that the filaments (~8 µm in diameter) have an inner tube and that the Fe-oxide crystal are goethite and radiate around the inner tube. New examination of the filaments using SEM more distinctly show the radiating character of these goethite crystals and the presents of voids near the center of the filaments (Figure 2). The center area of the filaments was analyzed for elemental differences using energy dispersive spectroscopy (EDS), but none were measured. The filaments are sinuous to vibrioid in character and branching is not obvious. Very similar Fe-oxide filaments occur in travertine in north central New Mexico (Figure 3) that has a similar hypogene-like origin.

Mn-bearing Fe-oxide Filaments of Mother Cave, Grand Canyon. A relatively thick (~5 to 10 cm) Fe- and Mn-oxide layer coats the walls of Mother Cave in Grand Canyon. On top of this layer is a thin mammillary calcite coating (1-5 cm). Initial examination of this black layer beneath the cave mammillaries shows the presence of abundant Fe-oxide filaments. While the deposit is black, goethite was the mineral phase identified. There are several varieties of microbial-looking

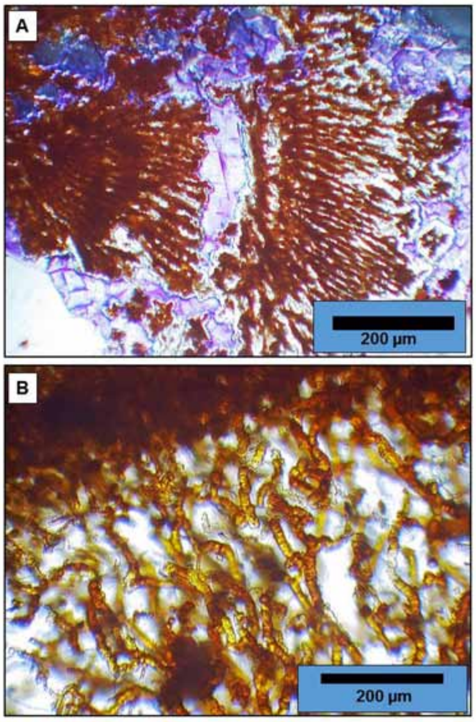

Figure 3. Optical thin section images of Fe-oxide filaments from travertine in central New Mexico that formed similarly to the process of hypogene speleogenesis. (A) Fe-oxide filaments in fan-like structure that are preserved in flowstone-like speleothems deposited in a cave that formed in travertine most probably by hypogene speleogenesis. (B) Note that the filaments are similar in size and structure to the Rusticles filaments.

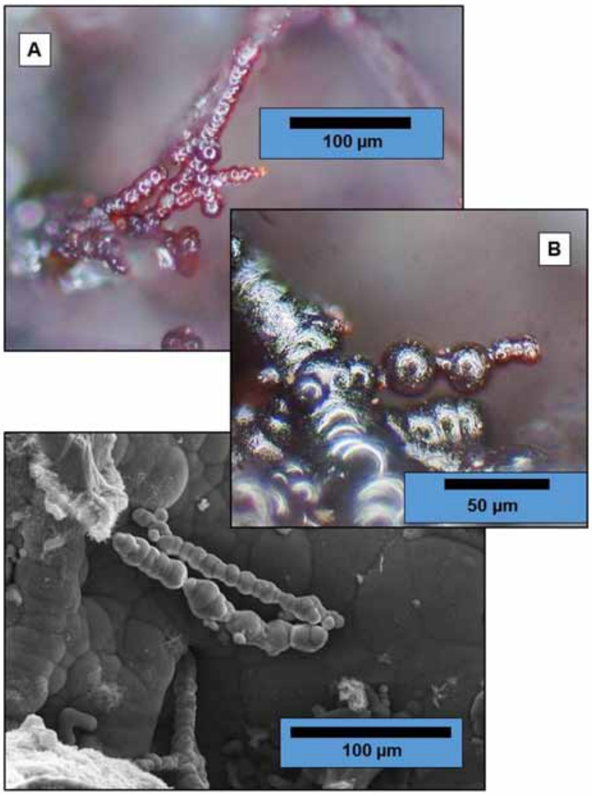

Figure 4. *Optical and SEM micrographs showing filaments preserved in a Mn-bearing Fe-oxide deposit underlying cave mammillaries in a Grand Canyon cave. (A) Optical image shows filaments with a beaded structure that are relatively straight and occasionally seem to branch. Note the more purple color. (B) These beaded filaments have a relatively smooth surface and are the same size or larger than the Rusticles filaments. (C) SEM micrograph of beaded filaments.*

filaments, but one type seemed more prominently displayed. These are relatively straight filaments that occasionally exhibit branching. They are beaded-looking filaments that have smooth surfaces (Figure 4).

Filaments in mammillary-like calcite that fill voids in basalt. A Miocene-aged basalt flow on the Hualapai Plateau of Grand Canyon hosts a thick layer of calcite that fills voids and fractures. These 'cave' mammillaries represent one of the latest phases of hypogene speleogenesis (Polyak *et al.* 2017). Within and at the base of the mammillary calcite (calcite-basalt boundary), weathered crystals from the basalt, likely Fe-rich, host Fe-oxide filaments. These Fe-oxide filaments are 2-5 µm in diameter and have sinuous to vibrioid shapes, similar to the Rusticles filaments (Figure 5).

Other examples from Grand Canyon caves. In other Grand Canyon caves, Fe-oxide filaments encased in calcite or in Fe-rich materials are found in similar settings as described above. In Fe-rich materials, the filaments formed in pore spaces as exemplified in Figure 6.

3. Discussion

Preserved bacterial-like filaments are observed in many different settings. In caves they are not limited to speleogenetic materials, but also occur in speleothemic deposits in both the subaqueous and subaerial settings. Here we describe filaments preserved in cave settings that distinctly represent

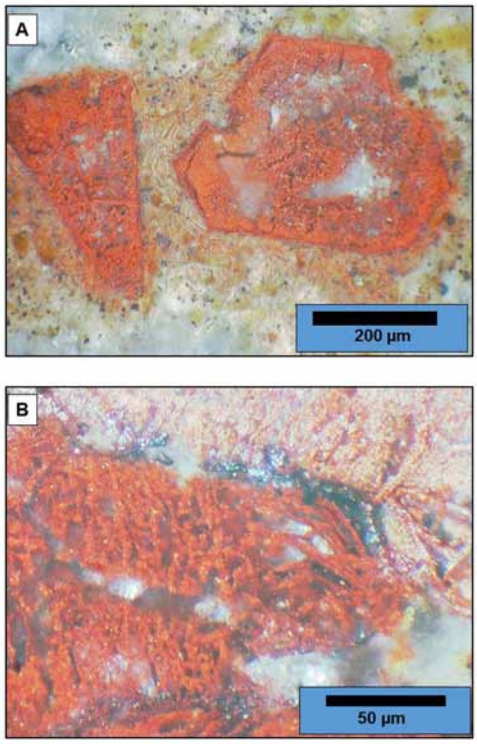

Figure 5. *Reflected-light optical thin section images of Fe-rich crystals from weathered basalt encased in calcite of mammillaries emplaced in voids and cracks of a basalt flow on the Hualapai Plateau of Grand Canyon. (A) Symmetry of weathered-looking crystals encased in calcite. (B) Note the Fe-oxide filaments within the weathered-looking crystals.*

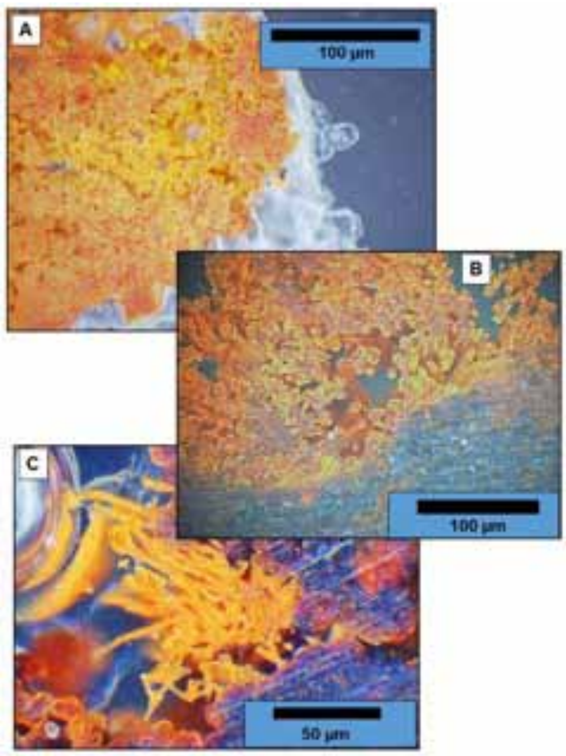

Figure 6. *Reflected-light optical thin section images of Fe-oxide filaments. Thin sections were prepared to a thickness approximately double that of typical sections, allowing for a three-dimensional-like view. (A) Mass of Fe-oxide filaments encased in calcite in cave mammillaries from Glenwood Caverns, Colorado. (B & C) Fe-oxide filaments preserved in Fe-oxide-rich materials that probably predate the cave mammillary phase of hypogene speleogenesis.*

hypogene speleogenesis as part of a further characterization of hypogene speleogenetic byproducts. These filaments appear to be microbial in origin or represent fossil microbes, and the Rusticles filaments from Lechuguilla have been interpreted as such (Davis *et al.*, 1990; Provencio and Polyak, 2001; Palmer and Palmer, 2012). However, these interpretations were based on geomorphic form. The curved filaments from Lechuguilla appear to have crystallized from an inner tube. An organic fingerprint such as residual carbon isotope ratios or residual organic skeletons has yet to be detected. Other types of analyses such as Fe-isotope values characteristic of organic life are also possible (Arand *et al.* 2006). Still, the striking physical resemblance to known bacteria are convincing.

Why study these filaments? Because byproducts of hypogene speleogenesis are being used to make interpretations on canyon incision and surface denudation rates, and for such interpretations to be robustly used globally, characterization of hypogene speleogenesis needs to be extensive and complete. Also, these Fe-oxide filaments preserved in speleogenetic byproducts may be useful analogs for fossil microbes that might be expected on Mars. Should we someday return materials from the Martian surface, the evidence of life may be in the form of fossils only. Davis *et al.* (1990) and Provencio and Polyak (2001) interpreted the Fe-oxide filaments associated with the Rusticles stalactites of Lechuguilla Cave as fossil Fe-bacteria, possible matches to species such as Leptospirillum ferrooxidans and Clonothrix sp.

Microbial activity can simply occur during cave genesis, or it can play a role in cave genesis (biospeleogenesis; Barton and Luiszer, 2005). The role of biospeleogenesis in the origin of the caves of this study is unknown. We conclude that the Fe-oxide filaments are most likely fossil bacteria preserved as a byproduct of hypogene speleogenesis. The Fe- and Mn-oxide phase of hypogene speleogenesis appears to relate to or predate early deposition of cave mammillaries in the samples offered above. In Grand Canyon caves, Fe-oxide deposits hosting filaments appear to occur as a late stage of speleogenesis. In Lechuguilla Fe-oxide filaments appear to be during speleogenesis and were later encased in the mammillary calcite.

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Water travelling on the edge of Fringed Cave Shawls

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Abstract

Water travelling down the underside of fringed cave shawls at Jenolan Caves, New South Wales, Australia, was observed to exhibit oscillatory behaviour. The nature of the water film had three components: a thin film, a spindle-shaped "lump" of water and an oscillating droplet. This was observed on both natural cave shawls and "wire-o-tites". The fairly static thin film stayed mainly between fringe projections ("teeth"). The "lump" of water moved slowly down the cave shawl swelling the film, and the oscillating droplet travelled down with the centre of the "lump". This droplet was briefly suspended from the teeth, oscillating alternately between the left tip and the next lower right tip, forming a sinusoidal track as well as bouncing up and down. The shape of the cave shawl suggests that at the top, water is initially slow, but speeds up under gravity up to a point, after which a different mechanism becomes prominent resulting in the lower edge of the cave shawl having two different angles to the horizontal. It is suggested that calcite deposition in the upper initial portion is governed mainly by CO_2 exchange from the surface of the water film. The water film expands as more water is added to the cave shawl, but the shape is governed by the surface tension of the film, gravity, and the meniscus (adhering to the calcite), resulting in the spindle shape of the lump which appears to be a soliton. As more water is added, gravity overcomes surface tension and the lump of water begins to move downwards (down the cave shawl) guided by the strong meniscus force. As speed increases, turbulence becomes more significant, which increases calcite deposition. A small stable wavelet forms, bouncing off undulations and increasing calcite deposition at each elastic bounce. A series of small, regular deposits of calcite results in the formation of the fringe, or "teeth" on the cave shawl. Subsequent droplets continue to adhere to these teeth in an oscillatory manner following a similar path. With higher flow rates, the lump of water runs more along the outside of curves resulting in a furled shape. It is suggested that the wavelength of the furl corresponds to the length of the lump; the width of the teeth corresponds with the width of the water droplet and the teeth spacing corresponds with half the wavelength of an oscillation of a water droplet.

Keywords:

Introduction

Cave shawls (also called curtains, draperies, bacons) vary from a simple line of calcite under a sloping ceiling, to long furled shapes and extensions to flowstone cascades (Moore and Sullivan 1997 p 55, Hill and Forti 1997 p65) – see Figs 1, 2, 3. The initial conditions required to develop a cave shawl are 1) calcite is being deposited from the water, 2) water being confined to flow down an overhanging surface, 3) the flow rate being low enough for surface tension to be more significant than the angular momentum of the water acting under the force of gravity and 4) evaporation rate being extremely low. The substrate can be any firm surface such as a rock, stretched wire ("Wire-o-tites", Fig 4) or concrete. When viewed from the side during active periods, water can be seen flowing along the edge of the shawl (Fig 5). When viewed from the edge, the behaviour of the water, and hence calcite deposition, varies according to the flow rate. This article concentrates on the geometry of the water flowing at different rates along the lower edge of a simple shawl and its effect on the pattern of calcite deposition. Shawls were observed in detail at Jenolan and compared to other examples elsewhere in Australia.

Figure 1. Parallel shawls in Bouverie Cave, Wombeyan Caves, NSW Australia illustrate the general form of a shawl.

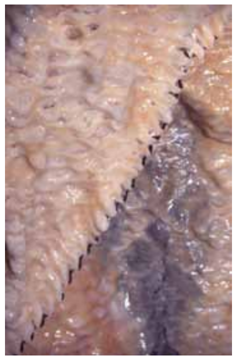

Figure 2. Part of a complex flowstone / drapery at Jenolan Caves, NSW. Water is guided along the projecting points which is becoming a shawl.

1. Cave Shawl Geometry

In two dimensions, the simplest shawl attached to a straight overhanging ceiling at first glance appears triangular, but more detailed examination shows that the upper part of the shawl has a slightly different shape compared with the lower part. The edge of the first 30 cm or so of the shawl follows an approximate half-catenary, that is, half the shape of a chain supported at its ends, or half of a hyperbolic cosine. The rest of the shawl forms an approximate trapezium and the final part is either truncated or merged with the wall depending on the ceiling pitch. Fig 6 shows the general pattern. The active edge may have a regular fringe ("teeth") along its lower edge, or it may be smooth along part or all of the shawl (Fig 7). In some cases the teeth merge with flowstone microgours at the wall. Close examination of the teeth shows that they are fairly regularly spaced, and often protrude slightly to one side or the other of the shawl. Measured shawls at Jenolan Caves have teeth spacings varying from 5 to 10 mm with a variation of 1 to 5 mm. The following discussions of flow rate assume the basic shawl shape has already formed, and we are observing water moving along the edge of the shawl.

Figure 3. Thin shawls at Jenolan Caves are often developed below "wire-o-tites".

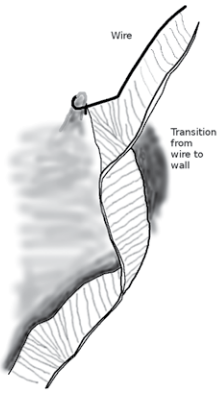

Figure 4. Sketch of a "Wire-o-tite" at Jenolan Caves.

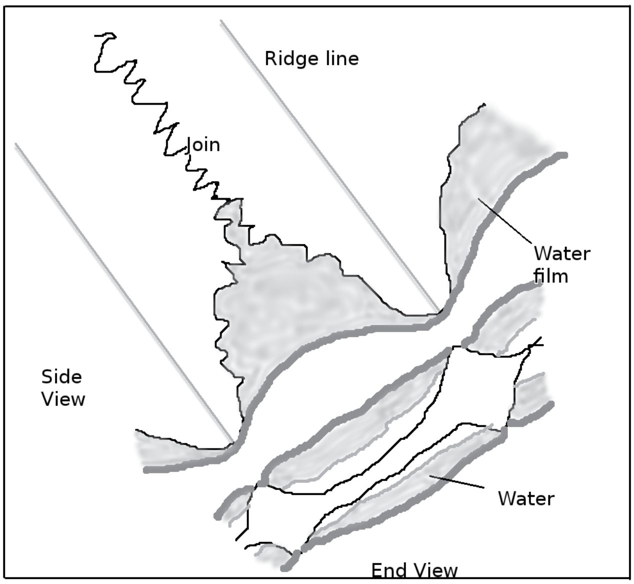

Figure 8. Sketch of the area between the teeth of a shawl showing the water film, the ridge formed by the teeth and the area where calcite joins the teeth.

Figure 5. Water hanging between the teeth of a small shawl.

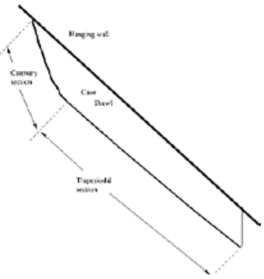

Figure 6. Schematic diagram of a cave shawl showing the general geometry.

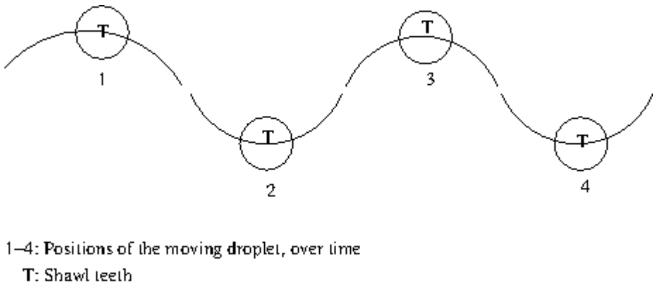

Figure 9. Sketch of oscillatory motion of water droplet as it moves between teeth on a cave shawl, viewed directly below the edge.

Figure 7. Small shawl with water adhering to the teeth.

2. Water Behaviour

2.1. Low flow rate, toothed shawls

In low flow conditions, e.g. one drip per minute, assuming there is very little evaporation, the shawl will have a film of water persisting on its lower edge. One such film of water was observed to lie between the teeth of the shawl (Fig 8) which formed a ridge. The calcite crystals on the teeth were aligned outwards – presumably this is the C axis. Interstitial sites had more random orientations of calcite, with small crystal aggregates forming a zipper or join pattern. As individual drips fall from the lowest point of the shawl, the film of water contracts as the drip falls off, then expands to accommodate more water coming down the edge.

2.2. Medium flow rate, toothed shawls

At a medium flow rate of about one drip per second, the film was observed to slowly fill as a "lump" of water moved slowly down the edge of the shawl, swelling the film as it did so until the lump had passed and the film settled back into its low-flow state. These lumps of water become entrained on wet shawls. Looking underneath the shawl, on the tips of the teeth, a small oscillating droplet was observed. This was briefly suspended from the teeth and travelled at the same speed as the lump of water. As it travelled down the edge of the shawl, the droplet would briefly suspend from one tooth, then the next, and was seen to form a sinusoidal track (Fig 9) as well as bouncing up and down.

2.3. High flow rate

A high flow rate was observed in Wet Cave, in Tasmania, where water was observed travelling rapidly around the outside of a stalactite cluster. The effect on a shawl is discussed below.

3. Discussion

3.1. Low flow rate

The amount of water in this film is generally governed by the surface tension of the water, the length of the shawl and the

Figure 10. A somewhat tattered shawl from Bouverie Cave in which calcite has migrated from intersticial sites, leaving the long C-axis teeth in place.

Figure 11. Underside of shawls in The Silk Shop, Kubla Khan Cave, Tasmania, Australia. The cave gets quite wet at times, and you can see how the shawls have developed more furls as they grow.

roughness (surface area) of the calcite to which it adheres. Water added to the top of the shawl is accommodated by expansion of the film, until a point where water begins to drip from the bottom of the shawl creating a stable repeatable state. Calcite deposition in the upper initial portion would be governed mainly by CO_2 exchange from the surface of the water film, resulting in a relatively even surface.

3.2. Medium flow rate

In medium flow conditions, there was still the fairly static thin film which stayed mainly between the teeth. The shape of the shawl suggests that at the top, water initially moves slowly, but speeds up under gravity up to a point, after which turbulence sets in. This limits the speed and changes the angle the shawl makes with the horizontal, from the half-catenary shape to a trapeziodal shape as the lump of water at this point is no longer accelerating. A soliton is a mathematical expression for a group of dispersed waves appearing as one lump. The buildup of water into a travelling lump, with an oscillating droplet at its middle appears to be a type of soliton with a carrier (a type of stable wavelet).

Since the oscillating droplet mainly adheres to the tips of the teeth, it is expected that calcite deposition would be enhanced at these points, making them longer, whereas the larger lump of water adds calcite more generally, filling in the bulk of the shawl. The gap between the teeth is more sheltered from turbulence and would tend to fill in slower with a more random orientation of calcite crystals, forming miniature pool crystal aggregations, whereas the more turbulent area at the teeth has the calcite C axis aligned pointing outwards and downwards. The stability of the radially aligned long crystals is highlighted in the case of old cave shawls which have preferentially corroded the interstices, leaving just the teeth (Fig 10).

The water film expands as more water is added to the shawl, but the shape is governed by the surface tension of the film, gravity, and the meniscus (adhering to the calcite), resulting in the lump shape of the soliton. As more water is added, gravity overcomes surface tension and the lump begins to move downwards (down the shawl) guided by the strong but elastic meniscus force. As speed increases, turbulence becomes more significant, which also increases calcite deposition. A small stable wavelet forms, limiting the speed and bouncing off undulations. One would expect calcite to be precipitated at each elastic bounce due to increased gas exchange. A series of small, regular deposits of calcite results in the formation of the fringe, or "teeth" on the shawl. Subsequent droplets continue to adhere to these teeth in an oscillatory manner following a similar path. With higher flow rates, the lump of water runs more along the outside of curves resulting in a furled shape. It is suggested that the wavelength of the furl corresponds to the length of the soliton, the width of the teeth corresponds with the width of the water droplet and the teeth spacing corresponds with half the wavelength of an oscillation of a water droplet.

3.3. High flow rate and development of furls

In higher water flow conditions, e.g. continuous dribbling of water, the shawl acts as a guide to the flow but with a more chaotic movement due to turbulence, assuming that the flow rate is still low enough for water to adhere to the shawl and not escape in a cascade. The speed of the water is still governed by the same conditions as above, but the amount of water has increased so the lump of water (as above) is larger but generally within the limits of the elastic surface tension "skin". Due to its mass, it runs more along the outside of any undulations or curves, resulting in a furled shape. It is suggested that the wavelength of the furl corresponds to the length of the lump. See Figs 11 and 12.

4. Further work

More field observations are needed to quantify these results. In particular, is the transition from smooth to oscillating droplets dependent on the chemistry, drip rate or the initial conditions? It would be interesting to more exactly describe the soliton and the geometry (the trapezium and half-cate-

Figure 12. Underside of shawls in The Silk Shop, Kubla Khan Cave, Tasmania, Australia. Looking back up the shawls illustrating the complex furling.

nary) as exhibited by shawls. What would a cave shawl look like if the material was different (e.g. ice or lava), or if gravity was different, such as on other worlds? Why is there such a variation in teeth height and spacing on shawls?

5. Conclusions

The shape of cave shawls is governed by an interaction between turbulence, calcite precipitation and gravity in an environment the width of a water droplet. At these scales, surface tension becomes significant and oscillatory behaviour can be observed. Teeth on the edge of cave shawls is the result of these interacting forces.

Acknowledgements

This work was made possible by the kind understanding of staff and managers at Jenolan Caves and Wombeyan Caves, NSW, who permitted access to the show caves for the purpose of studying the speleothems. Most of the field work was done between 1992 and 1994. All photos and sketches are by the author.

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(Abstract) **Mineralogy and origin of the 18 km-long Snowy River formation, Ft. Stanton Cave, New Mexico (USA)**

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Abstract

Fort Stanton Cave is an historic cave in central New Mexico that includes Snowy River passage, now explored to over 18 km in length with no end in sight. This section of the cave contains the Snowy River formation, a creamy-white, subaqueous calcite pool/stream deposit that covers the mud and gravel floor of the borehole-like passage, forming what could be the world's longest continuous speleothem. The passage has a very low slope (<0.8 degrees over 7.5 km) that responds quickly to large surface meteoric events, filling within hours, flowing for several months, and then draining and drying over a period of weeks.

With each flooding event, a new layer of calcite is deposited. The new layers are very fragile, but recrystallize into a more robust microstructure integrated with the underlying calcite over remarkably short periods of time (months). The carbonate crust has a cauliflower-like texture on the surface, and in cross section, consists of thin laminae that vary from microns to millimeters in thickness, interlayered with clastic mud layers. Eight drill cores taken over a distance of 1.1 km indicate that the deposit thins from 83-25 mm in thickness in the direction of flow, although explorers have noted thin fragile areas further upstream that may be a result of variable flow regimes. The laminae were counted in a thin section prepared from one core, which contained over 500 individual light and dark laminae. Each dark and light pair forms a couplet of dark detritus-rich calcite at the bottom, followed by a lamina of clear calcite. Each couplet records a filling-draining event with 250 such events taking place over the period of deposition of 821 (+/-120) years, as determined by uranium-series dating. This yields a calculated average of ~3.6 yrs between filling events, which approximates the interval of El Nino-Southern Oscillation events (3-5 yrs) in the southwestern US.

Clastic-rich layers are interspersed at unequal intervals within the core, and these layers are continuous and correlate across the eight cores. One core was sliced, polished, and etched to expose the interior of the calcite. Bacterial filaments, reticulated filaments, and biofilm were found entombed in the clastic-rich calcite and mud layers. Snowy River passage preserves a complex history of the cave in stream gravels and mud that underlie the calcite, while local weather-related events are recorded in the laminated calcite of the much younger Snowy River formation.

(Abstract) **Uricite From Gaura Țuranului, NW Romania**

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Abstract

Uricite, a mineral with the chemical composition of the anhydrous uric acid, $C_5H_4N_4O_3$, is one of only a few organic cave minerals reported in literature, all known cave occurrences being related to warm, dry climate. The type locality for uricite as a cave mineral is the Dingo Donga Cave (Western Australia), where the mineral resulted from bird droppings. Another known occurrence for this mineral is El Abrigo de el Manzano, a small cave inhabited by birds in Argentina. Here we report a new occurrence of uricite from Gaura Țuranului, a 6-m cavity in NW Romania where it was found in the composition of pinkish crusts resulted from bird droppings. The cave has two entrances located at the opposite sides of an andesite tower and is supposed to have formed in the place of a xenolith. Although small, the cave is dry and offers enough shelter from sunlight and precipitation to the various crusts located inside. The analysis of the crusts (X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS)) shows that uricite is associated with uric acid dihydrate (the dominant phase in the composition of the samples) and possibly with an unidentified potassium calcium urate. Two simple heating tests (at 40°C and 90°C) were done on the cave samples to test the composition and stability of such deposits in the temperate climate. We also analyzed several fresh bird droppings by XRD and SEM to check their initial composition. The source for uricite is bird urine, a white paste consisting of spheres (0.5 - 14 µm in diameter) which readily produce uric acid dihydrate crystals once voided. In its turn, uric acid dihydrate slowly transforms into uricite, a more stable phase, provided that local humidity and temperature conditions allow.

(Abstract) The Microbiome Of Manganese Speleothems From Baia Lui Schneider Cave, Romania

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Abstract

Allegedly, life arose in aqueous environments more than 3.4 Ga ago, and by rapidly reaching remarkable levels of metabolic sophistication nowadays dwells in virtually every "nook and cranny" of Earth, and thrives from its frozen poles to its hot hydrothermal vents and from the depths of Mariana Trench to the upper troposphere. Although in the recent years the subsurface ecosystems were shown to harbor active microbial communities which may provide clues regarding nutrient remineralisation and mineral transformation, their microbiota remains poorly charted. Here, we study the mineral composition of peculiar manganese speleothems found in Baia lui Schneider Cave, and describe their associated microbiome by using state-of-the-art microbiological techniques.

The cave is developed mainly in crystalline limestones and dolomites of Upper Devonian - Lower Carboniferous age, and consists of a large descending passage connected to various smaller galleries. The manganese speleothems (which occur as shiny soft crusts and "popcorn") extend over a surface of ca. 1m² and cover a calcite crust in the main passage of the cave, at ca. 90 m from the entrance. In their natural environment, the speleothems have metallic luster and a brownish color, which changes to steel gray with pink-purple hues and brownish black streaks when dried at room temperature. Once dried, they have a hardness of 1 on the Mohs' scale and a very low apparent specific gravity. They appear to have formed from water drops seeping from a fissure in an area where the crystalline limestones are in contact with graphite schists. The XRD analyzes showed that the speleothems are composed of ranciéite (as the main mineral) and todorokite. In SEM images, these minerals appear to have platy crystals (sometimes over 10 µm in size) usually with an irregular distribution, which in places could form radial structures.

The paired-end sequencing of 16S rDNA hypervariable region V4 generated 447,778 high-quality reads (appertaining to Bacteria and Archaea) with an average length of 254 nt. The microbiological and bioinformatics analyses showed that the studied speleothems harbored viable aerobic and psychrotrophic microorganisms, mostly belonging to: Proteobacteria, Acidobacteria, OD1, Nitrospirae, Actinobacteria, Gemmantimonadetes, Crenarchaeota and Euryarchaeota phyla. In spite of the fact that the microbial community contained more than 800 OTUs (Operational Taxonomic Units), it was found to be largely dominated (in proportion of 81%) by an uncultured species of the Halomonas genus.

(Abstract) # A Native Aluminum Occurrence In Roraima South Cave, Venezuela

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Abstract

The spectacular table-top mountains called tepuys, consist mainly of sandstone with minor shale and siltstone interbedded layers. These siliciclastic rocks belong to the Roraima Supergroup, a Mesoproterozoic age unit that is part of the Precambrian Guiana Shield outcropping in southern Venezuela. Mount Roraima is located at the border between Venezuela, Guyana, and Brazil. By early 2004, three caves in Mount Roraima were interconnected and Roraima South Cave reached 10.8 km; its main entrance lies at 2,746 m above sea level.

The investigated speleothem was found on the quartzite cave wall as a 0.5 to 2 mm thick soft efflorescence covering an area of ~0.25 m^2; its gray color contrasts the reddish bedrock. The passage has a cross section of 4 m wide and 1 m high, is completely dark, and is characterized by a moderate to strong ventilation. On bedrock edges along the same passage, small biologically mediated coralloid opal deposits were documented.

The main mineralogical phase of the speleothem was identified by X-ray diffraction as native aluminum and further characterized by X-ray fluorescence analysis, SEM, and Auger electron microscopy. The mineral appears as 80-150 μm specks formed by agglomerates of 2 to 8 μm curved flake crystals with thickness of about 0.1 μm.

To date, Roraima South Cave is the cave type locality of native aluminum, but the available field data on this occurrence do not provide clues as for its origin. The Al-rich efflorescences were deposited directly on the quartzite bedrock surface in a cave area without water seeping or visible passage morphology that may indicate former flow. Contrary to other opal speleothems occurrences within the same cave, no bacterial mats were identified within the Al deposit. The surface above the cave is rocky with scarce vegetation and no lateritic soil is present. Therefore, weathering of pyrophyllite - $Al_2Si_4O_{10}(OH)_2$ - existing within the quartzite may represent the likely source of aluminum. Pyrophyllite was produced by the reaction between kaolinite and quartz under low grade burial metamorphism. A speculative working hypothesis is that native aluminum may have precipitated from this mineral under a strong reducing, probably alkaline environment. Nevertheless, further research is needed to fully explain this particular occurrence and conclude whether microbial processes are involved.

(Abstract) **Effects of photosynthesis and groundwater input on diel variations of electrical conductivity and calcite precipitation in Chaotian River, Guilin, China**

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Abstract

Abstract Short time scale research on diurnal or seasonal variations is valuable in the investigation of the relatively rapid biogeochemical processes in waters. Specific conductivity is frequently used to estimate the mixing ratio of different sources of water in hydrological studies. Taking the Chaotian River, a tributary of Lijiang river, Guilin, China as an example, the diurnal fluctuation of specific conductivity and other chemical parameters were examined by conducting by high resolution field monitoring and high frequency sampling. Dissolved oxygen, pH, specific conductivity (SpC), HCO_3^- and Ca_2^+ all showed diurnal variations, reflecting the influence of photosynthesis and calcite precipitation. The concentrations of Ca_2^+ and HCO_3^- at two monitoring sites showed a diel cycle of daytime decrease and a night time increase, with an amplitude of 13-17 % and 18-25 % respectively at the Niaolingqiao site during a 48-h period (Fig.1). The average Ca precipitation rate is estimated to be 0.8×10-5 mmol L^{-1} s^{-1}. This low rate could be related to the presence of inhibiting solute of dissolved organic carbon in the water of Chaotian River. The night time increase in SpC could be explained by groundwater input from the upstream karst aquifer.

Keywords: specific conductivity; calcite precipitation; diel variation; aquatic vegetation; karst groundwater; Chaotian River

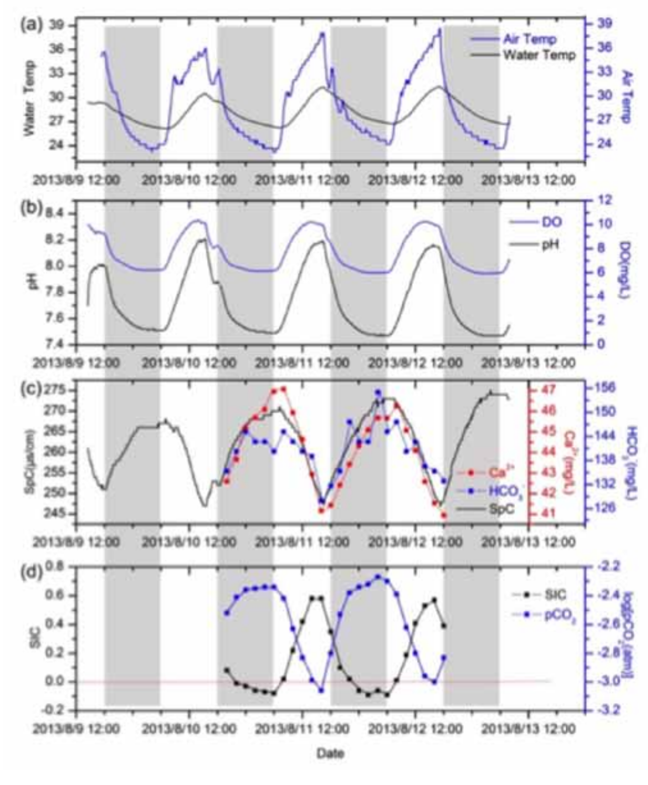

Figure 1. Detailed data at the Niaolingqiao site, August 9–13, 2013. (a) Air and water temperature. (b) pH and dissolved oxygen (DO). (c) Specific conductivity (SpC), HCO_3^- concentration, and Ca concentration. (d) The logarithm of CO_2 partial pressure (pCO_2) in water, and the logarithm of calcite saturation index (SIC). Positive values of SIC indicates supersaturation.

Exploration and Cave Techniques

New Discoveries In The Splinter Section, Jewel Cave, South Dakota

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Abstract

Exploration continues at a steady pace beyond the Southwest Splinter. Since July 2016, volunteer cavers have added over four miles (6.4 km) of passages to the Splinter section. Over 13.4 miles of passages (21.5 km) have been discovered since 2014, pushing the current length of Jewel Cave to over 186.43 miles (300.03 km), and the total depth to 814 feet (248 m). The work has been accomplished by 12 dedicated cavers who have been pushing the boundaries of the unknown.

Discoveries in this new area have begun to out-pace human capabilities. Round-trip commute time from West Camp to the end of the cave is now 8 hours (16 hours from the entrance), requiring extremely long days to reach the end. Making things more difficult, many of the leads in the northern part of the section have been exhausted, forcing cavers to travel further south to push the far edge of the cave.

In 2015, Hourglass and Piso Mojado Lakes were discovered at the intersection of the cave with the Madison Aquifer, providing an opportunity to create a new camp site less than one hour from the end of the cave. In November 2016, Deep Camp was established near the lakes to facilitate exploration of leads to the south, and to enhance caver safety. Camp water is pumped from Hourglass Lake using a peristaltic hand-operated pump. Deep Camp is the third camp created in Jewel Cave, and the second camp established within the last three years. Strong barometric airflow from the area beyond the lakes demonstrates that much more cave waits to be found.

Keywords:

1. Discussion

A breakthrough in exploration at Jewel Cave in March, 2014 has helped to push the length of the cave to over 185 miles (298 km) of surveyed passage. The Southwest Splinter, a narrow 300-foot long fissure, was first discovered at the western end of the cave by Dan Austin, Rene Ohms and Chris Pelczarski. The lead had been overlooked by the initial survey team in the early 1990's. Since the discovery, cavers have discovered 12.6 miles (20.3 kilometers) of passages and hundreds of unchecked side leads. Cavers continue to explore an average of 6 times per year, pushing the cave ever deeper and further to the south.

The initial breakthrough into the Splinter Section prompted a flurry of exploration trips during the latter part of 2014. As the end of the cave grew further from the entrance, the cavers were spending more time commuting to and from the survey areas. The last day trip to the end of the Splinter section took place in August 2014. It took 13 hours to travel to and from the end, leaving only 5 hours to survey. Even in that short amount of time, the team mapped over 3,000 feet (914 meters) of passage, proving that the cave continued, and that there was a serious need for a permanent camp in order to continue pushing the Splinter Section.

West Camp was established in November 2014, one hour north of the Southwest Splinter, near the only drip site in the western branch of the cave. Water was essential for establishing the camp, since it's not possible to carry the 15+ gallons needed to spend four days underground.

West Camp served its purpose well for over two years while cavers continued to push the Splinter Section. 2015 was the most productive year for exploration in Jewel Cave history, with over 7 miles (11 km) discovered, most of which was beyond the Southwest Splinter. The cave became deeper to the south, and soon depth records were being broken on almost every trip. In October 2015, cavers were astounded to find a lake at what was then the deepest point yet found in the cave. They named it Hourglass Lake, after the Hourglass Sea on Mars – the first named feature on another planet. Shortly after the discovery of Hourglass Lake, a second lake was found nearby, called Piso Mojado (Wet Floor in Spanish).

Figure 1. Caver Blase LaSala negotiates the Southwest Splinter

Over three hours from West Camp, Hourglass Lake became a much-needed water source. A hand-operated peristaltic

Figure 2. Deep Camp, located near the southern end of the Splinter section, about 8 hours one-way from the elevator entrance

pump with tubing allows the water to be pumped uphill and into drinking containers. The method allows the lake water to remain free of potential contamination caused by cavers climbing down to the lake shore to fill containers.

There was initial concern that the cave passages would dip below the water table, and that exploration couldn't proceed much farther to the south beyond the lake. However, both the water table and the cave have a downward gradient that allows the explorers to continue in dry passages beyond Hourglass Lake. Subsequent trips prove the cave continues to the south.

In April 2016, Dan Austin, Chris Pelczarski and Blase LaSala journeyed beyond the end of the Splinter Section to continue the southern survey. They discovered passages continuing through a broken up area, eventually terminating in a large room called Heinous Hall. The way forward became less obvious from this point, and subsequent trips to West Camp would only involve one day beyond the end due to the difficulty.

In August 2016, Steve Curtis joined Dan Austin, Chris Pelczarski and Garrett Jorgensen on his first West Camp trip. Much of the time was spent closer to camp, pushing leads that could bypass the Southwest Splinter. While no short-cut was discovered, several deep pits were found. They will require rope work, and currently remain unexplored. One day was spent beyond Heinous Hall, pushing the maze of leads in the broken up passages, with hopes of continuing south. They found a series of crawls called The Pound leading south from Heinous Hall. At this point, travel from West Camp exceeded four hours. Pushing the end of the cave became a grisly task that taxed even the most seasoned Jewel cavers, and the trips to the end were indeed heinous.

In September of 2016, Jewel Cave National Monument purchased gear to establish another camp deep in the cave. Over the next few months, cavers worked diligently to establish Deep Camp, located just minutes from Hourglass Lake. It took 7 people on three trips to haul the gear to its final location. Over New Year's weekend, the first four-day Deep Camp was conducted. Garrett Jorgensen from New Mexico and Derek Bristol from Colorado joined Dan Austin, Chris Pelczarski, and Rene Ohms for the momentous trip.

Much to everyone's delight, the first deep camp documented over 9,747 feet (2970 m) of new passage, and the team was again able to push further south, beyond The Pound. The crawls eventually led to larger walking passage at The Adoption Pit – so named because after spending much of their time crawling through The Pound, the cavers were finally "adopted" by borehole passage. On New Year's Eve, the teams met back at Deep Camp for a midnight countdown and celebration underground in one of the longest caves in the world.

Figure 3. Chris Pelczarski looks into New Year's Lake, discovered January 1, 2017

On New Year's Day, two more lakes were discovered beyond The Pound: Bonus Lake, a 12-foot (3.6 m) diameter pool, and New Year's Lake, measuring over 70 feet (21 m) long and 15 feet (4 m) wide, with a depth of over 20 feet (6 m). The lake continues around a corner and out of sight. New Year's Lake was also found to be the deepest point in the cave, and the new vertical extent of Jewel Cave is 814 feet (248 m). Bonus Lake was discovered in the vicinity of New Year's Lake at a much higher elevation, suggesting that it is perched above the water table. At the end of the trip, cavers left large passages continuing to the southeast, 15 feet (4.5 m) wide and 25 feet (7.6 m) tall.

A return trip at the end of January added another 5,361 feet (1,634 m), and cavers continued southeast in large walking passage. They discovered two more lakes that have not yet been named, and pushed the cave length to 186.43 miles (300.03 km). The cavers also left numerous passages with strong air to return to.

So far, Deep Camp has been a major success for exploration, and has improved not only the safety of the exploration teams by reducing daily travel time, but also because cavers can spend more time exploring beyond the end of the cave. Everyone agrees that the new lakes would not have been discovered without Deep Camp. Although cave camping is a high-impact activity, that is balanced by the fact that it reduces the number of trips one must take to reach the further end of the cave. Multiple trips – especially trips where travel time exceeds survey time - would lead to many others and become less safe for cavers as they try to maintain reasonable travel times.

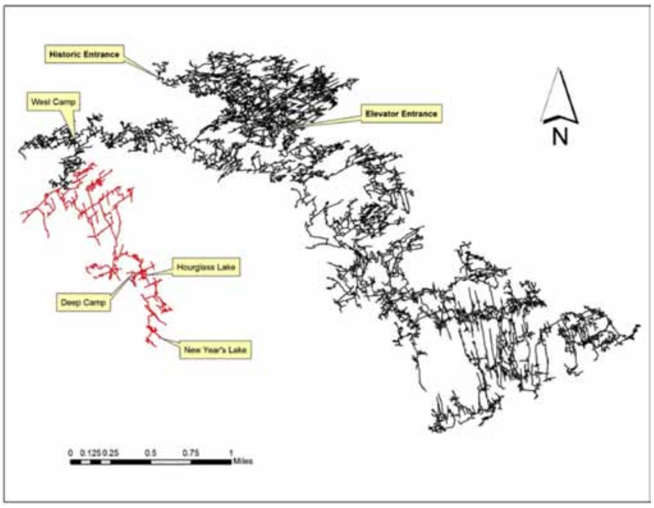

Figure 4. *The Splinter Section (in Red) as of January 30, 2017*

By the time this paper is published, the length of the cave will have increased significantly, and much of the new discoveries will be beyond the new camp. Deep Camp is the third camp established in Jewel Cave, and the second camp established in the western branch since November 2014.

Acknowledgements

The National Park Service manages Jewel Cave, and all exploration is conducted by volunteer cavers. The park strongly supports the exploration program, which is one of its top management priorities. Without the assistance from park staff and partnerships with cavers, much of the exploration and management being conducted today would be impossible. The authors would like to thank the cavers who have spent hundreds of hours exploring the Splinter section, and those who have helped support the exploration by hauling gear for the camps or participating in cave management objectives: Kim Acker, Dan Austin, Lydia Austin, Carl Bern, Derek Bristol, Ian Chechet, Matt Covington, Steve Curtis, Joel Derrick, Mike Hittle, Nate Hughes, Garrett Jorgensen, Blase LaSala, Sean Lewis, Nick Mann, Kelly Mathis, Ian McMillan, Marc Ohms, Rene Ohms, Tim Sauder, Oliver Stubbs, Chris Pelczarski, Larry Shaffer, Jonathan Venner, Adam Weaver and Nikki Woodward.

Humba Cave Project—Cave expedition in Sumba Island, Indonesia

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Abstract

Ritsumeikan University Explorers Club carried out an expedition, "Humba Cave Project" in Sumba Island, Indonesia in the summer of 2015. Sumba Island is a part of Lesser Sunda Islands, in eastern Indonesia. In Sumba Island, karst landforms have notably developed, although caves in Sumba Island had been investigated only twice before. Furthermore, the investigations had been conducted only in the western area of the island. Laiwangi Wanggameti National Park, where we explored is in eastern area of the island. It has never been investigated and we are the first explorers of the area. The final goal of our expedition is to suggest a way of resolving their problems for example water shortage and poor resources for tourism. In other words, through our expedition, we would like to contribute to the sustainable development of Sumba Island. As pioneers of the area, we tried to acquire fascinating information leading to continuous research. Specifically, we had focused on getting the coordinates of the caves, making a map of them and taking pictures inside of the caves. As a result, we discovered 75 new caves and surveyed 20 of them. We classified the caves according to the formation of their entrances. Seven caves are collapse dolines and eight are sinkholes. Moreover, some of caves have underground rivers with plenty of water. In conclusion, the area we explored should have considerable numbers of undiscovered caves. Our expedition just proved that the area has a potential value of using natural resources. We hope our expedition fascinates a lot of people and contributes to the sustainable development of Sumba.

Keywords: Indonesia, Sumba Island, Laiwangi Wanggameti National Park, exploration, new caves

1. Introduction

Ritsumeikan University Explorers Club carried out an expedition, "Humba Cave Project" in Sumba Island, Indonesia in the summer of 2015. The purpose of this expedition is to discover new caves and investigate them. The area we investigated was located in Laiwangi Wanggameti National Park, whose caves have never investigated before. This paper reports the results of our expedition.

Our Club was established in the 1960. In 1990s, we carried out many expeditions overseas, for example, eight cave expeditions in China and anthropological research in Niger and Indonesia.

For the expedition, we required two years of time to prepare. Through the pre-research, we decided that we carry out the cave expedition in Mahaniwa, which is located in Laiwangi Wanggameti National Park. The expedition took place from 18 August to 21 September 2015. Seven people from our club, some national park staff and local cooperators participated in the expedition. This expedition was named "Humba Cave Project" in honor of Humba, the original name of Sumba.

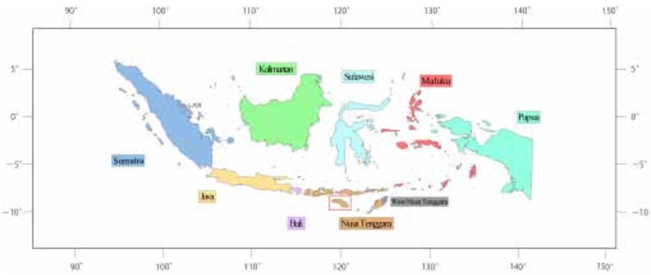

Figure 1. Indonesia

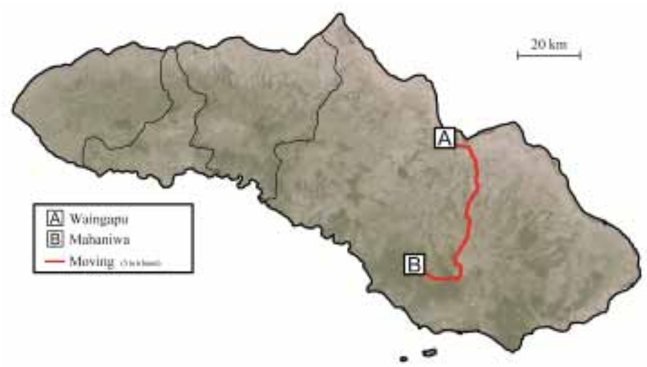

Figure 2. Sumba Island

2. Exploration Area

Sumba Island is a part of the Lesser Sunda Islands in eastern Indonesia (Figure 1). It has an area of 11,153 square kilometers. The island is split into four regencies which are Sumba barat, Sumba timur, Sumba tengah and Sumba barat daya. The climate of Sumba is Savannah. There is a clear separation between the rainy season and the dry season. The dry season lasts eight months from April to December. The annual rainfall in East Sumba is about 1,000 millimeters although during the dry season it is below 10 millimeters (Statistics …., 2013).

The area we investigated is located in Laiwangi Wanggameti National Park and Pinu Pahar, East Sumba, Nusa Tenggara Timur. In the whole island, only 0.2 percent of the land is over 1000 meters and 20 percent is over 500 meters. The area we investigated is at an elevation of 735 meters ASL, therefore it is located in a relatively higher altitude part of the island. In Sumba Island, karst landforms are notably developed at high altitudes. In Mahaniwa, formation *Paumbapa* is distributed, and mainly consists of stratified limestone (Acintyacunyata Speleological Club, 2009). Therefore, there are a number of doline, ubala and limestone caves in the area (A. C. Effendi, et al. 1993).

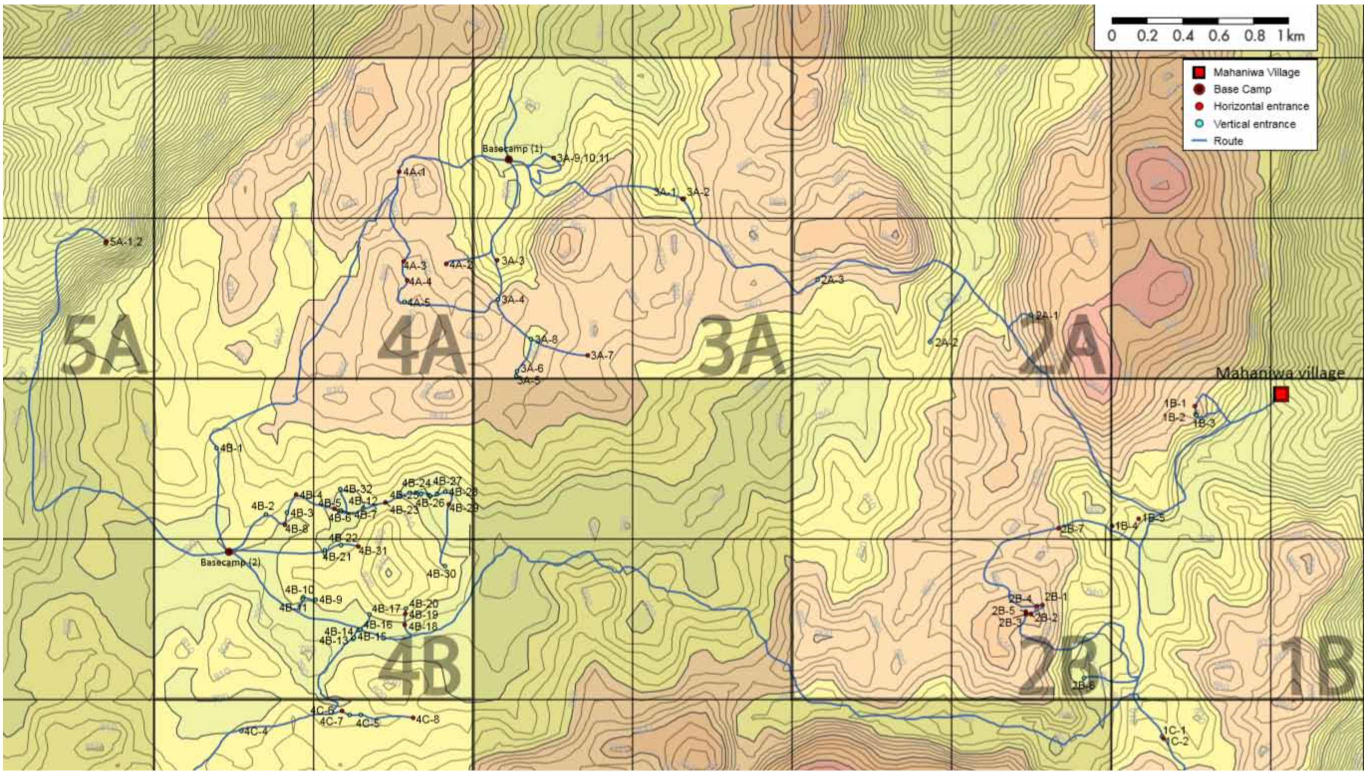

Figure 3. Positions of the cave entrances

In the western area of the island (Figure 2), cave investigation had been done in 1985 by the British Cave Research Association and in 2002 and 2008 by the Acintyacunyata Speleological Club (ASC, 2009). The eastern area of the island has never been investigated and we are the first explorers of the area.

Mahaniwa village is the poorest area in Sumba Island. According to the statistics bureau of East Sumba Province from 2013 (Statistics …., 2013)., its area is 22.1 square kilometers and the population is 726. Only 20 families out of 167 families have electric generators. Almost all people make their living in agriculture.

3. The Purpose of the Expedition

The final goal of our expedition is to contribute to the sustainable development of Sumba Island. People in Sumba have a lot of difficulties; for example, water shortage and poor resources for tourism. We believe that its cave could be natural resources to resolve these difficulties. If we find an underground river in caves, it may be helpful for people's livelihood. If we find a large and beautiful cave, it can become a resource for tourism. It is needless to say that our investigation is not enough to resolve these difficulties because we have nothing more than limited knowledge and experience. In this expedition, we had focused on Mahaniwa where existence of caves is expected. We explored around the village, found new caves and investigated them.

4. Methods

In basically, members divided into two groups and worked with local people and National Park staffs. We were looking for new caves based on information from local guides. We made it a top priority to keep records of the coordinates of cave entrances. A GPS device was used to get the precise location information and track data (Figure 3). Then, we focused on making a survey and taking pictures of the caves. To work effectively in the limited time for investigation, we chose the caves on a priority basis by its dimensions and whether a water stream existed or not. We had surveyed the caves in conformity to British Cave Research Association survey grades 5D. We used laser measurement devices and SUUNT compasses. In addition, On Station, a cave survey software, was used to process the data after the survey.

5. Results of Investigations

We discovered 75 new caves and surveyed 20 of them. The list at the end of the paper shows the caves we found. Area codes are given to all the caves based on their coordinates.

Features of some notable caves are described below.

5.1. Kiri Karanga (4B-4) (Figures 4 and 5)

This cave has three vertical entrances. Two of them are collapsed doline. Its length is 471.8 meters and its depth is 58 meters. This is the second deepest cave in the caves that were we found. Thousands of bats are living in the cave.

Figure 4. First Entrance of Kiri Karanga

Figure 5. *Flowstone of Kiri Karanga*

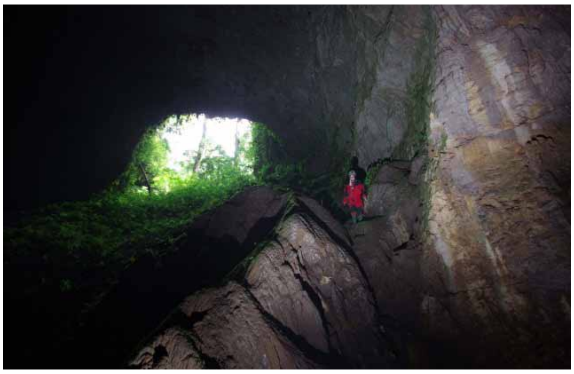

Figure 6. *Entrance of Lai Kanggu Huk*

Figure 7. *Water Stream of Lai Kanggu Huk*

5.2. Lai Kanggu Huk2 (4C-6) (Figures 6 and 7)

Its length is 161.3 meters and its depth is 25.7 meters. The formation of its entrance is sinkhole. The name of the cave, Lai Kanggu Huk, means sound of water. As its name suggests, this cave has a water stream from northwest to southeast. Furthermore, in the direction of the water stream, we found another cave. According to local people, there are many caves around the Lai Kanggu Huk. We couldn't explore the other caves. However, the area is worthy to explore.

5.3. Mata Wai La Rawa (4A-1) (Figures 8, 9, 10 and 11)

This cave is the longest one out of the 20 surveyed caves. Although we surveyed up to 1,681 meters, the cave continues with no end. The depth is 118.2 meters. Moreover, it has the greatest amount of water. Even though we only surveyed the main passage, this cave has a lot of branches. In addition, an old man of the village told us a story of Mata Wai La Rawa. According to the story, the cave lasts seven kilometers to the other entrance near the sea.

Figure 8. *Second entrance of Mata Wai La Rawa*

Figure 9. *Water Stream of Mata Wai La Rawa*

Figure 10. *Entrance of Tundu Njangga1 (4B-30)*

Figure 11. *Water fall of Kana Buwai (5A)*

Figure 12. Members of the expedition

Figure 13. Equipment of the expedition

6. Conclusion

In conclusion, the entrance formation of seven caves are collapse doline and eight caves are sinkhole. The caves that have these type of entrances are found largely in areas 4B and 3A. Furthermore in the 4B area, vertical caves are found most frequently. 21 caves are vertical out of a total of 32 caves. Some of the caves have bounty of water.

The area we explored should still have a considerable number of undiscovered caves. Around Lai Kanggu Huk, we may find another cave that has a bigger water stream. Mata Wai La Rawa may connect to another entrance seven kilometers ahead. To make this expedition more valuable, it is important that researchers or explorers visit this location and conduct additional investigation for better understanding of the region.

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Statistics Indonesia Sumba Timur Regency, 2013. https://sumbatimurkab.bps.go.id/index.php (access 20 Jan 2017)

Table 1. The List of the Caves

Code	Entrance Name	Altitude	Length	Depth	Entrance & formation
1B-1	Liang Lai Kade Rung	831			horizontal
1B-2	Humur Lai Lade Rung1	831			vertical
1B-3	Humur Lai Kade Rung2	831			vertical
1B-4	Liang La Wholah	766			horizontal
1B-5	Liang Hibu Karik	793			horizontal
1C-1	Liang Mara Ndakajor1	831			vertical
1C-2	Liang Mara Ndakajor2	831			horizontal
2A-1	Humur Bakur	867			Collapse Doline
2A-2	Humur Waila Tuna	774			vertical
2A-3	Humur Barakandu	859			vertical
2B-1	Kahala Baku1	908	57.3	6.3	horizontal
2B-2	Katuanga Baku1	932	34.2	3.9	horizontal
2B-3	Katuanga Baku2	886	60.9	10.2	horizontal
2B-4	Kahala Baku2	901			horizontal
2B-5	Kahala Baku3	906			horizontal
2B-6	Humur Lai Pati	806			vertical
2B-7	Liang Ri Uwi	803	108.5	8.5	horizontal
3A-1	Katauhi Buti1	825	35.8	3.8	horizontal
3A-2	Katauhi Buti2	825	23	3.4	Collapse Doline, horizontal
3A-3	Katik Tama Lai Mbongu	816			sinkhole
3A-4	Liang La Harru (Kadiu)	863			Collapse Doline, vertical
3A-5	La Wangga1	866			vertical
3A-6	La Wangga2	849			vertical
3A-7	Humur Bakul La Riui	908	167.3	22.8	Collapse Doline, horizontal
3A-8	Lai Kiri Ri Ui	858			vertical
3A-9	Miaha Langa 1	804			horizontal
3A-10	Miaha Langa 2	804			horizontal
3A-11	Miaha Langa 3	804			sinkhole
4A-1	Mata Wai La Rawa	842	1681.8	118.2	horizontal
4A-2	Kiri Marada Njara Haka Heong	841			horizontal
4B-6	Kiri Karanga 4-1	805	45.1	15.4	horizontal
4B-7	Kiri Karanga 4-2	805	80.3	37.7	Sinkhole, horizontal
4B-8	Kiri Karanga 5	787			horizontal, vertical
4B-9	Kiri Karanga 6	792	153.3	49.9	Collapse Doline, vertical
4B-10	Kiri Karanga 7	819	156.8	50	Sinkhole, vertical
4B-11	Kiri Karanga 8	802			vertical

Code	Entrance Name	Altitude	Length	Depth	Entrance & formation
4B-12	Lulu Kawaka	817			vertical
4B-13	Lulu Kawaka 1	812			vertical
4B-14	Lulu Kawaka 2	815	26.5	11.7	vertical
4B-15	Lulu Kawaka 3	803			sinkhole, vertical
4B-16	Lulu Kawaka4	805			vertical
4B-17	Lulu Kawaka5	786			vertical
4B-18	Lulu Kawaka6	795			sinkhole, horizontal
4B-19	Lulu Kawaka7	770	26.5	11.7	horizontal
4B-20	Lulu Kawaka8	802			vertical
4B-21	Katiku Lulu Kawaka2	814			vertical
4B-22	Katiku Lulu Kawaka3	796			vertical
4B-23	Kiri Lulu Kawaka1	768	101.8	-10.6	horizontal
4B-24	Kiri Lulu Kawaka2	798			vertical
4B-25	Kiri Lulu Kawaka3	810			vertical
4B-26	Kiri Lulu Kawaka4	794			sinkhole, vertical
4B-27	Kiri Lulu Kawaka5	916			vertical
4B-28	Kiri Lulu Kawaka6	792			vertical
4B-29	Kiri Lulu Kawaka7	786			horizontal
4B-30	Tundu Njangga	812	247.8	44.5	Collapse Doline

Code	Entrance Name	Altitude	Length	Depth	Entrance & formation
4B-31	Tundu Njangga2	896			horizontal
4B-32	Kiku Paraind Pahar	794			vertical
4C-1	Man Jaram1	815			vertical
4C-2	Man Jaram2	794			vertical
4C-3	Man Jaram3	804			horizontal
4A-3	Halinggi Marada Haka Heong	839			horizontal
4A-4	Ruhu Reni	871			horizontal
4A-5	Katiku Njara Haka Heong1	886			vertical
4B-1	La Pahar1	804			vertical
4B-2	La Pahar2	821			vertical
4B-3	La Pahar3	797			vertical
4B-4	Kiri Karanga	817	471.8	58	Collapse Doline, horizontal
4B-5	Kiri Karanga3	811			horizontal
4C-4	Man Jaram4	812			vertical
4C-5	Lai Kanggu huk1	786			vertical
4C-6	Lai Kanggu huk2	786	161.3	25.7	Sinkhole, horizontal
4C-7	Lai Kanggu huk3	806			vertical
4C-8	Lai Kanggu huk4	823			horizontal, vertical
5A-1	Kana Buwai1	612	19.2	4.3	horizontal
5A-2	Kana Buwai2	612	3.9	-	horizontal

Measure = meters

Recent Explorations In The Xe Bang Fai Cave System, Laos

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Abstract

The Xe Bang Fai cave, located in the Hin Nam No National Protected Area in central Laos, is one of the largest active river caves in the world and is beautifully decorated. Although the cave was first explored in 1905, the exploration and mapping was still incomplete. Expeditions by international teams of cavers were conducted in 2015 and 2016 to further explore and map this cave system.

The 2015 expedition focused on mapping the dry and seasonally dry passages at the upstream end of the Xe Bang Fai cave. Over 4 km of cave passage was surveyed in this section of the cave system, which is sometimes called the Grotte de Nuages. The expedition's survey brought the total cave length to 14.7 km, with the active river passage being 6.4 km long. An updated, detailed map of the cave has been produced from the survey results. During the expedition, the local villagers told us about another large cave hidden in the jungle nearby. However, there was only time to make a brief reconnaissance visit to this cave, called Tham Nguen.

The focus of the 2016 expedition was to explore and map Tham Nguen and other caves in the area just upstream of the Xe Bang Fai cave. Tham Nguen was surveyed to 1.5 km and connected to the Xe Bang Fai cave system, bringing the total length to 16 km. Near Tham Nguen another cave, Tham Nguen Mai, was explored and surveyed to over 2 km. Only 20 m of a water-filled sump separate Tham Nguen Mai from a connection to Tham Nguen and the Xe Bang Fai cave system. Beyond the upper end of Tham Nguen Mai lie the Tham Pha Pong shelter and cave, which were surveyed to a combined length of about 1 km. These caves are all large in size and well-decorated in places.

A major finding resulting from the exploration and mapping of the caves upstream of the Xe Bang Fai cave is that these caves, along with the Grotte de Nuages section of the Xe Bang Fai cave, appear to comprise an ancient underground route of the Xe Bang Fai river, upstream from the currently active river cave. The information gained from these explorations will contribute to the nomination of Hin Nam No as a UNESCO Natural World Heritage site.

Keywords: Cave Map, Exploration, Hin Nam No, Laos, Survey, Xe Bang Fai Cave

1. Introduction:

The Xe Bang Fai cave is a world class cave, located in the karst of the Hin Nam No National Protected Area (NPA) in central Laos, adjacent to the border with Vietnam (Figure 1). The Xe Bang Fai river has cut a 6.4 kilometer (km) underground course through the limestone mountain, creating one of the largest active river cave passages in the world. The active river passage averages 76 meters (m) in width and 53 m in height, with a maximum width of 200 m and a maximum height of 120 m. In addition to the size of the cave passages, the cave is superbly decorated with speleothems, including many large and beautiful stalagmites, flowstone draperies, gour pools and cave pearls (Pollack *et al.* 2009).

The first recorded exploration of the Xe Bang Fai cave was by a French team lead by Paul Macey in 1905, who traversed the main river passage on a bamboo raft. Macey produced a sketch map of the cave, and estimated the active river passage to be 4.2 km long. The next effort to explore and map the cave was in 1995 by another team of French cavers, who explored and surveyed 9 km of cave passage and published a small-scale map of the cave. In 2008, a North American caving team surveyed the cave using digital survey equipment and detailed sketching, and produced a high-quality map of the cave showing 9.7 km of cave passage. However, they did not have enough time to finish the exploration and survey of all the cave passages (Pollack 2016).

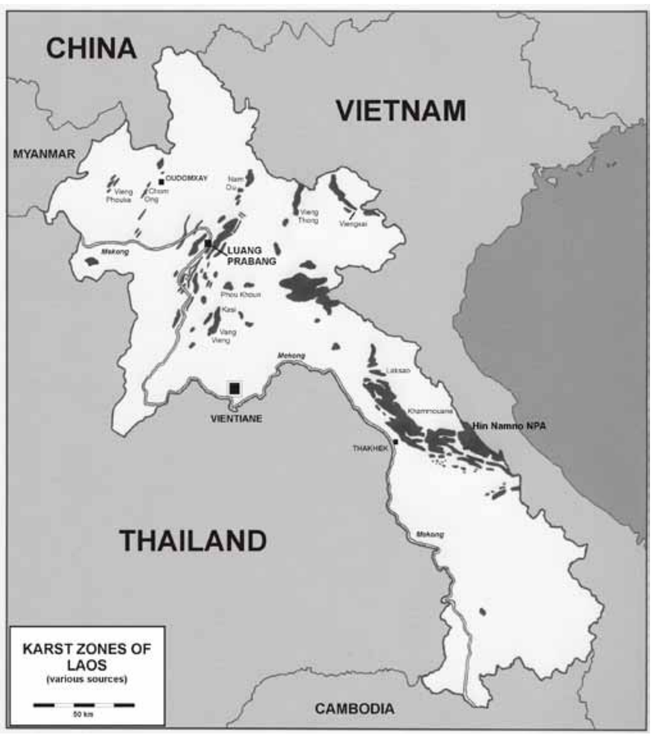

Figure 1. Map showing the karst areas of Laos (in black) and the location of the Hin Nam No National Protected Area in central Laos.

Figure 2. Map of the Xe Bang Fai cave overlaid on a topographic map with a 1 km grid.

2. Recent Explorations:

The North American team returned to the cave in early 2015 to finish the exploration and mapping of the cave in collaboration with the project 'Integrated Nature Conservation and Sustainable Resource Management in the Hin Nam No Region' (hereafter referred to as the Hin Nam No project), a German development cooperation project with the Lao government. The 2015 expedition focused on mapping the dry and seasonally dry passages at the upstream end of the Xe Bang Fai cave. An additional 4.4 km of cave passage was surveyed in this section of the cave system, which is sometimes called the Grotte de Nuages. The expedition's survey brought the total cave length to 14.7 km, with the active river passage being 6.4 km long (Pollack *et al.* 2015). An updated, high-quality map of the cave has been produced from the survey results. A small-scale version of the updated map of the cave is presented in Figure 2. A map of the Grotte de Nuages area of the cave, giving an example of the map detail, is presented in Figure 3. During the expedition, our local village guides told us about another large cave hidden in the jungle nearby. However, there was only time to make a brief reconnaissance visit to this cave, called Tham Nguen. A seasonally dry stream passage was followed to a small pool which was sumped shut.

A team from the France-based caving group Explo-Laos collaborated with the Hin Nam No project in early 2016 to further explore and map caves in the Hin Nam No NPA. The main focus of the 2016 expedition was to explore and map Tham Nguen and other caves in the area just upstream of the Xe Bang Fai cave. Tham Nguen was surveyed to 1.5 km and connected through the now-open pool to the Grotte de Nuages area, bringing the total length of the Xe Bang Fai cave system to 16 km (Figures 3 and 4). Near Tham Nguen another cave, Tham Nguen Mai, was explored and surveyed to 2.2 km. Only 20 m of a water-filled sump separate Tham Nguen Mai from a connection to Tham Nguen (Figure 4) and the Xe Bang Fai cave system. Beyond the upper end of Tham Nguen Mai lie the Tham Pha Pong shelter and cave (Figure 4), which were surveyed to a combined length of about 1 km. These caves are all large in size and well-decorated in places (Bolger 2016).

A major finding resulting from the exploration and mapping of the caves upstream of the Xe Bang Fai cave is that these caves (Tham Nguen, Tham Nguen Mai, Heup Pha Pong and Tham Pha Pong), along with the Grotte de Nuages section of the Xe Bang Fai cave, appear to comprise an ancient underground route of the Xe Bang Fai river, as illustrated in Figure 4. The large fossil passage between Tham Nguen and Tham

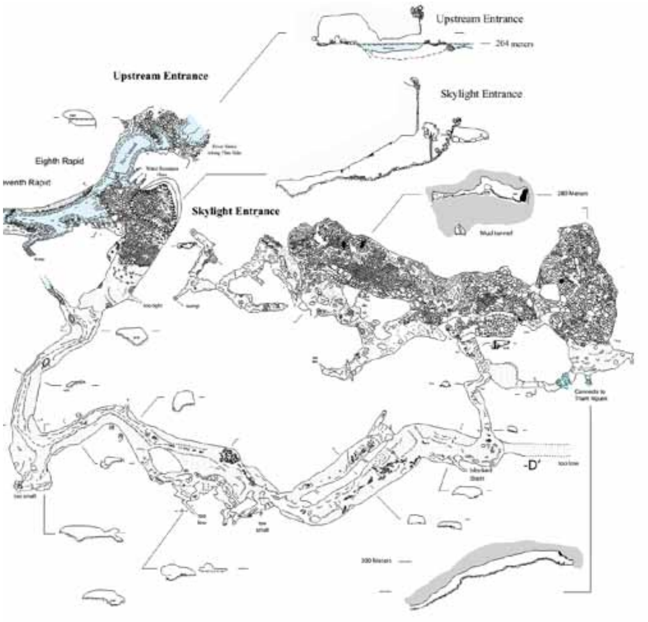

Figure 3. Map of the Grotte de Nuages area of the Xe Bang Fai cave showing passage detail.

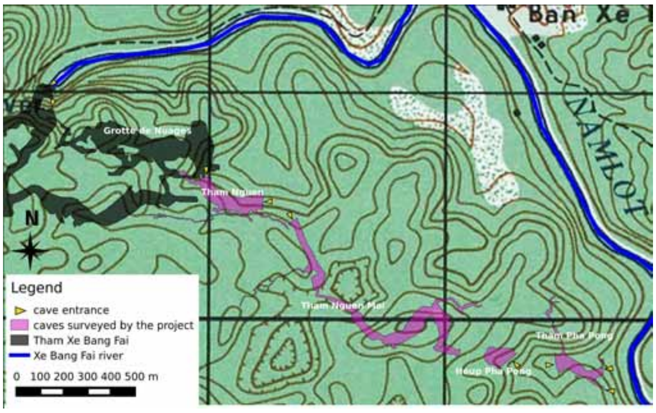

Figure 4. Map of the caves upstream of the Xe Bang Fai cave overlaid on a topographic map with a 1 km grid.

Nguen Mai appears to have been destroyed by erosion. Similarly, Heup Pha Pong and Tham Pha Pong appear to have been isolated by erosion. In general, these large, upstream fossil galleries are elevated between 30 m and 50 m above the current active river channel. Further studies of the cave geomorphology are warranted to confirm this hypothesis.

3. World Heritage:

The Hin Nam No NPA was recently placed on the World Heritage tentative list, a first step towards the nomination of Hin Nam No as a UNESCO Natural World Heritage site, under criteria for geoheritage (criterion viii) and biodiversity (criterion x). The Xe Bang Fai cave is the most significant and distinctive geomorphic feature in Hin Nam No NPA. Thus, it would be one of the key features for claiming the 'outstanding universal value' (OUV) of Hin Nam No under criterion viii. The information and knowledge obtained from these recent explorations of the Xe Bang Fai cave system will contribute to proving the OUV of Hin Nam No NPA in terms of its geological heritage. In addition, the outputs from these expeditions (reports and cave maps) can serve as a basis for management of the caves to conserve their geological heritage, as well as the sustainable use of some of the caves as tourism destinations.

Acknowledgements

This report has resulted from the contributions of a number of people and organizations: Members of the 2015 expedition (John Pollack, Bob Osburn, Patricia Kambesis, Aaron Addison, David Sawatzky), members of the 2016 expedition (Jean-Michel Osterman, Bernard Lips, Stephane Maifret, Alexis Augustin, Helmut Steiner, Josiane Lips), the Hin Nam No project and participating staff (Sisomphone Soudthichak, Mirjam de Koning, Joost Foppes, Ronny Dobbelsteijn, Ms Vanhxay, Mr Khamphao, Mr Bounlong, Mr Joy, Mr Tithavanh, Mr Souphanith) and local guides from Nongping village (Mr Songka, Mr Sak, Mr Phong, Mr Lop, Mr Sai, Mr Nuch, Mr Ak, Mr Gon).

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Multi-faceted training of caver-explorer

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Abstract

Since 1975 the Club of cavers based at Novosibirsk State University has performed an extra-ordinary method of caver training. Serious rock-climbing preparation and technical mountaineering with a background of intensive physical cramming have resulted in the discovery of large cave systems on the Altai and Sayan ranges.

Overcoming high walls up inside the caves using free climbing and the use of aid techniques from alpinism was mandatory. Mountaineering skills allowed us to investigate plateaus on high altitudes on Zeravshanskiy (Mount Patroush) and Gissarskiy (Mount Hodja-Ahcha-Baroun) ranges, as well as pseudo karst in the vicinity of Khan-Tengri, Kilimanjaro, Aconcagua peaks, combined with geological surveying and prospecting.

For all times the philosophical aspects of fair play in sports was an inherent part in our activity.

Keywords: caving, alpine-climbing, training, sport, mountaineering.

1. Introduction

Caving is a complicated multi-faceted sport, so one has to remember all aspects of preparation. There are several directions of training.

1. General physical preparation: any exercise (cross-country race, skiing, gymnastic) to increase our health, endurance, stamina, strength of muscles is acceptable.
2. Technical preparation: comprising working with equipment, ropes and steel cables, belaying, rescue operations.
3. Psychology: including personal, moral and strong-willed preparation, ability to work in a group, stress management, conflict resolution, and an ability to recognize one's own mistakes.
4. Cognitive knowledge which unifies all theoretical information about contemporary equipment, tactics and strategy, physics of belaying, and of course, a general geology about caves and mountain formation.
5. Special physical preparation. This is a training of climbing on different types of relief. Initially it may be possible to use a climbing gym but the main aim must be an outdoor experience.

The qualifications of a caver are determined not by the best what one can do under the points above but the opposite, by the weakest application of one's skills. Although we were already strong cavers with experience in Sneznaya cave (-1370m, Caucasus) many of us found that climbing was our weakest skill. That is why it appeared to be best to improve our climbing abilities.

2. Comparative experiment

An experimental hypothesis was proposed to prove that rock-climbing training would increase the efficiency of overcoming of challenging routes in caves. The criteria of efficiency were necessary to define, i.e. data by what was possible to judge which group or individual was better. Caving is a sport involving parties of 2 or 4 participants; parties are a big expedition comprises several such parties. Therefore, two groups of 4 people were compared in a number of caves on similar challenging routes. The first group was a basic (traditional) one who had not used climbing training. The second group was experimental one who persistently trained in rock-climbing. The criteria of an experiment were time and quality of overcoming of a route. The tasks proceeded were as follows.

2.1. The investigation topic (object); the preparation of sportsmen-cavers.

General (traditional) training of a caver is widely discussed in text-books (Дублянский и Илюхин 1981) where there is a common training process for classic routes to get the bottom of the cave and to escape to the surface along prior fixed ropes. Climbing in caves is mostly limited by easy chimney scrambling. Nevertheless a feature of caves in Siberia consists in a necessity of a lot of free climbing in ordinary routes. One of our best training grounds is Torgashinskaya cave situated near the border of Krasnoyarsk city. There are many various challenging routes; as described herewith. A sequence of precipices 40, 30, 20m interrupted by a short labyrinth, 20m chimney up, and 40m traverse of a fault. The cave continues with two 20 and 40m precipices to get the bottom of the cave. To continue the route demands not to use the fixed ropes (usually we remove all of them). The group has then to free climb up a 10m wall to enter the vertical labyrinth system of up-going wells where there are a lot of free climbs (up to 6b+ French category, 5.10d USA). This ascent is a way to the surface instead of rope climbing ("jumaring"). What are the results of the experiment? In terms of quality the traditional group (T) has to have at least one good rock-climber who is able to lead on French 6-th categories (5.10), otherwise the group may be stranded at the bottom because the fixed ropes have been removed. If the group has such a climber he leads and organizes fixed ropes for all other participants up a long multi pitch ascent. In case of the experimental group of climbers (C) they ascend in independent two parties of two people in each; all participants free climb and use no fixed ropes. It looks like a beautiful and glorious alpine climb. In terms of time, without previous rehearsals ("on-site") group C overcomes the route twice as fast as group T. Subsequent replays only increase a gap of time spent, irrespective of climbing quality.

2.2. Climbing training (subject) for preparing cavers for challenging caves.

What is the training process we follow? On the one hand it is a typical routine (Пиратинский 1987), i.e. persistent repeated coaching until a climber is noticed to rest to a set limit and can't guess how to make a breakthrough. So, on the other hand our honor is to direct the climber for the sake of success and consequently, pleasure. Climbers overcome long multi-pitches routes in caves or mountains, thus our advice is appropriate to the specific technique (Ситник 2016).

Firstly, all accidental falls from height are excluded during a lead and this eliminates two reasons of falls:

a) climber finding himself on a pitch that he had underestimated before; our observations resulted in 2 pieces of advise: to climb more with top belay up to 50m on rocks to learn to orientate oneself on relief and to lead pitches that are at least 1 category easier than one's upper level;

b) muscles of hands and feet (mainly, calf) are haggard and may be seized with cramp; the advise is to avert it by smoothed composed deliberate climbing in an aerobic regime; for this a special climbing technique is proposed and used as follows.

- Climb mainly with the use of feet. Position of the body is vertical or slightly leaned back to increase a normal pressure on the rock making better friction.
- Optimal position of legs – one is straight, another is lifted up and bent in the knee. Don't lift high the heels for long as the calf may exhaust and suffer from a cramp.
- Climb without strain; stress only muscles that are necessary for that move.
- Use twists instead of pulls up, revolving a body around a loaded forearm, turning a leg into inside and transforming a body position to layback one.
- On a cornice hold the pelvis closer to the rock and try to use laybacks more.
- Climb with straight arms and hold them raised as less as possible. Optimal position is with straight arms at heart level. If holds are high then move feet higher quickly.
- Chimney scrambling, laybacks, "stem"-climbing are preferable when possible. It is opposing pressures on sidewalls that increase friction on the rock.
- To decrease stress of muscles of the arm when taking a hold above, make by the other arm an opposing pressure on the hold lower down (technique of "third leg").
- In order to set up protection, dispose legs on opposing sidewalls supporting a balance. Often it's necessary to lift one leg higher in layback to get an opportunity to move the free arm very high up to insert a cam or nut.
- Concentrate will-power and thoughts before a crux. After the crux dispose the body on ledges to decrease stress shaking hands by turns. Follow smooth breathing.
- To develop endurance and stamina, the regular cross-country skiing (or running) races are undertaken all year round (Bulychov and Sorokina 2013).

2.3. Changes in subject during experiment were carried out.

Instead of limitless climbs with top belay, a method working out special technical elements was offered.

To develop the ability to not be afraid of falls during leading, it was believed to climb 1-2 categories of difficulty lower routes than one's top belay level. However, special trainings of premeditated falls were worked out for same categories of either top or leading belay (Todhunter 1998). It develops confidence and trust in the elements of protection set by a climber.

2.4. Expertise of efficiency and inferences.

This experiment was further undertaken in a number of well-known caves such as Napra (-970m, Caucasus), Kievskaya (-980m, Kyrk-Tau), Kek-Tash (-350m, Altai) (Boulytchov 1999), Altaiskaya (-240m, Altai). The result was found to be the same everywhere – time spent to overcome equal segments by a group C was about twice as fast as that by a group T. Participants in all groups were different in every cave noted.

Most remarkable was a sporty route offered in the cave Big Oreshnaya (Boulytchov 1999) (A=234m, L=47700m, East Sayan) and due to our free climbing abilities, the 70-m sheer wall (6b French, 5.10c) was overcome (first ascent). On the upper part of the wall we stumbled upon extreme narrow squeeze that led to a new huge system, Sibirskaya. Later in the lowest part of this system a connection with main cave was dug (V.Sherbakov), so a challenging circle to overcome might be tried. Another circle was the traverse of the Lake: a 20m chimney and 10m face (5c, 5.9) led down to the lake; a 20m face (6b, 5.10c) traverse above water followed; a traverse 20m above a precipice and 5m face up (6a, 5.10b) led to a wide 20m tube (in shape of bottle with neck from the top) mandatory to climb up (6b+, 5.10d). This tube began with exclusively hard 5m full-body stretch and continued with wide chimney climbing up all upper part. Big Oreshnaya cave represents a huge intricate labyrinth so in the maze the way was properly marked to set groups in equal conditions so they did not loose time seeking the correct route in non technical areas. In the experiment 20 different groups C and T took part for 10 years. The group C worked during the ascents in independent 2 parties of 2 people; all participants free climbed. In the group T the first climber led, all other 3 participants used fixed ropes and appropriate gear; the traverse along the lake was avoided and substituted with the use of a dinghy. Average time spent by groups C for all route occurred about 3 times less than appropriate one of groups T. One drawback of the climbing style is that it demands use of an alpine sit-harness since the speleo one isn't convenient for leading on ascents. Also cave-climbers often transform to alpine-climbers and change their passion to mountains.

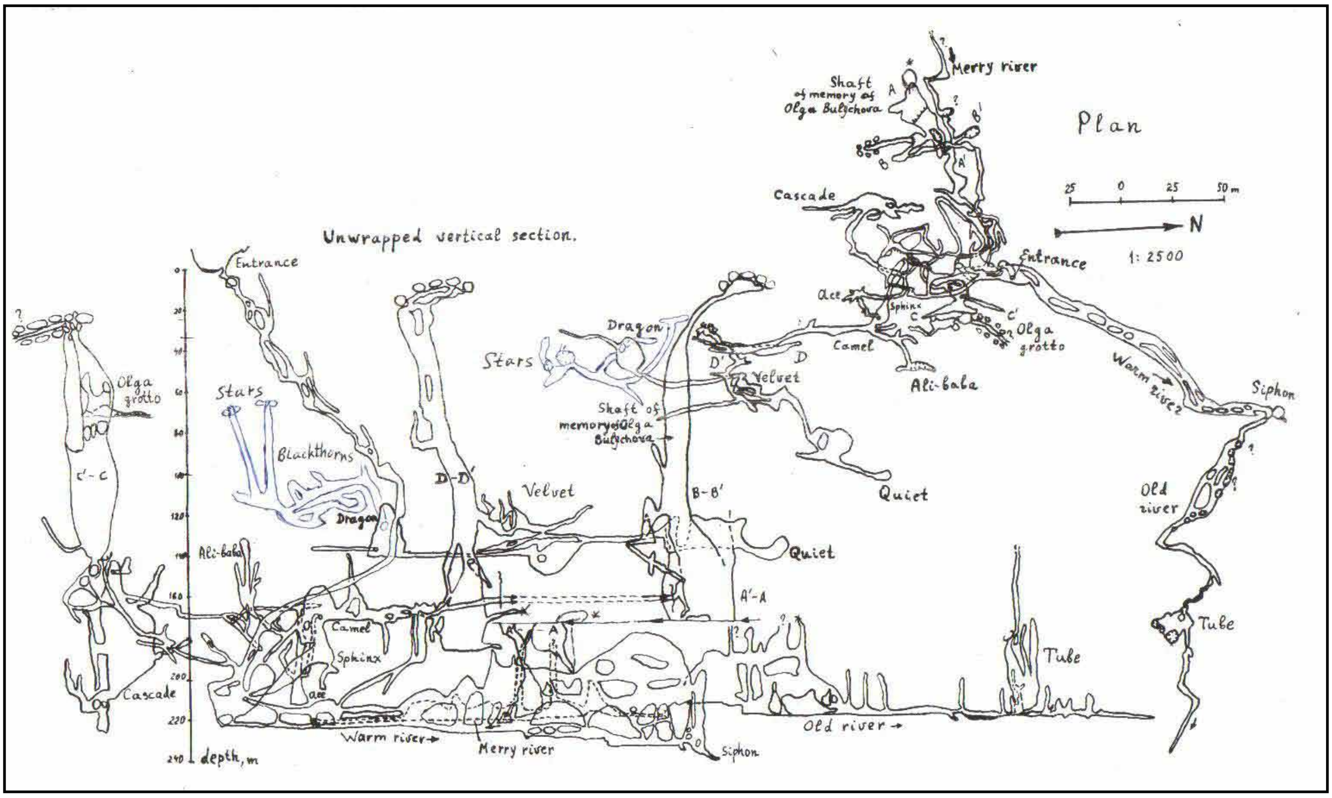

Figure 1. Altaiskaya cave (mapped by A. Bulychov), L=4740m, -240m, on 2016 year

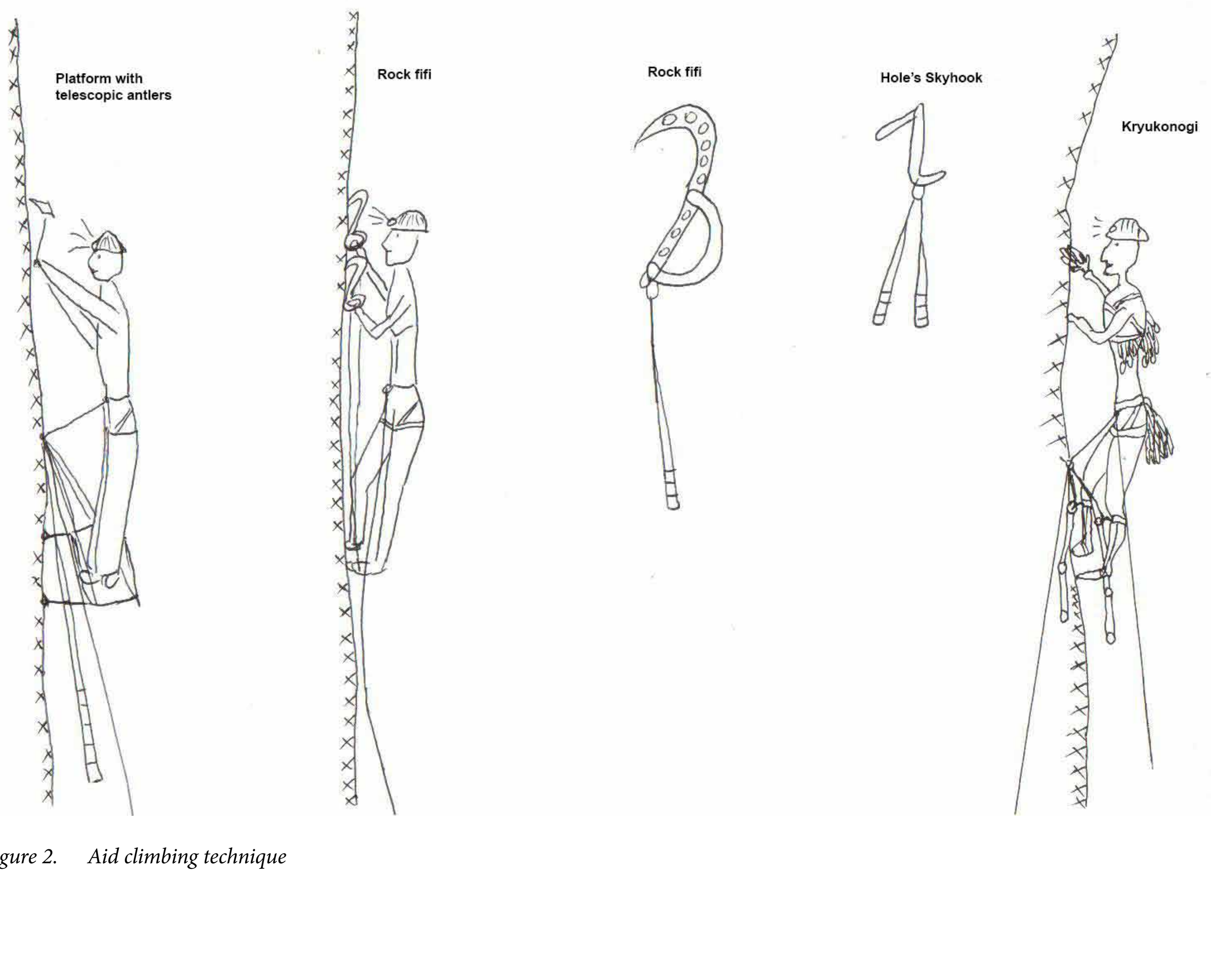

Figure 2. Aid climbing technique

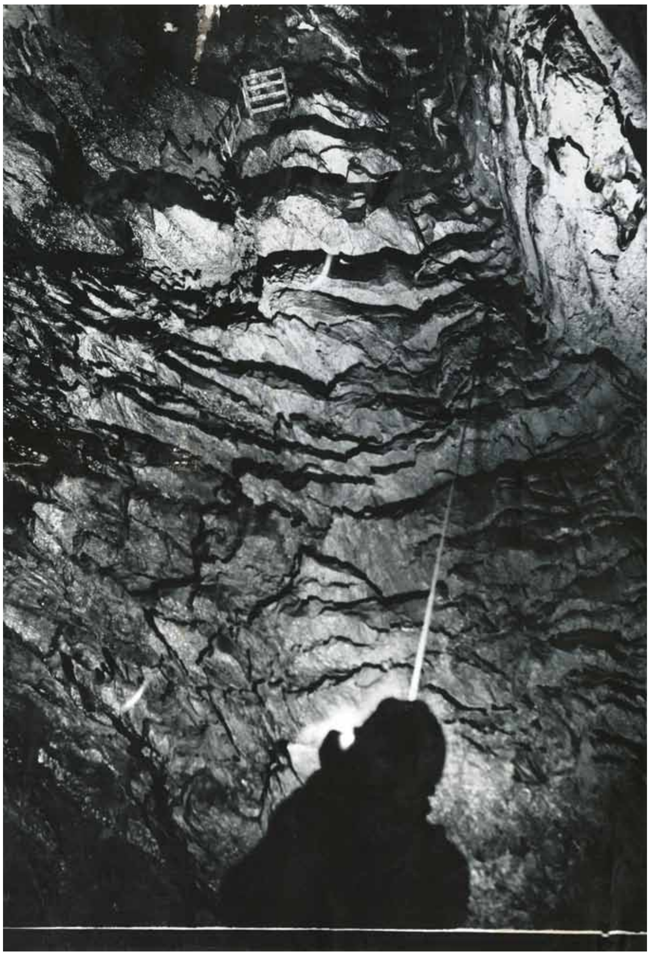

Figure 3. Climb up with a telescopic platform

Figure 4. Climb up on Knives Face above Old River

3. Training in the field

3.1. Alpine climbing in caves.

Climbing passion headed us to a new endeavor. Due to tectonic and geophysical investigations (Boulytchov 2000; Sorokina and Boulytchov 2001) in caves in Siberia there had to be new systems - geographical "white spots" to be discovered. To get there we faced the need to ascend high sheer walls from lower cave levels to upper ones with help of aid alpine techniques since free climbing was insane and it is either impossible to set up protection or because there was not any face-relief. This practice in our club was begun in 1979 and appeared to be one of the first in the world [Серафимов 2006]. It required a qualitative leap in the training process so far as neither cavers nor sport-climbers taught before this technique.

Appreciable discoveries were made in Altaiskaya cave (fig.1), technically the most difficult cave in Siberia with almost 3km of vertical sections to ascend and descend. To ascend 40-180m hanging faces (to get upper sub-horizontal storeys) it was mandatory to use storm climbing stairs or kryukonogi (straps with steel rings and steel hooks on stirrups under knees), rock-fifi, hole's sky-hooks (fig.2), telescopic platforms (fig.3), cams, nuts, rurks, pitons, bolts, etc. To perform a complete sport route, a skilled group is required to spend 10 days inside the cave. Compulsory to ascend are shafts Giants (110m), Birthday (170m), named after Olga Bulychova (180m), Tube (70m), 4-th Sump (30m), Sphinx (30m), Red-White (25m), Merry river (several 30m), Old River (several 40m) (fig.4), and "Through blackthorns to the stars" (40m) (Шварц 2016), etc.

3.2. Alpine mountaineering experience.

A penchant for climbing has led us to Mount Patroush (fig.5) on the Zeravshanskiy Range (Pasroud valley). The plateau (100x3000m) on the top (4050m) is elevated 2,2km above its water discharge (powerful stream around the base of the mount). Table shaped, cut from all sides by sheer walls, this huge limestone massif required climbing an alpine route of D+ (IY) category (first ascent). The funnel and moat on the plateau are deadly corked by shuttered rocks. A promising cleft was found 100m lower on the face but it ended up only so far on 150m depth and is too narrow to continue without widening.

The Hodja-Ahcha-Baroun Plateau (Gissarskiy range) is situated not far from famous Hodja-Gurgur-Ata area (where Boi-Boulok cave is laid in) at 3900m altitude with water discharge to Tamerlan cave at 1100m. Mighty layers of carbonate rocks (Mesozoic Jurassic J_{1-3}) are interrupted on depths of about 180m (fig.6) by dense dolomites and siltstones so all caves previously found here from the surface are blocked at these depths by collapses and mud. The sheer hanging face up to 600m high on the flank of folding ridge of the plateau performs a natural cross-section where two holes of possible caves were visible (fig.7). Lamagaier Cave (about 200m up from the base of the wall) was found to be large but blind. Vulture Cave (370m to climb up, fig.8) looks like a fissure with a squeeze passage (100m) but it stretches along monoclinal

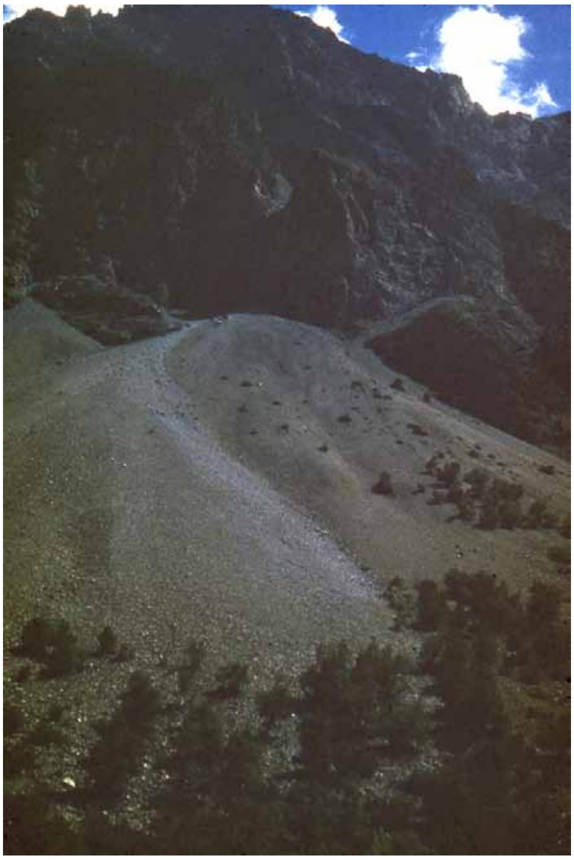

Figure 5. Mount Patroush Face

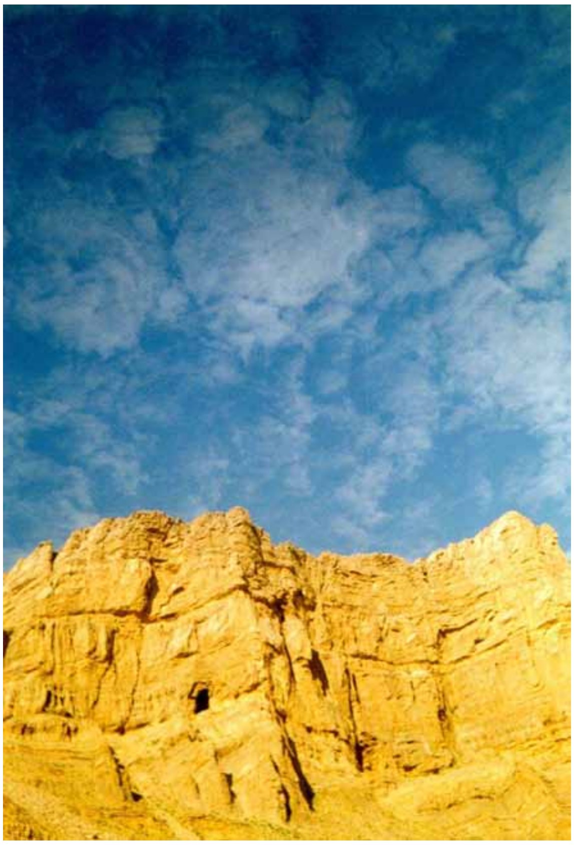

Figure 7. Hodja-Ahcha-Baroun Face

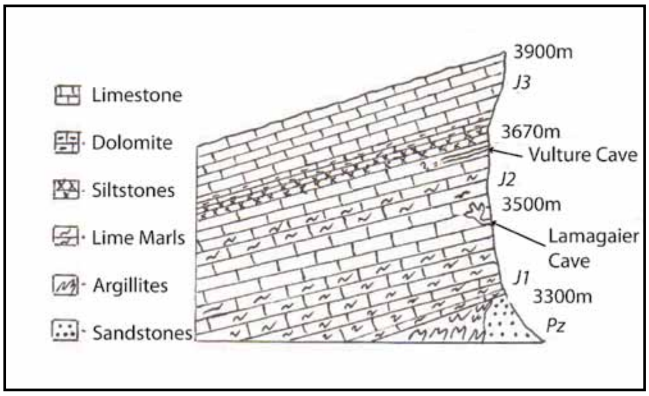

Figure 6. Cross-section of Hodja-Ahcha-Baroun Face

layer lower than the blocking rocks in direction of Tamerlan Cave. The squeeze needs work to widen it, because of its draught. In Tamerlan Cave a series of cascades along a river was aid-climbed up by the team of Tim Guilford (Oxford) heading to the plateau (Зубков 2000); they ended up on the next shaft up because of time and gear limitations.

After an alpine expedition on Khan-Tengri and Pobeda peaks (Kirgizstan) the lake Merzbaher (altitude 3300m) was explored. Water (capacity 0,13km^3) from this reservoir (area 2km^2, depth 50-80m) disappears usually once a year (end of August) or occasionally twice (end of October) into 20km of tunnels under Inylchek Glacier totally discharging for 2 days. The lateral moraine of the glacier is a natural dam of the lake with mix of clay, clayey-rubble mass in lower part. This mass when under extra-water pressure (up to 6-8 atmospheres) becomes liquid-saturated converting to a thixotropic slurry,

Figure 8. View from Vulture fissure

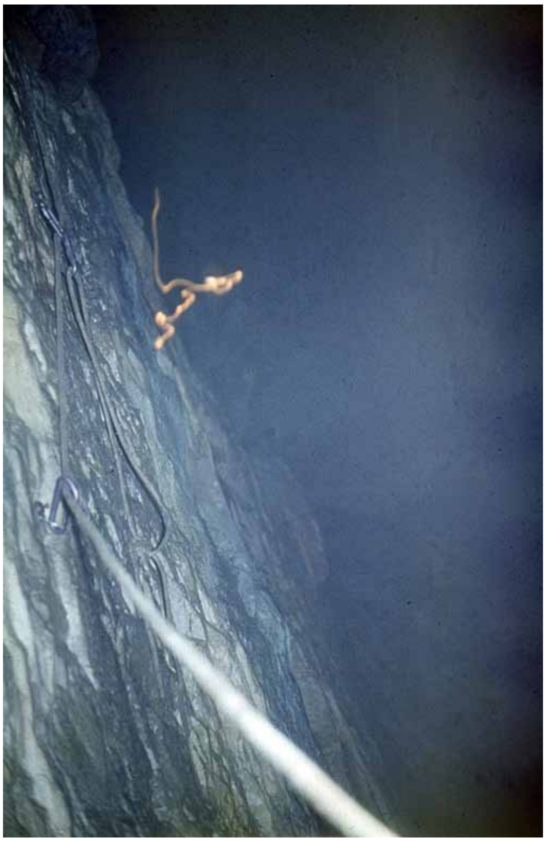

Figure 9. Climb up to Glory grotto that can be flooded

Figure 10. Climb up Breach wall

the fluidity of which increases like a hydraulic blow removing all material in its way (Головин 2005). When the water totally disappears from the lake, the fluidity drops to zero, and the suspended clay transforms to pure clay sealing all conduits. In this way the accumulation of water starts again creating new lake.

A similar phenomenon and explanation was surveyed in Kashkulakskaya Cave in Siberia. Water floods this cave occasionally forming a 50m deep big lake that gradually increases for a month (fig.9). Finally all water disappears discharging dartingly into a griffon in the valley.

While climbing Kilimanjaro peak on the upper part (about 5000m) of Breach wall (fig.10) a gravitational fissure was observed, ending up at 50m (blocked by shuttered rocks).

On descent from Aconcagua peak at an altitude about 6900m, a niche in rocks was found for overnight stay (Вронская 2016). This appeared to be a cleft squeezing 80m deep down but we had to escape after the five day ascent of the 3-km South Face due to the tempest and almost no gas or food.

4. Ethics

Relevant to my long-term caving practice two painful ethical moments should be noted. While mapping one has to provide proper information appropriate to measuring devices but not just to imagination. One has not to forget or to deliberately conceal information from previous explorers and always provide references to their papers or corresponding web resources.

Fair play (Huizinga 1950) in our process is to train but not to loose health and ability to be virile, vigorous. Meanness is thought to jeopardize mates by instigating to rush into doing insane bold exploits for vanity. Opposite, we discourage competition inside the group but aim to help mates since when we are in a cave we are an immediate family. We try to overcome a route not due to a desperate audacity or prevailing upon oneself but according to skills that are being improved by regular trainings. The purpose is to be well-rounded, to feel a balance and serenity on nature and in life.

4. Conclusion

Multi-faceted training of cavers resulted in qualitative breakthrough in overcoming of known sporting routes, the discovery of new ones, and in the exploration of new objects either in caves or mountains.

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Cave exploration in the Amari region of central Crete and its connection with Australian soldiers in the aftermath of the Battle of Crete.

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Abstract

The island of Crete is well known for its karstological wealth and its caves which are world renowned archaeologically and historically especially in connection with the birth and upbringing of the god Zeus. Of the 12,000 recorded caves in the official archives of the Hellenic Speleological Society (founded in 1950) around 5,000 alone have been found on Crete. One of the deepest is Gourgouthakas, a cave (pothole) located in the Lefka Ori (White Mountains) of western Crete. It is the deepest cave in Greece, with an explored depth of 1,208 metres (3,963 ft.) and is the 43rd deepest in the world.

The Hellenic Speleological Society has conducted a number of expeditions since 2005 to the Amari region of Central Crete, a relatively unexplored area in search of new findings and has come up so far with a record number of 70 caves and potholes 45 of which are new finds and the other 25 were recorded in the personal archive of the late Eleftherios Platakis one of the pioneers of caving in Crete.

The explorations also came across a number of caves which were used as places of refuge by allied soldiers especially Australian soldiers after the Battle of Crete in between their long and arduous retreat from the north to the south of the island in order to be transported safely across to northern Africa by submarines. Some of these findings were also based on personal accounts of the author's grandfather who was executed by the Germans for feeding and harbouring Australian soldiers in these caves.

Keywords: Central Crete - Amari region, Mt. Psiloritis, Kedros, Samitos, Katsonihi,Veni , caves, potholes, Meronas caves, Australian soldiers.

1. Introduction

The Greek island of Crete, world renowned for its Minoan Civilisation has always been linked with caves. It is here according to mythology that Zeus, king of the gods was born and raised in two consecutive caves. It is a karstological paradise with over 5,000 caves, officially recorded in the archives of the Hellenic Speleological Society founded in 1950 by the internationally acclaimed speleologist Anna Petrohilou. Gourgouthakas one of the deepest caves (potholes) on Crete and worldwide (ranked 43rd in depth) is located in the Lefka Ori (White Mountains) of Western Crete with an explored depth of 1,208 metres (3,963 ft.).

Figure 1. The island of Crete

2. The Amari Region (Central Crete)

The Amari basin is a scenic fertile valley lying five to six hundred metres above sea level located in the centre of the province of Rethimno, 35 kilometres south of the town of Rethimno.It is bordered on the east by the Mt. Idi (Psiloritis) massif - the highest mountain on Crete with an altitude of 2,456m and on the west by the conical Mt. Kedros (1,777m) and situated in between we have Mt.Veni (605 m.) towards the north ,Katsonihi or Meroniana Aori (1,108 m.) towards the centre and Samitos (1,013 m.) towards the south. In sharp contrast with the barren mountain peaks overlooking it, the valley has plenty of water and vegetation and has been inhabited as early as Minoan times.

Figure 2. The Amari Valley(From left to right- Mt.Kedros,Mt. Katsonihi,Mt.Veni,Mt.Samitos,Mt.Idi(Psiloritis).

2.1. Mt. Idi (Psiloritis)

Mt. Idi (the ancient name) or Psiloritis as it is commonly known today is the highest mountain on Crete with an orientation of north to south. It is here according to Greek mythology that Zeus was raised in the Idaion Andron cave by the goat Amalthia and protected by the bodyguard warriors the Kourites who would bang their shields in order to cover the infant Zeus' cries and thus protect him from being eaten alive by his father Kronos.

From its peak at an altitude of 2456 m. at least three major levels of karst are formed in limestone layers creating caves most of which are at relatively large altitudes and above the displayed phyllite - quartzite series in the more thickly – bedded permeable Tripolis series of limestone. The phyllite – quartzite series are impermeable rocks causing the waters to remain on the surface and flow downwards creating ravines

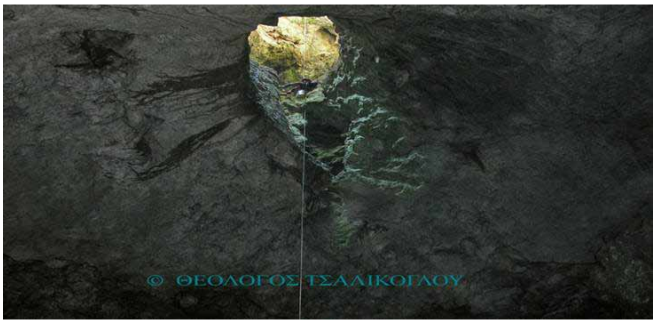

Figure 3. The pothole of Mavri

with dense vegetation and supply the Platis and Platanias Rivers with water which flows into the Libyan and the Cretan Seas respectively.

Many large caves and deep potholes have been found here at altitudes ranging from 1,100 to 1,500 metres The deepest cave (pothole) found so far is 'O Tafkos tis Mavris ' (The pothole of Mavri) above the village of Vistayi or Bistai at an altitude of 1,221 metres reaching a current depth of 200 metres and a possible further continuation as it is likely to form an underground river system.

It is a large doline (sinkhole) 20 metres in diameter at its entrance with five successive descents or rappels the first being 50m. and large chambers ranging from 250 to 1,000 square metres. Inside were found many animal remains especially skulls of large horned male goats and an intact skeleton of a male Kri-Kri an indigenous Cretan wild mountain goat which has disappeared from the area for the past 200 years and is now an endangered species on the island. Other finds included tens of wild pigeon's nests reaching to a depth of fifty (50) metres. These are common in other sinkholes across the island and are due to the fact that in there is no threat from other predators.

Another cave worthy of mention is the cave of Pan or Bana above the village of Platania at an altitude of 1,385 m. which according to Paul Faure (1964) is amongst the most important sacred caves of Crete with a history spanning many eons. It was dedicated to the god Pan (god of the flocks and of shepherds) in antiquity and there are many local shepherds who still worship and believe in him. In the summer of 2009 another larger cave of Pan was found in the area which constitutes a very important find for the history and archaeology of the area.

- Caves explored from the archives of Eleftherios Platakis : The potholes of Mavri and Modi (Vistagi), the cave of Pan (Platania),the cave of Leska (Fourfouras),the cavernous church of St. Anthony (Mt. Veni), the pothole 'Birbikou I Tripa' (Apostoloi)
- New discoveries : The potholes – Peristere,Mavrali Poros ,Pirovole,Voidarolithos,Alexi Tafkos,No. 46 (Vistagi),new cave of Pan(Platania), the caves Habathoura,Koufio,Katoi and the pothole Korakies (Fourfouras)

2.2. Mt.Kedros

Mt. Kedros is the second largest mountain in the Amari basin with an altitude of 1,777m.and an orientation of north to south. It lies above the village of Gerakari , Vrises and Ano Meros. The rock formations are composed mostly of thin bedded limestone of the Pindos series and are often covered by the Pindos flysch. Under these appear other limestone formations of the Tripoli series which is more thickly bedded and on the peaks of Agathi-Soros (1,186m.) above the village of Pandanassa they meet their underlying phyllite- quartzite series. Therefore for this reason there are many important springs or 'anavalouses' as they are known locally on the higher slopes of this mountain above an altitude of 800 m. This is due to the fact that the top thin layered limestone allow water to permeate through the first grey limestone layer but when they reach the second layer which is composed of a black siliceous impermeable formation the water collects and forms large underwater cavities which, when after heavy rainfall they fill up, water is spouted in a waterfall like manner from the cavity's entrance.

The largest accessible of these underground cavities is the 'anavalousa' next to the monastery of Kaloeidina above the village of Ano Meros- with meandering passageways 100m in length and two small lakes (large gours) . A second smaller one is found next to the cave of Profitis Ilias (the Prophet Elijah) with a small stone built chapel inside the cave.Tradition says that there are a total of 99 springs on the slopes surrounding the mountain and they have yet to find the 100th which apparently has magical properties and contains the legendary 'immortal' water.

It is on this mountain and specifically above the village of Gerakari and in a cave called Hainospilios that the last stages of one of the boldest military abductions of World War Two took place. General Heinrich Kreipe the commander of the Nazi forces on Crete during World War Two, was abducted by British commandos and Cretan resistance fighters from the city of Heraklion ,marched over Mt. Idi (Psiloritis) into the Amari region ending up in the cave of Hainospilios before being taken south to the coastal village of Rodakino where he was ferried across to Egypt by a British submarine .

For this action the retaliation of the German (Nazi) forces was relentless – a total of 164 men were executed in the villages of Gerakari , Gourgouthi, Kardaki , Vrises , Zmiles, Drigies, Hordaki and Ano Meros and the villages of Gerakari and Zmiles were razed to the ground in what came to be known as the Amari or Kedros Holocaust.

- Caves explored from the archives of Eleftherios Platakis: the cavernous church of Profitis Ilias (Gerakari),the cave of Tripiti (Ano Meros)
- New discoveries: the potholes Koliakoude 1and2, Sto Gyrisma tis Plakas and Shisma and the 'anavalousa'- spring of Profitis Ilias (Gerakari), the pothole of Koure and the 'anavalousa'-spring of Kaloeidina (Ano Meros)

2.3. Mt. Samitos

Mt.Samitos with an altitude of 1,113m, a.s.l., is the third largest mountain in the Amari valley and lies between the two larger massifs of Mt. Idi and Mt. Kedros with an orientation of east to west. It is composed mostly of thin bedded limestone of the Pindos series and most of the caves here are also found at relatively high altitudes . It rises above the villages of Amari (the capital), Opsigias, Monastiraki and Petrohori.

It is on this mountain during World War Two in a cave called Vothonolakos, that resistance fighters under the leadership of Petrakogiorgis would gather secretly to plan their raids and also hide the only radio-transmitter of the time which was used to listen to the BBC world service and also relay messages to the British High Command.

1. Caves explored from the archives of Eleftherios Platakis: the pothole of Havde and the c Neraidospilios cave (Petrohori).
2. New discoveries: the pothole 'Sto plai ton Koukistron'and the caves- of Pan,Vothonolakas,Amari 4 and 'Ston Koukistron to Haraka (Amari) , the pothole Amygdalos (Monastiraki), pothole under the cave of Neraidospilios (Petrohori), cave of Gerondospilios (Zmiles).

2.4. Mt. Katsonihi (Meroniana Aori)

Mt. Katsonihi or Meroniana Aori as they are known locally with an altitude of 1,108 m. and an orientation of east to west is the fourth largest mountain in the Amari valley and lies above the villages of Meronas and Pandanassa. It too is mostly composed of thin-bedded limestone of the Pindos series. Quite a few smaller caves and potholes at altitudes of 600-700 metres a.s.l, reaching a maximum depth of 90m. have been found on this mountain. It is also here, above the village of Meronas that the author's grandfather used to feed and harbor Australian soldiers in a few caves during the Second World War after the battle of Crete and was finally betrayed by locals and finally executed by the Nazi forces for his actions.

- Caves explored from the archives of Eleftherios Platakis:the potholes Theriotripa,Katrada,Galinomanoli and the caves Neraidospilios, Migiospilio, Aghion Deka, Voukole/Spiri and Pavlou Spiloi (Meronas) and the Neolithc cave of Margieles (Elenes).
- New discoveries: the potholes of Ahnotrypa, Aerotrypa, Aghiou Pnevmatos, Strogili Harakoi and the caves of Profitis Ilias, Moshakenas, Mesohorianis Vrisi and the cavernous church of St. Antonios (Meronas), the pothole of St. Irene (Elenes)

2.5. Mt. Veni

Mt. Veni with an altitude of 605m. and an orientation of east to west is the fifth largest mountain of the Amari valley. It is a flat table- topped mountain forming a plateau roughly one kilometre in length by five hundred metres in width. It is mainly composed of marly limestone of the Miocene period and has a few smaller caves with the exception of one larger one which is formed along a fault line with a total length of 30 metres . Veni is known throughout Crete for its famous monastery of Aghios Antonios (St. Anthony) which is situated in a cave which was dedicated according to Paul Faure (a famous French speleologist /archaeologist) in antiquity to the god Pan. On the plateau are remnants of an ancient city called Vini or Ornithe dating from the 5th century B.C part of which was excavated in 2008.

- Caves explored from the archives of Eleftherios Platakis: the cavernous church of St. Antonios (Mt.Veni)
- New discoveries: the caves of Trypa, Veni I,II,III,IV and V (Mt.Veni).

3. Hellenic Speleological Society – 12 Expeditionary Missions (2005-2012)

During the years 2005 – 2012 ,the Hellenic Speleological Society in cooperation with its two Cretan divisions from Western and Eastern Crete based in the cities of Rethimno and Heraklion respectively, have conducted twelve expeditions to the Amari region of central Crete a relatively virgin and unexplored area speleologically. They have come up so far with a record number of almost 70 caves and potholes 45 of which are new finds and the other 25 were recorded from the personal archive of the late, great Eleftherios Platakis one of the pioneers of caving in Crete.

The findings also relied heavily upon the knowledge of local shepherds like: Mr. Manolis Vergitsis and the Patena brothers from the village of Vistagi , Mr. Stellios Vernidakis from the village of Gerakari , the Kokkinos brothers from the village of Meronas, Mr. Apostolos Hatzidakis and his son Manolis from the village of Ano Meros , the speleologist and mountain climber Mr. Aris Koutakis from the village of Opsigias and the alderman of the Amari municipality Mr. Thanasis Christodoulakis from the village of Vistagi and lastly on the author's origin and concise knowledge of the area.

4. Caves in the Amari region used as places of refuge by Australian and other allied soldiers after the Battle of Crete (includes a personal account)

4.1. The Amari valley during World War Two

The Amari valley is located away from the major urban centers and saw little presence of German forces during the occupation. It provided shelter to several Commonwealth military personnel still hiding on the island. Many more had crossed the valley heading to the south coast for evacuation to Egypt. Later, residents helped transport supplies and equipment for guerrillas opposing German occupation, as well as offering food to them. The Amari became an important center of the Cretan resistance.

The support of the locals, combined with the region's beauty, led the British Special Operations Executive (SOE) agents then serving in Crete to coin the nickname Lotus Land for the Amari valley or 'Elefthera Hellas' – Liberated Greece as it was known locally.

4.2. The Battle of Crete

The Battle of Crete began on the morning of the 20th of May 1941, when Nazi Germany began an airborne invasion of Crete. Greek and Allied forces composed of British, Australian and New Zealand forces together with Cretan civilians defended the island for a total of thirteen (13) days from the 20th May until the 1st June 1941. Defences in the north of the island were finally overwhelmed and allied forces withdrew to the south coast. Over half were evacuated by the British Royal Navy; the remainder surrendered or joined the Cretan resistance. The area of Rethimnon was defended by Australian soldiers of the 2/1st and 2/11th battalions under the leadership of lieutenant colonel Ian Cambell and Major Sandover respectively. The former ordered his men to surrender while the latter instructed his men that they could either surrender or evade capture. Many chose the latter by hiding in the hills some protected by local Cretans who were under constant threat of being executed by the Germans. One of those Cretans was my grandfather who was finally executed by the Germans for feeding and harbouring Australian soldiers in caves above the village of Meronas in the Amari region.

4.3. Caves and Australian soldiers (a personal account)

My grandfather's name was George Kallergis (descended from a famous Byzantine noble family of Crete), a police officer and farmer at the time (Fig. 4). Like many local Cretans today he was self-sufficient with an assortment of crops and plantations in different areas, one of which, his potato field would take him up to the hills to a small plateau an hour's walk above the villages of Meronas and Pandanassa where he also maintained a small hut with a large cauldron. It is on this plateau in the summer of 1941 that he met up with a group of Australians and possibly one British soldier who were on the run from Rethimnon towards the south. According to personal accounts from my mother and grandmother and from other villagers he would boil potatoes in his cauldron and feed these soldiers who he had found shelter for in at least three different caves in the surrounding area. One of these caves to the west of the plateau called Neraidospilios or cave of the fairies with an adjoining smaller cave was the ideal hideout as the locals kept away for fear of it being haunted and it was also hidden by thick foliage. After, the soldiers were moved for some reason to a larger more spacious cave called Tou Pavlou i Spiloi or Paul's Caves which were also used by the local villagers as a hideout and this may have caused problems for him. It is not clear for how long this harbouring took place, accounts differ from between a few months to a year. One thing is clear though, these actions led to his final betrayal by locals and his tragic end.

On September the 11th of 1944 on the outskirts of the underlying village of Apostoloi a mere one kilometre from my grandfather's hut resistance fighters ambushed and killed 30 German troops known as the 'Battle of Potamoi ' . This, coupled with the fact that the Germans were losing on all fronts enraged the German forces who carried out harsh reprisals. On September the 14th in the presence of my mother and my aunt, a platoon of German soldiers consisting of 40 to 50 soldiers marched up the plateau and two officers walked up to the hut. When my grandfather walked out they opened up a small notebook and asked if he was George Kallergis , he nodded and they asked him to come with them. They led him east towards the village of Apostoloi into a stream bed where they shot him several times and left him lying there for days. His legacy - of the 2/11th, 13 officers and 39 other ranks managed to escape to Egypt. I would like to imagine that the soldiers he helped out were amongst these men.

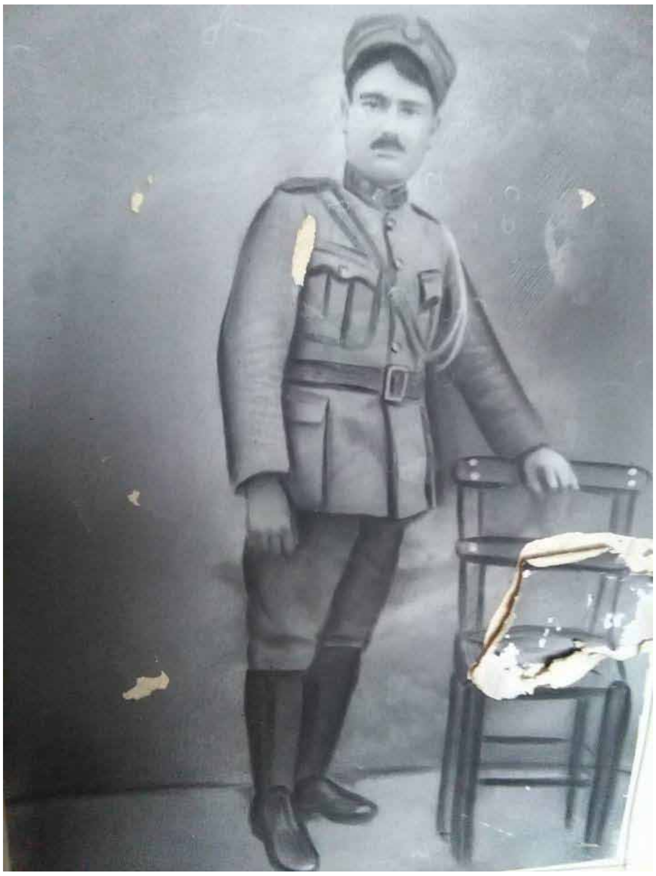

Figure 4. George Kallergis – my grandfather in his police uniform , just before the outbreak of the Battle of Crete.

5. Summary

A general overview of the work done in the Amari region of Central Crete by the Hellenic Speleological Society between 2005 -2012 and a personal account connected to Australian soldiers and caves during the Second World War.

Acknowledgments

We are most grateful to all the cavers of the Hellenic Speleological Society that took place in the expeditions especially to my close colleague Mr. Theologos Tsalikoglou whose help and assistance was vital throughout these years, to all the above mentioned shepherds and friends from the Amari valley,to Mr. Vasilis Simitzis , the former mayors of the Amari Mr.Mihalis Petrakakis and Stefanos Simandiras, Mr.Antonis Patrikalakis and Niko Varouha for their hospitality, Mr.Apostolos Vamiadakis , Mr.Aleko Petrakakis, Mr. Lefteri and Vasili Litinas, Mr. Babis Skepentzakis , Mrs.Maria Lagouvardou and Ms.Konstandina Aretaki.

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The Caves Of Armenia

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Abstract

The first U.S. caving expedition to Armenia, the South Caucasus, by NSS cavers took place in August, 2007. Subsequent expeditions by the author took place in 2010, 2011, and 2013, with additional trips planned for the future. The goal is the exploration and photo-documentation of the caves of Armenia, and to increase awareness of its underground realms. Although, in the past, there had been a few known caving expeditions to Armenia, overall little information existed. In addition, Armenia's local caving community is small in number. As a result, the author researched this topic and organized the first official U.S. caving expedition to Armenia in 2007. During the first expedition, four of Armenia's significant natural caves were explored in the province of Vayots Dzor: Mozrov Cave, Arjeri Cave (Cave of the Bears), Mageli Cave, and Karmir Cave (Red Cave). Man-made caves were also visited. Subsequent trips to Armenia in 2010, 2011, and 2013 included (1) further exploration of Mozrov, Arjeri, and Mageli caves, (2) a cave trip to the neighboring independent Armenian Republic of Nagorno-Karabagh to explore Azokh Cave, and (3) the exploration of several caves in the northeast Armenian provinces of Tavush and Lori. Natural caves consisting of limestone, conglomerate, and lava were explored during these expeditions. Also, a number of man-made caves were visited, some of which were used as churches in centuries past. This article summarizes the four expeditions, and discusses both the natural and man-made caves of Armenia.

Keywords:

1. Introduction

The present-day Republic of Armenia lies geographically in the South Caucasus, between the Black Sea and the Caspian Sea. The most ancient of the countries and nationalities of the Caucasus, the Armenian people have a legacy stretching back 3,000 years. Eastern Turkey, southern Georgia, western Azerbaijan, and a northern portion of Iran are all part of historical Armenia. The Republic of Armenia is a rugged, mountainous land, with an average elevation of approximately 1,500 meters ASL, and a population of just over three million. (Due to Armenia's tumultuous and tragic history, there are presently more Armenians residing outside Armenia – the Diaspora.) Armenia holds the distinction of being the first nation to declare Christianity as its state religion in 301 A.D. Ancient churches in Armenia (among the oldest in the world), many still standing and in use, pre-date those of Europe by centuries. Some of these churches were hewn out of rock, thus cave churches.

Prior to 2007, available information and literature on natural and man-made caves in Armenia was sparse. After researching this topic and making contact with local Armenians in Armenia, this author organized the first United States (NSS) caving expedition to Armenia. The expedition was a success, as we explored and photo-documented four of Armenia's significant caves in the province of Vayots Dzor in south central Armenia. Participating in this first expedition were Steven Johnson, James Wilson, Greg Chavdarian, Seda Chavdarian, and Chuck Chavdarian of the United States, and Vrezh Nazarian and Samvel Shahinyan of Armenia, who also acted as our guides.

This was followed by expeditions in 2010, 2011, and 2013 by this author. As a result, further exploration occurred not only in Vayots Dzor province, but also in the northern provinces of Tavush and Lori, and the eastern province of Syunik. In addition, we also travelled to the neighboring independent Armenian republic of Nagorno-Karabagh. Both natural and man-made caves have been explored and are discussed in this paper. The following cavers participated in some or all of these subsequent trips: Lara Chavdarian and Chuck Chavdarian of the United States, and Vrezh Nazaryan, Smbat Davtyan, Pegor Papazian, and Nyree Abrahamian of Armenia.

2. Discussion

2.1. Vayots Dzor Province, Republic of Armenia

For the 2007 expedition, we maintained a base camp near the village of Mozrov, at an elevation of about 1,700 meters. For subsequent expeditions in Vayots Dzor province in 2010 and 2011, we stayed in bed and breakfast homes in the town of Yeghegnadzor, the provincial capital. We explored and photo-documented several caves.

Mozrov Cave: Mozrov Cave, primariy a limestone cave, was first discovered about 40 years ago during road construction, when a collapse occurred resulting in a large entrance to the cave (which is also the only known entrance to the cave). The cave sits at an elevation of approximately 1,550 meters ASL adjacent to a mountain road. Due to its accessible location, the cave is vulnerable to visits by non-cavers and tourists, and has sustained some damage. Over the course of the four expeditions, we have explored the cave five times, and have taken a number of photographs. There is substantial decoration in this; cavecolorful stalactites, stalagmites, columns, moonmilk, flowstone, coral, popcorn, crystalline spars, soda straws, helictites. We were to soon find that Mozrov Cave is not unique in this regard. The cave has over 300 meters of known passage. The cave consists primarily of an undulating large and long main chamber, with a separate large chamber that can be entered through a low, hard to find, crawl passage at the back of the main chamber. This second chamber

Figure 1. Decoration Hall, Mozrov Cave, Republic of Armenia – Photo by C. Chavdarian.

Figure 2. Hall of Giants, Arjeri Cave, Republic of Armenia – Photo by C. Chavdarian

is noteworthy for its extensive multi-colored decoration (and has been aptly named as "Decoration Hall"). In 2010, at our request, our local Armenian caving colleagues, headed by Smbat Davtyan, returned and surveyed the cave and provided the first cave map of it.

Arjeri Cave (Cave of the Bears): Arjeri Cave, at an elevation of nearly 1,700 meters ASL, is Armenia's largest known cave, with currently about 4 kilometers (2.5 miles) of passage. Our only map was a rudimentary overview of the cave which was created by Russian cavers nearly 30 years ago. The cave does require an updated and detailed cave survey and map. A total of four trips were made into this cave in 2007 and 2011. Arjeri Cave, a limestone cave, is the most highly decorated cave in Armenia, and one of the most highly decorated caves this author has ever seen. To reach the only known cave entrance, one must leave their 4WD vehicle off-road, and at an elevation of 1,500 meters ASL, and undertake the final steep hike to the cave. Just inside the Entrance Hall, explorers are immediately greeted with the sight of huge flowstone columns. After passing through this first large chamber, one enters a slope requiring a steep belly crawl upward over slick flowstone. Along the way, this area is decorated with various formations. This leads into a large chamber known as Photographer's Hall, and the name is certainly appropriate as the room is rife with colorful formations – stalactites, stalagmites, columns, draperies, bacon, coral, and popcorn. The sheer quantity and density of the decoration in this large chamber is overwhelming. From here one continues on into Bear's Hall, which contains the bones of a bear (and, thus, the name of the cave). On the way to Vayk Hall, there is a deep pit, which is estimated to be at least 18 meters deep. This pit has not been explored by us (and may possibly lead to more passage). On entering Vayk Hall, one is actually standing near the top of the hall. The hall descends about 10 meters, and contains large, colorful columns, massive flowstone, and a myriad of formations. Overhead is voluminous white calcite coral – almost cloud-like in appearance. Continuing beyond Vayk Hall, there is a nearly 10 meter climbdown that can be negotiated with a handline. This then leads into a broad swath of massive columns, which we have appropriately labeled as the Hall of Giants. Continuing from this point leads one through a variety of colorful formations along the way, including nearly blood-red speleothems. Continuing on, the passage gradually slopes downward, and eventually leads to the "Lake" near the end of the cave's known passage. On other trips into Arjeri Cave, we also explored some areas that were not present on the Russian map. There is much more exploration and detailed survey required of this cave, and it will surely extend the length of all known passages well beyond 4 kilometers

Karmir (Red) Cave: In 2007, from our base camp, we did a very steep hike of over 400 meters up the mountain-side to Karmir Cave, located at an elevation of over 2,100 meters ASL. The hike took over two hours and required careful negotiating of brush, loose talus, and some exposure along the way. Reaching the entrance requires care due to the final short exposed climb. Nearby is another cave – called Kiklop Cave – but the final 30 meter climb to reach it has significant exposure and is also more challenging. Time also prevented us from exploring this other cave. Karmir Cave has a large entrance chamber, allowing a group of cavers to congregate and also change in and out of caving attire. It is a limestone conglomerate cave with other mineralization, which provides the amazingly intense red color of much of the interior of the cave. From the entrance chamber, there are several passages leading into the cave interior. The passages tend to intersect and loop back around. Well inside the cave we walked, crawled, climbed, and traversed. Although not highly decorated, there was some flowstone, stalactites, and red coralloids. There is also an approximately 90 meter long passage in the cave, but none of us could find it on this trip. The cave is well worth further exploration, and is unique. A detailed survey is needed.

Mageli Cave: Mageli Cave is located along a gorge near the town of Areni, in Armenia's wine country. It sits at an elevation of nearly 1,100 meters ASL and has over 2 km (1.3 miles) of passage. Mageli Cave is a classic example of a conglomerate cave, (a mixture of limestone and other minerals). During our expeditions, this cave was explored on two different occasions – in 2007 and 2010. After entering the cave by crawling on hands and knees through the main borehole entrance, one can resume walking through parts of the cave. Immediately, on entering the cave, the conglomerate nature of it is obvious, as the interior of the cave resemble coarse, pebbled or gravelly concrete. Some flowstone is observed, but, for the most part, the cave is devoid of decoration (primarily due to the conglomerate composition of the cave). Not far inside the entrance, there exists a bat colony. Fortunately, because

Figure 3. Massive Conglomerate Block, Mageli Cave, Republic of Armenia – Photo by S. Johnson

of the various passages, one can avoid passing near the bats. Exploring further into the cave, there are tall, narrow passages, boreholes, and a steep, slippery climb-down to a lower level (handline recommended). Well-inside the cave there is also a 3-meter long belly-crawl squeeze with an incredibly intense, cold wind blowing through it (similar to a venturi). We negotiated this squeeze, but were unable to locate any sizable opening or passage related to the heavy wind. After gradually working our way towards the cave entrance by a different route, we encountered long, booming passages and came upon an impressive, massive conglomerate block hanging down from above, one of the signature features of the cave. After exploring additional side passages, we exited the cave. In a subsequent trip to this cave in 2010, we entered through the main entrance and then proceeded to negotiate our way through passages, including boreholes, to the upper level of the cave (above the main entrance). As we worked our way along this level, we encountered a 12 meter pit (but with no vertical gear, we did not drop the pit for further exploration). However, by passing through another nearby passage, the pit can be avoided, and one can reach a narrow ledge above the main entrance (thus, an upper entrance), with a spectacular view of the gorge below. A more detailed survey and subsequent map of this cave is certainly warranted.

Trchuneri Cave (Cave of the Birds): In 2007, we briefly explored Trchuneri Cave near the town of Areni. This cave is of particular note, and we observed evidence of an archeological excavation at the entrance of the cave. Subsequently, in 2010 and 2011, significant archeological discoveries were reported at this dig, with artifacts dating back 6,000 years. Excavations continue to this day.

Jerovank (Water Cave Church): From the base camp in 2007, we travelled lower in elevation to a gorge with a path, which lead to a very unique cave, known as Jerovank. After hiking through the gorge, we reached the small limestone cave, next to a running stream. The locals make a religious pilgrimage to this cave each year and a church altar has been built inside the cave. Some of the nearby water actually permeates into the church, and the water can be seen along the back of the main chamber, and also in an alcove next to the church altar. Along one side of the church chamber a brick wall was built, further enclosing the cave and church from the outside. We observed flowstone along the natural walls of the cave. Due to centuries of turbulence in Armenia, church caves like this existed to provide protection for the congregation.

2.2. Syunik Province, Republic of Armenia

In 2011, we travelled to Syunik Province to photo-document the man-made caves of Khndzoresk and the man-made caves of Old Goris near the eastern border of Armenia.

Caves of Khndzoresk (Deep Gorge): The man-made caves of Khndzoresk are in an isolated and lightly populated mountainous rural region. We hiked into this site. In centuries past, this was a thriving village, with man-made caves (homes) carved into the sandstone cliffs scattered all around. This even included a small church. It was inhabited up until the 1950s. The caves housed people, food supplies, and even livestock. All that now remains are the empty caves and the vacated church. Centuries ago, if one wanted a cave shelter or home, the local mason would fashion or carve a cave out of the soft rock. The caves sit on high ground, thus providing shelter in a strategic location – especially, important considering the enemies that had invaded Armenia over the ages.

Caves of Old Goris: In the hills above the thriving Armenian town of Goris are a series of rock spires. The spires actually consist of many man-made caves, similar to those in Khndzoresk. This was the centuries-old village of Old Goris, and is extensive. The present town of Goris lies in a valley below Old Goris. One can access Old Goris, walk through it, and enter some of the carved sandstone caves. In some cases, where sandstone rock shelters may have already been present, the shelters were likely enlarged by local masons. The area is no longer inhabited. Once again it is important to note that Old Goris strategically sits on high ground, having provided protection to its former inhabitants.

2.3. Tavush Province – Republic of Armenia

In 2013, the focus was on the caves in the northeast section of Armenia, specifically in Tavush Province. We stayed in the town of Ijevan during our explorations in this province.

Lastiver Cave (aka Anapat Cave): Lastiver Cave is perched near a cliff, in a mountainous region of Tavush Province, west of the town of Ijevan. After driving up the mountainous terrain with our 4WD vehicle to a parking area, we then hiked about 4 km to the cave. The cave lies at an elevation just below 1,200 meters ASL. This natural cave is in limestone. The cave has had some frequent visits, and, as a result, is fairly devoid of

Figure 4. Cave Village of Old Goris, Republic of Armenia – Photo by C. Chavdarian

decoration. The chambers in the cave range from about 10 to 100 meters deep to about 15 meters wide. In the past, one of the chambers was used as a crude church, dating back to the 12th century. In this chamber, and opposite the centuries-old altar, are a series of nearly two-meter tall, human wall carvings that appear to be ancient, but were actually created about 80 years ago. In the largest room to the right of the church chamber, there is some actual flowstone remaining along the walls but is now a fairly dry cave. In one of the other chambers we did observe two bats. We explored various large and small chambers. Lastiver Cave is a natural cave that was also used as a church.

Large Grotto Cave, Pool Cave, and Crystal Cave: Hiking beyond Lastiver Cave, we gradually came upon a huge wall or cliff of karst at an elevation of about 1,200 meters ASL, where we came upon a large cave shelter. We named it "Large Grotto Cave", as it consisted of a large entrance estimated to be approximately 45 meters in width. The cave extended back about 15 meters. There was breakdown at the back of this large cave shelter, and we looked for additional passage but did not locate any.

We then hiked on along the karst wall and encountered another cave high up in the karst cliff. The way to this cave required some vertical rock climbing with exposure. We used a handline that was there and our team member, Vrezh Nazaryan, did the climb into the cave entrance. This cave measured about 7 meters in width at the entrance, and 10 meters deep. Further inside, the width expanded to 35 meters. Someone had actually constructed a circular pool containing water in the chamber. Stones lined the pool. Thus, we named the cave "Pool Cave". It is not clear the purpose of the pool. It may have provided a water source for the more contemporary inhabitants, or possibly a source for bathing.

We then continued our hike along the bottom of the karst wall and soon came to another cave at an elevation of approximately 1,200 meters ASL. The walk-in entrance was approximately 2.5 meters high and 2 meters wide. The cave extended back over 20 meters. There was no noticeable decoration, and a fair amount of breakdown. It is possible that there had been an excavation inside this cave. The notable feature was that there was a pile of crystalline calcite near the entrance, which had been partially scavenged by others. Because of this, we simply named the cave "Crystal Cave".

Hovk 5 and Hovk 1 Caves: The Hovk caves are high in elevation in a remote area of the mountains west of Ijevan. Some archeological digs have occurred there. From our base in the town of Ijevan, we drove high up into that area, parked off-road, and hiked up a very steep slope to the base of karst cliffs. We found Hovk 5 Cave at an elevation of approximately 2,380 meters. The cave is a rock shelter with dimensions of about 9 meters wide and 2 meters deep. We found evidence of an archeological dig.

We then continued the hike near the karst cliff toward Hovk 1 Cave. During the hike, we noted limestone outcroppings scattered all along the way, and an undulating landscape with sinks. As a result, there is great potential in this region for a potential cave system(s) waiting to be discovered. Once we reached the cave, we hiked up a slope and entered the elevated entrance, which sits at an elevation of over 2,050 meters. The first section of the entrance is about 0.5 meter wide and 3 meters long. This is followed by two large steps cut into the entrance – due to excavations - which then lead into the main part of the cave which is approximately 3 meters wide and over 21 meters in length. The main passage has a high ceiling which eventually pinches down to a marrow slot at the back of the cave. There is little decoration. The cave strategically sits higher up into the side of the karst cliff.

Zrngan Cave (or Zerngan Cave): We travelled east of our base (the town of Ijevan) and up into the mountains towering above the town. The goal was to reach Zrngan Cave at an elevation of approximately 1,850 meters ASL. The last part of our trip was off-road. This cave has a deep vertical entrance drop thought to be at least 45 meters in length. We were aware of only one attempt at dropping down the entrance pit, which occurred about 30 years ago. A group of non-cavers had lowered one of their people down to the bottom of the pit. This person actually explored some passage, but became frightened, and was hauled out of the cave. No one knows the true extent of the cave. Unfortunately, on the day we were there, this author was the only caver with extensive experience at single-rope technique. Although very tempting, the correct decision was made to not drop the pit – that is, not to do any solo caving for obvious safety reasons. Instead, this author did a demonstration for our Armenian caving colleagues by rigging the entrance drop, gearing up, and only rappelling down a short distance, followed by a changeover and ascent out of the cave. An actual cave trip into Zrngan Cave may be planned for in a future expedition.

2.4. Lori Province – Republic of Armenia

After leaving Tavush Province, our final caving destination of the 2013 expedition was to a lava cave in the neighboring province of Lori, to the west. This is also a rugged mountainous area of Armenia that also has caves.

Sanahin Lava Cave: Sanahin Lava Cave is the second largest lava cave (aka lava tube) in the Republic of Armenia, as noted by our colleague Smbat Davtyan. The cave is located near the town of Alaverdi, and is just off a main mountain road and on the side of a cliff, at an elevation of nearly 1,000 meters. The cave looks out over a spectacular and scenic

Figure 5. Sanahin Lava Cave, Republic of Armenia – Photo by C. Chavdarian

gorge below. This lava cave has about 80 meters of passage and three entrances with only the main entrance being negotiable. The cliff entrance has an approximate 30 meter vertical drop outside. Inside, there is mostly walking passage. At one end, there is 9 meters of wet passage requiring kneeling and crawling, where we observed small secondary formations of small stalactites of about 2.5 to 5 cm in length, generated from solution deposition. Inside the main entrance and to the left is the main trunk passage. This passage curves and eventually ends at the wide cliff entrance with the sheer vertical drop. This cave is well worth exploring.

2.5. Kotayk Province – Republic of Armenia

Geghard Cave Church: In Kotayk Province sits the medieval monastery of Geghard. This church is noteworthy as it was originally created by excavating by hand into a rocky mountainside. It is now a UNESCO World Heritage Site. The majority of the church sits inside the mountainside, thus, the interior walls and massive columns of the main chapel, built in 1215 A.D., are entirely carved out of the existing rock. It is Armenia's most famous man-made cave church. Our team spent a day inside the church, marveling at it. The original name of the monastery was Ayrivank, which means "The Cave Monastery" or "The Monastery of the Cave". It was later called Geghard, which refers to the spear which wounded Christ during the crucifixion, and was subsequently alleged to have been brought to this church for storage (the spear currently resides in the Holy See of Echmiadzin, near the capital of Yerevan, Armenia).

2.6. The Nagorno-Karabakh Republic

East of the Republic of Armenia lies the Nagorno-Karabagh Republic (NKR), home to an estimated 150,000 Armenians. This present-day independent Armenian republic is actually part of historical Armenia (and contains Armenian churches dating back centuries), but was tragically partitioned away and placed under the jurisdiction of Azerbaijan by the Soviet Union. Following the break-up of the Soviet Union in 1991, the Armenians of NKR fought for and regained their independence. Presently, one can travel through most areas of the NKR. As a result, we journeyed there in 2011 to explore a specific cave.

The Caves of Tegh: On our way to NKR, we initially passed through the border village of Tegh, located just inside the Republic of Armenia, and east of the town of Goris. Along a ridge, just below the main plain of the present-day village, we saw a number of large holes. These were indeed caves, but it was not clear if they were all man-made. Some may have been natural caves that may have been enlarged to house families, and some may have been totally man-made. We did not stop there, but we did capture some photos. This author hopes to return one day to explore and document the caves of Tegh.

Azokh Cave: Azokh Cave, located in the southern region of NKR, was the goal of our trip. Lying on a hillside in NKR's Hadrut province, and overlooking the village of Azokh, is Azokh Cave. This cave is of archeological significance, and there have been excavations there. A number of artifacts have been found, but the excavations are all at the three entrances (not deep inside the cave), with most of the excavations at the large main entrance (which is a high and wide vertical slot entrance). It was known that the cave consists of roughly three chambers, and has about 180 meters of cave passage. In researching this cave prior to the expedition, this author found very little information regarding the actual interior of the cave (beyond the main entrance), and hardly any photographs. There is only a very rudimentary hand-drawn outline map of the cave. It appeared that very few individuals ventured beyond the main entrance and deep into the cave. Once we passed through the main entrance chamber and into the next chamber, we discovered why there was so little information. In the second chamber and beyond, one is subjected to massive amounts of flying bats, flies, and guano, which can be overwhelming. This answered the riddle of this cave, as to why so little was known of it. We were determined to explore and photo-document the cave in spite of the conditions. We gingerly moved through the narrow passages connecting the chambers, either upright or by crouching. The cave is mostly devoid of decoration, however, we were pleased to find two large limestone columns – one of which was rather impressive with surrounding flowstone. We also discovered an incredibly large mound of guano taller than us – reminiscent of the guano mound in the Planet Earth television series. As tough as this trip was, all caves deserve to be explored, regardless of the conditions one may encounter. We accomplished the objective, and now have a clear understanding of the nature of this cave.

3. Conclusion

Over a period of six years, with four expeditions to Armenia in 2007, 2010, 2011, and 2013, we explored and photo-documented a number of natural and man-made caves – limestone, conglomerate, sandstone, and lava. We experienced the color and beauty of Armenia's natural caves, the intriguing man-made cave villages, and the reverent use of caves as chapels and churches. Caves have been an integral part of the landscape and culture of Armenia and the Armenians. Through these expeditions, one cannot help but gain a greater and enduring respect for this ancient land and its people.

Caves in Bolikhamsai Province, Laos

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Abstract

This is a report from cave expeditions in Bolikhamsai Province of Lao People's Democratic Republic 2016 and 2017. There is a large karst mountain range called Phou Louang (1,251m) in this area, and we took our expedition to around this mountain. As far as I know, the Bolikhamsai Province has not been surveyed thoroughly before, and the Phou Louang mountain range lies right next to the Khammouane Province which has the famous Tham Nam Root – Xe Bang Fai Cave. The limestone of Bolikhamsai is not massive like that of Khammouance, but we found 8 caves by interviewing the villagers in the expedition of 2016, and we were hoping to find more in 2017. Before we actually visited this area, we believed that the caves would be located in this mountain, but so far, most of the caves are found in the small mountains around the Phou Louang. The presentation is about some of the caves which we visited in 2016 and 2017. At the same time, we are interested in the stories about caves which are related to the people who live in the area. Some of the stories are real, and some are just made-up stories.

Keywords:

1. Introduction

The Bolikhamxay Province is located in the middle of the Lao People's Democratic Republic, near the capital city Vientiane (Fig. 1).

This province borders the Khammouan Province to the south, which is famous for the Tham Nam Root – Xe Bang Fai Cave, the longest cave system in Laos.

We visited Laksao, which is a small simple city, 30 km from the Vietnamese boarder. There is a large karst mountain range called Phou Louang (1,251m) in the north of the city (Fig. 2, Fig 3).

This karst mountain is very close from the karst area of Khammouan Province, so we expected to find the big caves.

Our first visit to Bolikhamxay was in 2016, 11 days from 28th March to 7th April with 3 members of the team. We considered this expedition as the research before the main expedition, so we didn't spend very long hours in each caves, and we just tried to find as many cave entrances as possible. We drove around the area to visit many villages and ask about the caves in their neighborhood. We got information about 8 possible caves in 2016. Despite our expectation, most of the caves are located in the small mountains around the big karst mountain, Phou Louang (Fig.4).

Three caves, A, B, and I are in the Phou Louang mountain, and we also could get information about a vertical cave on the top of Phou Louang, but the local authorities didn't allow us to climb the mountain. There is a small spring water near the caves A and B. This spring never dries up even in the dry season, that local people enjoy swimming every day. We tried to find where the water is coming from, and it is from between the rocks under the water. If we could get permission to climb this mountain, I'm sure we could find some vertical caves.

In 2016, we picked one cave to survey. It's called Tham Nam Dam Din (The "Water Diving Ground Cave" in Lao) (C in Figure 4). The entrance is at the bottom of a big sinkhole, and the river from the mountain goes in to the cave. We wanted to find where this water goes.

Figure 1. Location map

Figure 2. Phou Louang Mountain range area

Figure 3. Phou Louang Limestone Range

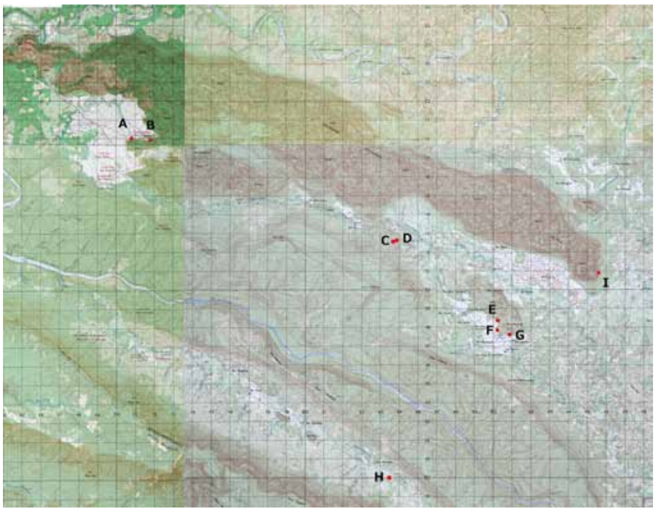

Figure 4. Location of Caves in P Phou Louang region

We had 3 days left before our flight, and we surveyed 2.3 km, but the cave still continues (Fig. 5). We visited this cave again in 2017 to continue our survey, but we couldn't reach the point we finished survey last year. There is a narrow passage at about 1 km from the entrance, and this place was filled with water in 2017. 2016 was very dry year, so the water level was lower than this year. We were just lucky to reach the deep end of this cave.

In 2018, we will prepare for passing through this sump to survey the rest of this cave.

The other cave, Tham Nomhair is covered with beautiful formation. It's in the Phou Louang mountain (A in Figure 4). Its entrance is very small, but there are some big and small rooms inside. We were surprised to see all the white formations.

Most of the caves in this area, people regularly goes inside so we usually saw many footprints. They visit caves to get bats or guano for their living. They love to eat bats, and guano is useful for making fertilizer or gunpowder. In the small room under the main passage, the guides from the village showed us a set of human bones with some vases and offerings (Fig 6).

According to the chief of the village, an Archaeologist from the Lao University studied the bones and he said the bones are more than 400 years old. Some people said a monk died here after long meditation, but no one knows the truth.

There is an old story about this cave.

Tham Nomhair, the name of this cave is the name of monster. "Nomhair" was the golden monster, and it came out from the cave every year to receive a sacrifice from the village. The sacrifice is a child chosen from the village. That year, a child living with his grandmother was chosen. This grandmother didn't want to give him up but it's not possible to refuse the decision.

The day "Nomhair" coming out from the cave, everyone from the village prepare a huge cooking pan and big fire. The chosen child was put in the cooking pan. While everyone is getting so crazy, this child tried to talk to his grandmother. She gets close to the child to listen to him. He was telling her, "Hey, you have a leech on your eye. You should remove that!",

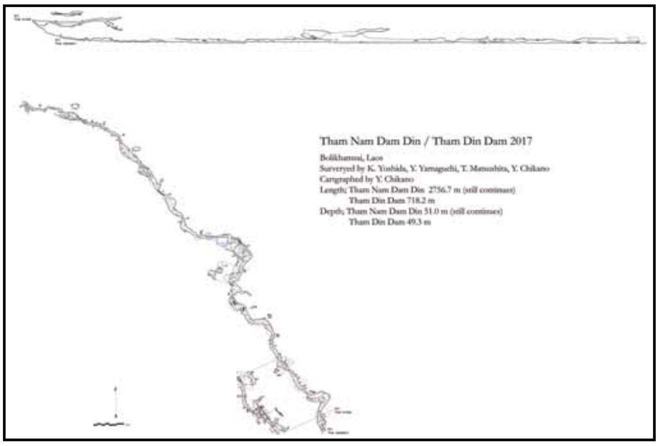

Figure 5. Map of Tham Nam Dam Din (The "Water Diving Ground Cave")

Figure 6. Artifacts in cave.

When a grandmother hears this, she was surprised that this child cares about her even when he is in a worse situation. She suddenly took a child from the cooking pan, and run away from the village.

They run to the other village, and they lived very happy life together.

The story itself is not so unusual, a child was helped by the monster, but it sounds funny when a grandmother finds her deep love to her grandson when he tells about a leech. I didn't see a leech while I was staying in Laos, but this story tells that it's very common creature in this area.

It's very interesting to learn about the culture from the stories with caves.

After we had very good experience in 2016, we visited Bolikhamxay again for survey and more expedition, but the situation was completely different in 2017. We could not get permission to visit caves from the authorities before our arrival, so we had to visit the local tourism office and spend many hours to wait for their answer. We stayed in Laos for 19 days, and we had to just wait for our permission for 9 days. According to our local guide, the chief officer of the ministry had changed, and he made a new rule about this kind of special tourism, but we could not understand what's actually going on. After all, we had only 10 days in Bolikhamxay this year, so we could not visit many places. We still are very interested in visiting the caves in Bolikhamxay next year, but I think I need to prepare very carefully for getting permission.

Acknowledgement

I would like to express my deepest appreciation to all those who supported our expedition.

Mr. Sitthasone Kangnavong a.k.a. Toh; the best guide and friend of us all who helped with big smile, Dr. Klaus Schwettmann who helped us from his office of the Green Discovery Laos, Mr. Thongkhoon Sayalath and Mr. Inthy "the President" of the GDL. Mr. Chang; an officer of Bolikhamxay tourism information office, Mr. Keo; a chief of the village and Mr. Xay; an officer of Tourism Police in Paksan. I also thank all cavers who had lots of experience in the South East Asia, and never hesitated to give us the knowledge. Dr. Charles Ghommidh who recommended us to try Bolikhamxay, Mr. D Joerg who always cares about us with long time experiences. Mr. Terry Bolger gave us information about caves in Bolikhamxay.

(Abstract) **Paraíso Cave: a remarkable limestone cave system in the Brazilian Amazon**

Leda de Almeida Zogbi, Janice Muriel-Cunha, Augusto Sarreiro Auler, Francisco William da Cruz, Aecio Rodrigo Motta

Abstract

Paraíso (Paradise) cave is located in western state of Pará, at the basin of the Tapajos river, one of the major tributaries of the Amazon. This outstanding limestone cave with an average internal temperature of 28°C develops in anastomotic passages, some of them containing streams. Since 2004 cave mapping has revealed 2,800 m of cave passages, presently the longest known cave in the Brazilian Amazon. High quality calcite in speleothems has provided invaluable information about paleoclimate in the Amazon. A high resolution oxygen isotope profile dated by U-series techniques resulted in a record of the last 45,000 years. It was demonstrated that precipitation in this region was substantially low in the late glacial period, while it became noticeably abundant during the mid-Holocene. These conclusions are extremely important and will provide valuable input for studies related to tropical precipitation response to anthropogenic warming. Paraíso cave is, so far, the only cave in the Brazilian Amazon where this type of work has been carried out. The biodiversity of Paraíso cave also challenges the biological conservation - occurrences have been reported for invertebrates and vertebrates, with new species of opiliones from the genus Guerrobunus as the first register for the family Phalangodidae in South America and a new report of a troglobitic species for Amazon caves. The catfish Rhamdia poeyi (Heptapteridae), very rare in scientific collections, seems to be the first record for the Siluriformes order at an Amazonian cave. Marine fossils from Carboniferous for the Cnidaria and Brachiopods groups were also registered from cave walls. Given the length of the cave - which continues to expand – it is clear that Paraíso Cave holds great potential for exploration and scientific work. All these new discoveries should estimulated the conservation of Paraíso cave and very recently we suggested this remarkable Amazon limestone cave system to be granted the status of an official conservation unit by the Brazilian government.

(Abstract) **"Lights in the Darkness" Project captures images of the most beautiful caves in Brazil.**

Leda de Almeida Zogbi, Allan Silas Calux, Annie Guiraud, Philippe Crochet, Mirjam Widmer, Kevin Downey

Affiliation: *TBA*

Abstract

During the 3rd international meeting of cave photographers during in July 2016 in Turkey, each night there was a different slide show. 21 cave photographers from several countries were there. One evening, a presentation about Brazilian caves was well received. Some photographers were highly motivated and started making plans for coming to Brazil to photograph these caves with care at a standard of high quality. From this enthusiasm a project took form and eventually incorporated three main products: a book, videos of the making of the expedition and an itinerant exhibition. The project was proposed to the Ministry of culture in Brazil, under a law to encourage culture. The expedition took place in July and August 2016 and was attended by four foreign photographers: Kevin Downey (USA), Philippe Crochet (France), Michel Renda (France) and Mirjam Widmer (Switzerland) and four Brazilian photographers: Ataliba Coelho, Daniel Menin, Marcelo Andrê and Ricardo Martinelli, plus the assistants and the organizing team, a total of 17 people. The route of 5,500 km - of which 1,000 was on dirt roads - crossed 4 Brazilian states: São Paulo, Minas Gerais, Goiás and Bahia. 30 beautiful caves were visited and carefully photographed. Among them, we highlight "Caverna do Diabo" (Devil's Cave), in São Paulo state, with a 12-hour crossing along the Roncador River, with several stretches of swimming to reach the dry and more ornate halls of the cave; "Lapa do Janelão" (Big Window Cave), in Minas Gerais state, where the main conduit, cut by the Peruaçu River is more than 100 m high and is illuminated in places by skylights that allow small forests to grow in the cave; São Matheus Cave in Goiás state, an extremely ornate cave containing spectacular helictites and in Bahia state, Toca da Boa Vista, (the largest cave in Brazil currently with 111 km of development) a hypogenic cave, especially notable for the textures and colorations of the rock, which charmed all the photographers. The relationships between the members of the expedition were fantastic, and we decided that this would be only the first edition of this project. We soon hope to organize another expedition to different regions and caves: there are still many caves to be photographed in Brazil.

Caving and Cave Exploration in Pakistan

Durrani, Hayatullah Khan [1,2], Brooks, Simon James [3]

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Abstract

Pakistan's rich and varied culture; sometimes-sensitive geo-political situation and variable infrastructure can make the search for caves within its extensive areas of limestone a challenging experience. With regular systematic cave exploration only taking place from 1990 onwards and most recently in April/May 2006 and 2010. The 2006 PAK-UK joint Expedition saw a total of 14 caves explored and surveyed to yield 531m of cave passage that took the total number of surveyed caves in Pakistan to 127 with a combined passage length of 6,230m. This lecture gives an overview of the karst and caves in Pakistan and describes the exploration that has taken place within this fine country from 1990 to 2013.

Keywords: Caves, Exploration, Karst, Pakistan.

1. Introduction.

Pakistan's rich and varied culture, sometimes-sensitive geo-political situation and variable infrastructure can make the search for caves within its extensive areas of limestone a challenging experience.

Pakistan, covering an area of 803,944 sq. kms, stretches from the Arabian Sea up to the high mountains of Central Asia. Much of the country is mountainous with the mountain belt stretching from the Karakorum Range in the north to the Sulaman Range in the south/south west of the country. Within this long chain of mountains are some significant areas of limestone and karst that ranges from Triassic through to Eocene in age. In the Karakorum Range in the very north of the country, between the villages of Passu and Soust, very hard and highly marbleized limestone have yielded some small caves, seldom more than a few tens of meters in length. The Chitral District also in the north has limestone but only a few very small caves. Immediately north of Islamabad are the limestone Margella Hills in which just over a dozen small single chamber caves have been found whilst to the north of Islamabad, between Muree and Abbottabad, is a large block of limestone that also contains some small caves.

To the north and south of Peshawar lie the tribal areas of Karran and Waziristan, both of which contain extensive tracts of limestone and some caves. Small caves have been recorded in the Khyber limestone that form that walls infamous Khyber Pass. The largest areas of limestone and karst are found in the semi-arid state of Balochistan. This comprises of limestone surrounding the former hill station of Zairat, mountainous limestone's surrounding the provincial capital of Quetta and the limestone's of the Kalat Plateau further to the south. It is here the largest and deepest caves are to be found. Pir Ghaib Gharra situated in the Bolan pass being the longest with 1270m of passage and Kach Gharra near to Zairat with a passage length of 353m and a depth of –127m. The latters elevation at over 2200m asl, near the top of limestone that is well in excess of 1000m thick give an indication of the depth potential that may exist in Pakistan.

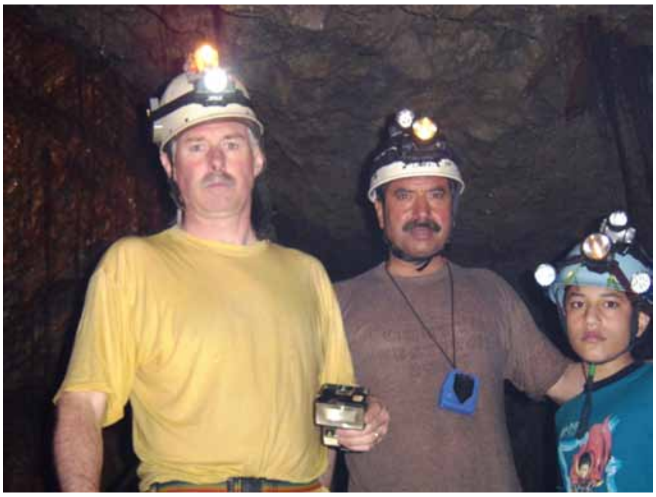

Figure 1. Hayat Durrani, Simon James Brooks and Mohammad Abubakar Durrani in Lamoor Cave Balochistan, Photo Ali Mohammad Khilji

2. Cave exploration 1990 to 2015.

Much of the systematic cave exploration in Pakistan has been conducted from 1990 onwards by arrival of British Groups (Orpheus Caving Club, Derbyshire, UK) working in Partnership with Pakistani Cavers and Mountaineers (Chiltan Adventurers Association) and (Pakistan Cave Research and Caving Federation) based in Quetta.

The first 1990 expedition was a reconnaissance that visited all the major karst areas in Pakistan and made some useful contacts with officials and groups in Pakistan. In the Karakorum Range in the very north of the country, between the villages of Passu and Sost, very hard and highly marbleised limestone have yielded some small caves, seldom more than a few tens of meters in length. In North West previous North West Frontier Province (NWFP) now changed to Khyber Pakhtune khwa (KPK) to the north of Peshawar the impressively sized Kashmir Ghara. In Balochistan the Pir Ghaib Ghara caves were located with the Pakistani Cavers and Mountaineers of CAAB / PCRCF and were explored for 90m and the exploration of Bartozai Ghara between Qillasaifulla and Zhob Districts begun.

Figure 2. Hayatullah Khan Durrani and Malik Rahim Babai in Pidati Maran Ghara, Johan, Baluchistan 1997 (Photo Simon James Brooks)

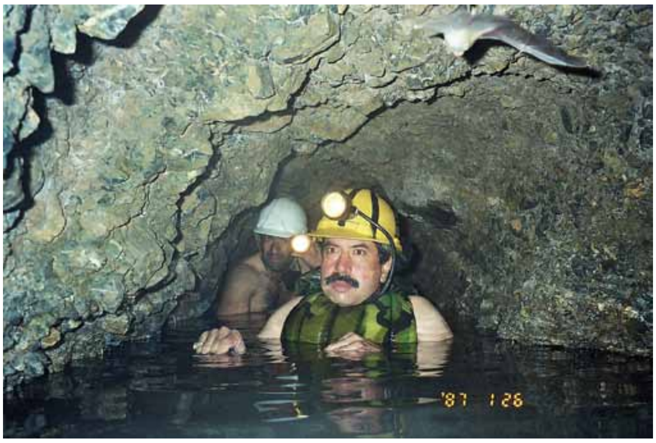

Figure 4. Hayat Durrani in Pakistan's first Water Cave Lamboor cave Balochistan (Photo Mohammad Abubakar Durrani).

Figure 3. Hayat Durrani & Ali Mohammad Khilji surveying the Spinkai Cave (Photo Imran Durrani)

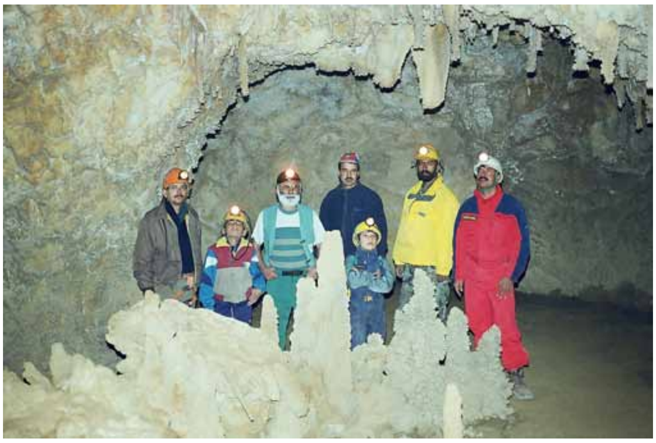

Figure 5. Hayat Durrani With group of Chiltan Adventurers Balochistan in (Pidati Marran Cave Johan 1996) (Photo Wali Mohammad Acahkzai)

This was followed by another expedition in 1991 when a small group of three British Cavers again visited on the official invitation of local Pakistani Cavers / Mountaineers from the

Quetta based Chiltan Adventurers Association and PCRCF along with good contacts in the Tribal Area's of Balochistan in Western Pakistan. In North West Frontier Province now (Khyber Pakhtune Khwa) several caves were explored in the Khyber Pass Area. In the Margella Hills to the North of Islamabad Mohra Muradu Cave was explored for 148m. In Balochistan Pir Ghaib Ghara was extended from 90m to 250m, several small caves were explored in the Ziarat Area and Bartozai Ghar explored for 250m.

November 1994 saw a small team of three British cavers return to Balochistan and the Margella Hills to the North of Islamabad. These early expeditions had identified the main caving areas, which between them had yielded some 2.2 km's of cave passage divide between 43 separate caves. Significant discoveries in Balochistan on this trip the extension of Pir Ghaib Ghara No 1 its previous 1991 surveyed length of m to 512m and the exploration of Bartozai Ghara to 330m in length. Whilst in the Margella Hills several small single chamber caves were explored none of which were more than 100m in length.

October/November 1997 three British and one German caver joined forces with members of the Quetta (Pakistan) based Chiltan Adventurers Association as part of the 5th Pakistan Joint Mountaineering and Cave Exploration Expedition. Over a three week period 30 new caves were explored and Pakistan's longest cave (Pir Ghaib Ghara No 1) was extended from its previous 1994 surveyed length of 512m to a significantly longer 1270m. This has firmly established it a both Pakistan's longest cave and the first Pakistan cave to exceed 1 km in length.

November 2000 a team of five cavers from the UK (mostly from the Orpheus Caving Club, Derbyshire) joined with members of the Pakistan based Chiltan Adventures Association (Balochistan) and Pakistan Cave Research and Caving Federation to participate in what was described as the '7th Pak-Britain Mountaineering and Cave Exploration Expedition 2000' during which the expedition explored over 20 new caves in the mountains of the tribal areas of Balochistan (Western Pakistan). Over the three weeks of the expedition over 1.7km's of new passage was explored and surveyed. Significant finds of the expedition included the impressive Murghul Ghul Gharra (Cave of the Bats Shit) located in the Harnai District that with a large chamber measuring 40m wide by 90m long and 580m of surveyed passage became Pakistan's second longest cave. Other significant finds included Kach Gharra (Kach Cave) located on the Peil Ghar Mountain (Elephant Mountain) that contained a 35m entrance pitch and an impressive 70m second pitch. With 350m of passage and a depth of 127m it is Pakistan's deepest cave to date. In October

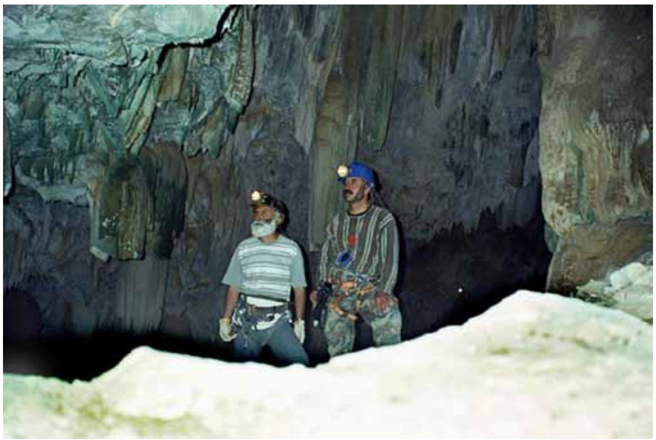

Figure 6. Hayat Durrani & Malik Rahim Baabai in Mughall Saaw Cave Harnai (Photo Simon James Brooks)

Figure 7. Hayat Durrani in Seaizgai Mount Cave Window (Photo: Simon James Brooks)

2000 the Pakistan Cave Research Association was formed to further cave exploration and research in Pakistan. Based in Quetta this organisation has very close links with the department of Geology at the University of Balochistan and Geological Survey of Pakistan also based in Quetta.

The most recent expedition in April/May 2006 saw a total of 14 caves explored and surveyed to yield 531m of cave passage. Significant finds on this visit included Lamboor Cave situated in the Aghbaragh Mountains to the west of Quetta that is truly unique in Pakistan being the only known active resurgence

Figure 8. Pak-Britain Joint Caving Expedition Gaazk Qalat Pakistan 1997. (Photo: Mohammad Aslam kassi)

cave that has been found to date. Although only having 48m of passage the cave begins as a chest deep canal that opens into a chamber containing a waterslide and a short section of vadose streamway. North of the town of Sharigh that lies on the Southern side of the Ziarat (Khalifat) Mountain range two small dry caves were explored, Ghwa Ghara (Cow Cave) at 50m in length and Sharigh Ghara (Sharigh Cave) at 34m. At a location to the North of Sharigh two more caves were explored, Killi Parri Ghara (Cave) at 94m in length of passage and many with fine formations and a second cave, Farishta Wazzar Ghara (Angles Wing Cave) began with an 11m pitch and again had many fine formations, one of which provided inspiration for the caves name. In the Loralia Area six small caves were explored in the remote Draggi valley whilst near to Loralia itself Pathan Coat Ghara (Cave), AKA Shipana Ghara (Shepherds Cave) proved to be somewhat larger with 87m of passage an impressive entrance and a good sized chamber. On the summit of the impressive Siygazi Ghar (Siygazi Mountain) Siygazi Mountain Siygazi Pot was explored and surveyed to yield 102m of passage. At 2,470m altitude this is the highest known cave in Balochistan to date.

3. Discussion

To date there are 129 recorded caves in Pakistan with a combined passage length of 6,230m. The sometimes-sensitive geo-political situation and variable infrastructure will continue to make the search for caves within its extensive areas of limestone a challenging experience. However the positive collaboration that has been formed between the Orpheus Caving Club (UK) and the Pakistan based Chiltan Adventurers Association (Balochistan) and various government agencies is likely to lead to more discoveries and a better understanding of the Pakistan Karst and Caves.

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British Caving Association.

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Table 1. Pakistan Longest and Deepest Caves – December 2015.

Longest

	Cave Name	Location/State	Surveyed length
1.	Pir Ghaib Ghara	Balochistan	1270m
2.	Murghul Ghul Ghara	Balochistan	580m
3.	Kach Ghara	Balochistan	353m
4.	Bartozai Ghara	Balochistan	330m
5	Mohra Muradu Cave	K.Pashtunkhwa.	148m

Deepest,

	Cave Name	Location/State	Surveyed Depth
1.	Kach Ghara	Balochistan	-127m
2.	Maraan Ghar Ghara	Balochistan	-52.2
3.	Siyazgi Cave	Balochistan	-48.9m
4.	Shabaz Sah Ghara	Balochistan	-33m
5.	Thaan Ghara	Balochistan	-32.2

Recent progress in Polish cave exploration projects in Northern Limestone Alps

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Abstract

Cave exploration in the Austrian alps is a flagship activity of the Polish caving community. Currently, five major long-term projects receive financial and organisational support from the Polish Mountaineering Association. Although the projects are led by particular speleological associations from Kraków, Wrocław, Żagań, Sopot and Poznań, expedition participants recruit from a majority of Poland's 28 caving clubs. Between 2012 and 2016, every summer at least four expeditions took place, resulting in discovery and mapping of more than 25 kilometers of caves in Hagengebirge, Hoher Göll, Tennengebirge, Leoganger Steinberge and Kitzsteinhorn mountains. Polish exploration of these massifs has in fact a much longer history, the most prominent discoveries taking place in the Lamprechtsofen cave system (1632 m denivelation), Hochschartehöhlensystem (1285 m deep), Interessante Höhle (19 km long, 639 m deep), Jägerbrunntrog-Höhlensystem (28 km long, 1078 m deep), Jack Daniel's Cave (10 km long) and Feichtnerschacht (1145 m deep).

Keywords: Northern Limestone Alps, Northern Calcareous Alps, caves of Salzburg, Polish cavers

1. Introduction

The Polish Western Tatra mountains, hosting the most important karst area in Poland, have a surface are of merely 100 square km. In fact, only a minor fraction of this area contains karstic rock outcrops. Although new discoveries are still being made, these mountains are well explored, with over 133 kilometers of cave passages and 857 entrances known as of 2015 (Nowak 2015). The longest and at the same time deepest cave in Polish Tatras – the Wielka Sniezna Cave System – is 824 m deep and 23,8 km long (Novak 2015). Meanwhile, caves outside of the Tatras caves are less than than 4,1 km and no deeper than 113 m, with only singular caves nearing these thresholds. In light of these figures, it is no wonder that the Polish caving community, estimated to be more than 1 000 strong, is highly involved in exploration of foreign caves.

Due to alpine nature of the above mentioned caves, Poland's most important karst area, Polish cavers are accustomed to cold and deep caves featuring a significant amount of SRT ropework as well as other difficulties and requiring a few hours of mountain hikes first to actually reach a cave entrance and start caving.

Between 2012 and 2016, Polish Mountaineering Association distributed approx. 25 000 EUR annualy in financial grants to cover 20 – 40% of costs of expeditions to explore and map previously unknown caves abroad. This funding was directed to regular expeditions going to Leoganger Steinberge (Austria), Prokletije (Montenegro), Hoher Göll (Austria), Hagengebirge (Austria), Arabika and Bzyb (Abkhazia), Picos de Europa (Spain), Valbona Valley (Albania), Tennengebirge (Austria), Kanin (Slovenia), Western Taurus (Turkey) and Daluo Shanmai (China), as well as a few singular cave diving projects[1].

As clearly seen, Austria is the country that repeats most often on the list and it is not merely a coincidence. Northern Limestone Alps or Northern Calcareous Alps, a vast conglomeration of soluble massifs located in Austria and Germany, closely

Figure 1. The big picture: Northern Limestone Alps (pink) within the Alps.

resembles the Polish Tatras. The underground of these areas is still far from being thoroughly explored. At the same time, Austrian county-level governments offer very clear terms of cooperation with cavers, requiring mainly the observation of the nature conservation rules and producing cave maps and descriptions in German in exchange for cave exploration permits. With very friendly attitude of local caving clubs towards Polish cavers and approximately 8 hours of driving separating cities in Southern Poland from Salzburg, it is no wonder going to one of the annual Polish expeditions in Austria is a natural step for many cavers from Poland after completing an elementary caving training in the Tatras.

Table 1. List of Polish expeditions to Austria officially supported by Polish Mountaineering Association between 2012 and 2016 (source: PMA's website, http://pza.org.pl).

Mountain group	Manpower and duration			
	2012	**2013**	**2015**	**2016**
Hoher Göll	9 2 weeks	11 3 weeks	9 3 weeks	8 3 weeks
Hagengebirge	14 3 weeks	15 3 weeks	18 4 weeks	23 4 weeks
Tennengebirge	20 3 weeks	11 3 weeks	25 3 weeks	13 3 weeks
Leoganger Steinberge	19 4 weeks	17 4 weeks	20 3 weeks	13 3 weeks
Kitzsteinhorn	16 3 weeks	17 3 weeks	---	---

1 According to information available in the news archives of http://pza.org.pl, the official website of Polish Mountaineering Association

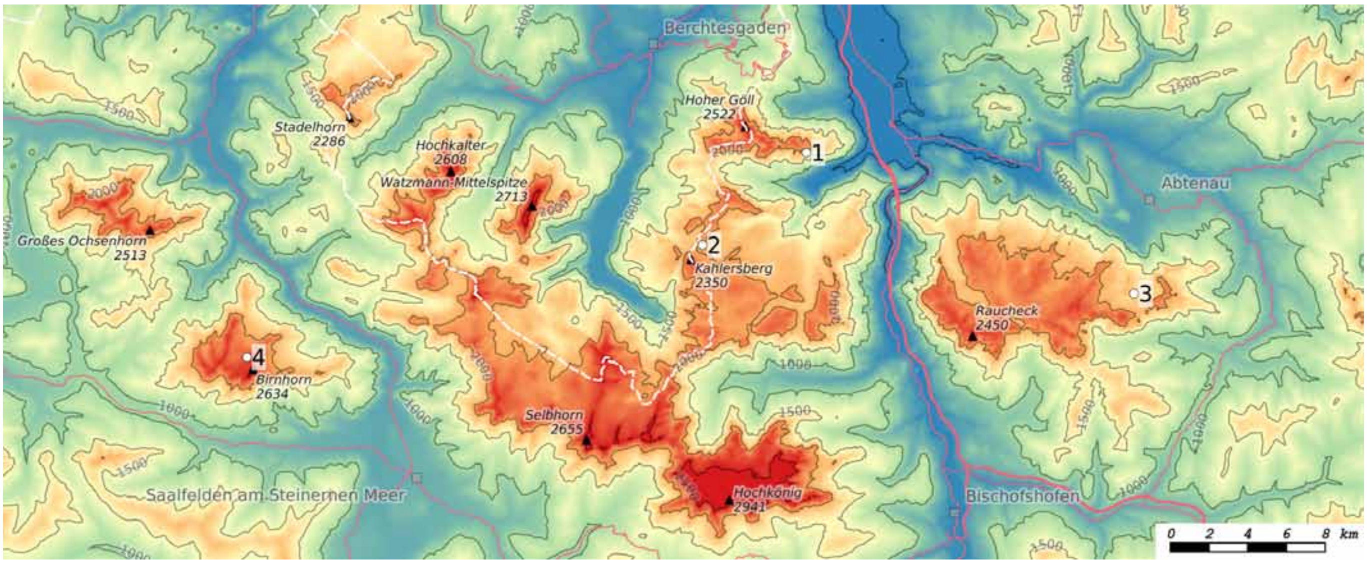

Figure 2. Locations of expedition camps: 1 – Hoher Göll, 2 – Hagengebirge, 3 – Tennengebirge, 4 – Leoganger Steinberge.

2. Flagship projects

Flagship, long term Polish projects in Austria are focused on a couple of mountain groups in the central part of Northern Limestone Alps (Figure 1). Table 1 lists expeditions that took place between 2012 and 2016. Although the Kitzsteinhorn area lies in the Central Eastern Alps, it is mentioned in this paper due to its proximity to other areas and in order to present a complete review of all Polish projects in Austria.

All of the caves in Northern Limestone Alps are being explored by Poles on two to four week long expeditions taking place during the summer months, ie. between June and September. Activities are carried out from expedition camps located at elevations between 1800 and 2300 m asl (Figure 2). Hagengebirge, Hoher Göll and Leoganger Steinberge use helicopter supplied tent camps, whereas the Tennengebirge team resides in a mountain refuges. In-cave camps are also frequently used.

Although the four limestone massifs exhibit vast differences in tectonics and hydrology, their lithology is similar, the most prominent caves developing in Dachsteinkalk (Klappacher and Knapczyk 1977, 1985; Klappacher and Mais 1979). Temperature under the ground is usually between -1 and 5 °C. With notable exceptions, caves are usually scarcely decorated and generally lack cave life other than bats.

The logistics and geology of Kitzsteinhorn is remarkably different. Expeditions take place in winter, March, and the camp is located in the basement of a ski resort facility at 2450 m asl. The caves have developed in a calcareous schist.

In case of all of the projects, assuring safety requires much more effort than documenting the discoveries. Nevertheless, survyeing is taken seriously. Recently, owing to consistent, nation-wide trainings taking place every spring, the Polish alpine projects follow the paperless surveying approach (Heeb 2008), which in cold vertical caves turns out to be much more efficient than traditional methods.

3. Hoher Göll

Hoher Göll is a small area of limestone karst, being essentially a single, narrow ridge, culminating in a 2522 m high peak. Nevertheless, its significance for Polish cavers cannot be overstated. It is the area where the Poles' presence in Austria began back in 1969, with a series of joint Austrian-Polish trips to explore Gruberhornhöhle, the then-deepest cave of Austria (Gorzelańczyk 2012).

Figure 3. Expedition camp on Hoher Göll; Hagengebirge is visible in the background (photo: M. Golicz)

Today, the area is known for remoteness and difficult access to cave entrances (Figure 3). Most of the caves on Hoher Göll begin vertically, with the largest ones exhibiting a consistent pattern of two distinct horizontal levels accessible through vertical shafts. The two most important caves that were explored recently are Unvollendeterschacht and Gamssteighöhle. The former actually connected with two different caves, resulting in a system 1285 m deep and 14.7 km long (Gorzelańczyk 2012). A possible connection with a fourth cave, resulting in a denivelation of 1394 m, is yet to be confirmed. The latter cave, Gamssteighöhle, had been originally explored by Austrian cavers back in the 1960's (Klappacher and Knapczyk 1985), but was abandoned in favour of more appealing discoveries in the nearby Gruberhornhöhle. In 2013 the Polish team got through a critical squeezy passage, finally arriving at a hori-

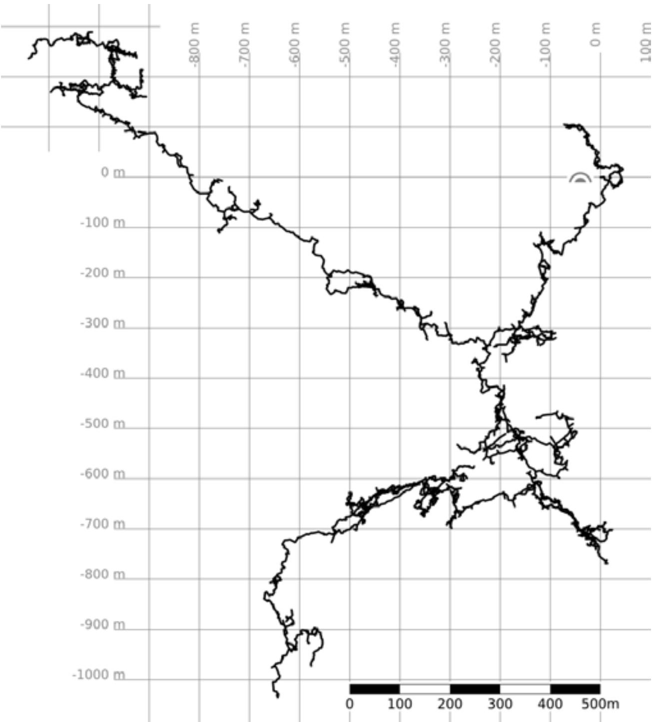

Figure 4. Polygon of the Interesting Cave on Hagengebirge (courtesy of D. Lubomski)

zontal level that branched into a couple of prospective leads that are still being followed and mapped.

4. Hagengebirge

The latest Polish caving project in Austria, operating since 2002, focuses on searching for caves in the northeastern part of the Hagengebirge mountains. In fact another Polish group had been working in a different part of Hagengebirge, however its activities ceased in 1988 (Paternoga 2011). The area is very difficult to navigate due to its karst plateau landscape extensively covered by dwarf pine. Thus, potential cave entrances are very hard to locate, in addition being usually very narrow.

The expedition is known for its effective management and as such attracts prominent Polish cavers. Its latest big discovery, Interessante Höhle (Wierzbowski 2015), is very demanding in terms of fitness and SRT proficiency. Even though its horizontal extent barely reaches 1,6 km, by alpine standards it is a vast horizontal maze (Figure 4). One of the open leads, reaching a depth of 639 m relative to the entrance, takes more than six hours to reach from the in-cave camp. In turn, a full day caving trip is needed to reach that camp from the surface. The cave is still far from being fully known, with many other leads branching from the main horizontal level.

5. Tennengebirge

Most of the caves in the eastern Tennengebirge mountains are vertical, with the largest ones featuring horizontal levels featuring spacious galleries. Many caves end suddenly at approx. 400 – 500 m below the plateau level due to a bed of poorly soluble limestone at 1500 – 1600 m asl.

Recent Polish expeditions in this area were mostly occupied by exploring Jack Daniel's cave, which was discovered in 2003

Figure 5. In Jack Daniel's cave of Tennengebirge (photo: R. Kondratowicz)

Figure 6. Surveying the CL-3 cave on Leoganger Steinberge (photo: M. Ciszewski)

by Jacek Wiśniowski and Daniel Oleksy (hence the name; Furtak and Kondratowicz 2013). Almost 3,3 km of passages were discovered and mapped between 2012 and 2016. The cave is notable for its rich decoration (Figure 5).

6. Leoganger Steinberge

The Polish project in Leoganger Steinberge hit worldwide news in 1998 when the 1632 m Lamprechtsofen system became, for a brief moment, the deepest cave of the world (Ciszewski 1998). The system, now boasting seven entrances, still remains the deepest known natural cave traverse on Earth. Interestingly, most of the system's denivelation was explored from its lowest entrance, though nowadays the project's strategy is to camp high up in the mountains and search for caves that could potentially connect from above. The latest entrance, Cave 240, was connected in 2015.

In recent years the expeditions focused on the Tropik-Viertel cave system and the CL3 cave (Figure 6). According to surveys, newly discovered parts of the latter are merely a few dozen meters away from Lamprechtsofen. Unfortunately, any further progress seems to require digging through a breakdown zone.

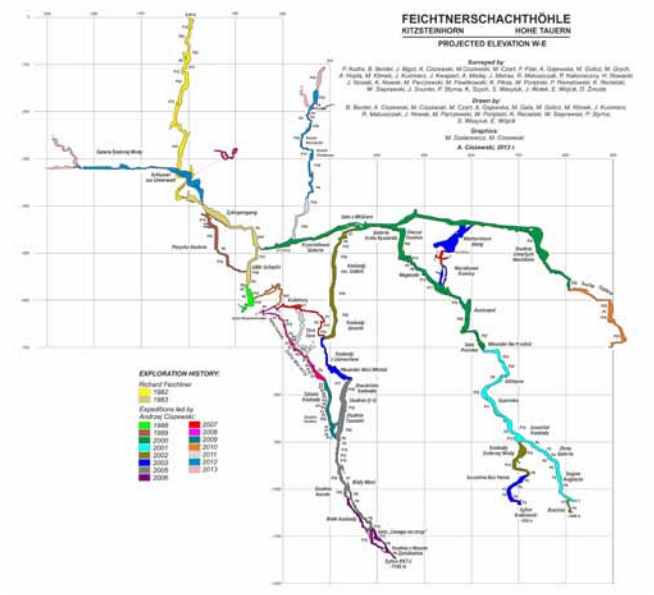

Figure 7. Projected elevation of Feichtnerschacht (courtesy of M. Ciszewski)

7. Kitzsteinhorn

The Kitzsteinhorn area is in fact not a part of Northern Limestone Alps, rather being located in the nearby High Tauern mountains, home to Austria's highest peak (Grossglockner). It is a geologically unique area, containing a 1145 m deep cave (Figure 7) that was developed in kalkglimmerschiefer (a specific kind of calcareous schist) rather than limestone (Audra 2001). Latest expeditions, in 2012 and 2013, involved climbing towards the surface from the in-cave camp at -450 m in hope of finding another entrance. The cave ends with a sump and thus reaching a greater depth is not very likely.

8. Summary

Polish cavers have been exploring and mapping the karst of Northern Limestone Alps for almost half a century. As clearly seen in Table 1 and Table 2, Polish projects steadily continue their contribution. This contribution is sustained through consequent exploration planning, possible through emphasis on surveying, as well as systematic, annual expeditions. The standardized cavers' training within Polish Mountaineering Association results in a few young cavers from Poland going to their first alpine expedition every year, which also contributes to the projects' stability by preventing generational gaps. As of writing this paper, subsequent expeditions to the four mentioned limestone massifs are being planned for July and August 2017.

Acknowledgements

Current information on particular projects was obtained directly from their leaders, namely Andrzej Ciszewski, Rajmund Kondratowicz and Marek Wierzbowski. The leaders collectively urged the author to acknowledge the enormous support all Polish expeditions receive from Austrian cavers and particularly from Landesverein für Höhlenkunde in Salzburg.

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Table 2. Most important caves explored by Polish caving expeditions to Austria between 2012 and 2016 (source: communication with expedition leaders)

Mountain group	Cave name	Length	Denivelation	Years explored
Hoher Göll	Hochschartehöhlensystem	14,7 km	1285 m	1994 – 2012
Hoher Göll	Gamssteighöhle	2,5 km	471 m	2013 – 2016
Hagengebirge	Interessante Höhle	19 km	639 m	2008 – 2016
Tennengebirge	JackDaniel's Cave	10,1 km	748 m	2003 – 2016
Tennengebirge	Snow-plug Cave	3,6 km	280 m	2000, 2015
Leoganger Steinberge	Lamprechtsofen-Höhlensystem	51 km	1632 m	1973 – 2016
Leoganger Steinberge	Tropik-Viertel Höhlensystem	5,4 km	780 m	2006 – 2012
Leoganger Steinberge	CL3 Cave	7,8 km	748 m	1997 – 2016
Kitzsteinhorn	Feichtnerschachthöhle	7,7 km	1145 m	1998 – 2013

New Findings In Underwater Exploration Of The Bjurälven Valley Caves

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Abstract

Bo Lenander, a member of the current expedition crew, discovered the entrance to the Dolinsjö cave in 1979. 2017 marks the 10th year of the winter expeditions to the Bjurälven valley, which is situated in the county of Jämtland far up in the Swedish North. Dolinsjö cave is the longest underwater cave in Sweden with its 2135 meters, and it is among the 120 longest underwater caves in the world. The cave explorers have made considerable progress since the last ICS conference in Brno in 2013, where the reported length was 700 meters. During the last four years, the cave has been extended considerably, and the end of the line is now located in the fifth sump. It currently takes approximately 3 hours of alternating diving and caving to reach the end of the line, and the explorers are facing a challenge of negotiating a complex boulder collapse at 18 meters of depth.

New equipment and methods for determining the position of the divers in the cave in relation to the surface have been developed, improving previous techniques. New transmitters and receivers are more reliable, accurate and compact. They also offer means of simple two-way communication with the surface. Advanced satellite positioning, combined with extensive post-processing of the data, allows for exact determination of the surface coordinates. The cave and the exploration effort has been documented thoroughly using still images and video. Two professional short movies were produced about Expedition Bjurälven, and one of them reached the finals in 2015 Banff International Film Festival in Canada. High-quality still images are taken during each expedition in order to let as many people as possible enjoy the discoveries in Bjurälven.

A lot of attention has been given to safety of the expedition members. The exposure during exploration dives is reaching the limit, where a simple mistake can lead to severe and tragic consequences. Sub-zero outside temperatures, water temperatures around zero degrees, lengthy exposures up to 8 hours, hazardous activities such as climbing in dry sections of the cave beyond the water-filled sumps, and the use of snowmobiles are all factors being taken into consideration during safety planning.

Keywords: cave diving, cave mapping, radiolocation, cave cxploration, cidemount

1. Exploration and mapping

Mapping of the Dolinsjö cave has been carried out since 2007 (Gorski et al. 2013). This has been done by different people using different techniques and different software, and the map has therefore grown inaccurate. An extensive re-mapping of large parts of the cave was carried out in 2016. The re-mapping was accomplished using digital compasses underwater built into Suunto diving computers and DistoX in the dry passages. The use of digital compasses, instead of analogue ones, improved the accuracy considerably by making the reading of the compass heading more accurate. In addition, all the mapping data was corrected by using fix points in the cave located from the surface using radiolocation and advanced satellite positioning. These techniques are described further in the next chapters.

A map of the cave can be seen in Figure 1, where water-filled sections (sumps) are marked in blue and air-filled passages in black. Sump 5 ends with massive and complicated rock collapse at approximately 18 meters of depth. An attempt to negotiate the collapse might be undertaken later. The end of the line is not far from an air-filled cave called Svenonius cave. There is still more than a kilometre of linear distance to the Bjurälven cave, where the water stream coming from the mountains across the Norwegian border disappears into

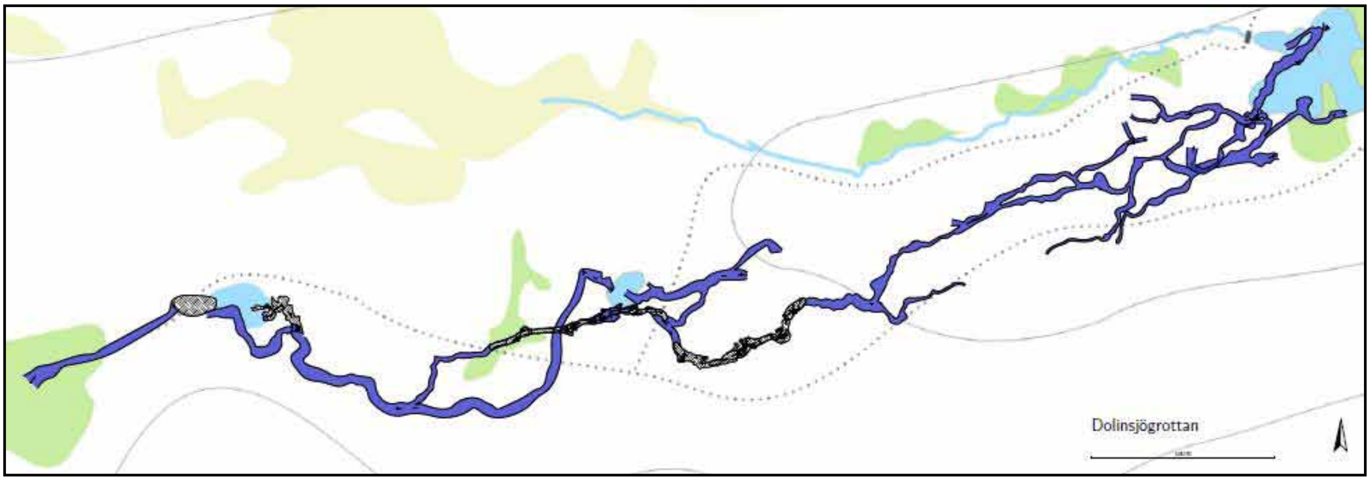

Figure 1. Map of the cave and surface map of the Bjurälven valley

the karst. However, existence of a continuous diveable cave system connecting the current end of the line to that point is less likely. This is due to the fact that the rest of the way towards the Bjurälven cave is underneath a deep valley called the Blind Valley. It was formed a long time ago as a huge collapse and hence there is a reason to believe that the cave underneath is fragmented by collapsed rocks into many small passages.

It takes approximately 3 hours to reach the end of the line. This time is spent diving through the water-filled passages and carrying scuba equipment between the sumps, see Figure 2 The total time required to conduct a dive to the end of the line can be 7-8 hours depending on the goal of the dive. The lengthy exposure to the cold water and air temperatures around 0 °C makes safety planning challenging. A cave diving physician with experience from trauma room joined the expedition in 2016, and the chapter 'Medical and risk perspective' in this paper contains the medical point of view on exploration under these conditions.

Until now 3D mapping of the cave was conducted mainly using a manual technique where a diver would measure the cave passages using a depth gauge and a measuring tape. The data would then be fed into software, e.g. Therion, which would generate a 3D image. This classical technique has several drawbacks. It is time-consuming, and there is a high potential of making a measurement error. During recent years, another technique called photogrammetry was attempted. A movie of the cave passages containing all the details can be turned into a series of 3D images using image processing software. The 3D images can then be used to calculate various parameters of the cave such as the distance and the dimensions of the passages. The first results have been encouraging and there is a hope that photogrammetry, combined with digital image processing, will replace the manual cave measuring in the future.

2. Video and photography

Documenting the exploration using still images and video might sometimes require a lot of effort, especially if high quality is the goal. However, such documentation contributes to promotion of the exploration effort as well as cave exploration in general. Two short movies were produced by a professional video crew in 2015 and 2016. Due to the costs, associated

Figure 2. Diver, carrying his scuba equipment between sumps of the Dolinsjö cave

with production of such movies, external sponsorship was required. The first movie ("Underground Movement", 2015) produced by the Swedish outdoor gear manufacturer Klättermusen has received almost 10,000 views on YouTube in one year. It was also selected for finals at the Banff International Film Festival in 2015. The second movie ("Signal Seeker", 2016) produced by the Finnish diving equipment manufacturer Suunto has received almost 5500 views on YouTube in three months.

3. Radiolocation

Accuracy of the cave mapping was improved further by correcting the mapping data gathered by divers through locating so-called fixed points in the cave from the surface. This technique is described in more detail in another paper (Lenander, 2017). A number of tags were bolted into the cave floor. Their position with respect to the cave map was noted. The tags were then located from the surface through radiolocation. The cave map, compiled in Therion, could then be adjusted using this data. Aspects of this technique is shown in Figures 3 – 4.

Radiolocation and depth measurement of fix points in the cave was done with the aid of a electromagnetic transmitter (M-16P and M16MK) and direction finding receiver (M-16R at 32 kHz). Divers carried transmitters to fix points in the cave, and the position of the fix points relative to the surface

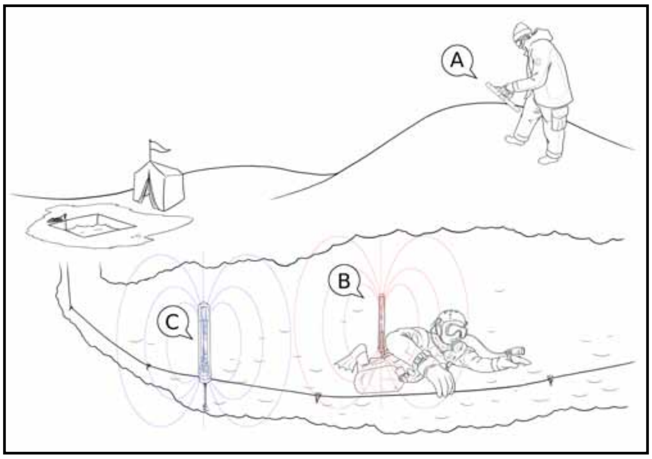

Figure 3. Direction finding receiver M-16R (A) and electromagnetic transmitters M16MK (B) and M-16P (C). Illustration by Per Lenander

Figure 4. Diver, equipped with an M-16MK marker (here attached to the rear D-ring) can be followed and identified from the surface. Photo by Janne Suhanen.

was determined using the receiver. One of the transmitters, the M-16P pinger, was equipped with settings that allowed divers to choose which pre-set message/signal to transmit. Additional functionality was added through enabling simple two-way communication, where it was possible to send a "fix point located" signal from the surface down to the pinger. This was achieved by turning on an array of light-emitting diodes mounted on the pinger by a signal from the surface.

Using radiolocation, it could be determined that the cave is located at a depth of 20-45 meter below the surface. The ground consists of marble at the location of the cave with a layer of gravel on top, originating from the end of the ice age.

One issue with the technique is that the magnetic field is very strong near the ends of the ferrite rod antenna inside the markers. An influence was noted on both a digital Suunto compass and an Apple iPad. It was necessary to reset both devices after they were placed close to the marker. Neither of the devices was damaged permanently.

4. Satellite positioning

Radiolocation of cave divers and surveying of fix points in the cave has been performed during every expedition since 2011. Using the radiolocation equipment, a relatively accurate point on the ground surface directly above a fixed point can be obtained. Also, the depth from the surface down to the fixed point can be estimated. In order to make a 3D and georeferenced cave map, the ground surface elevation, the depth of the cave and the X and Y coordinates for the point on the surface are required. For this purpose, the National Land Survey/SWEPOS kindly lent us both GNSS equipment (**G**lobal **N**avigation **S**ystem **S**atellite = GPS and GLONASS) and communication equipment with connection to the SWEPOS correction services during the expeditions in 2013, 2014 and 2015. Network RTK (**R**eal **T**ime **K**inematic) is a technology for accurate GNSS positioning in real time. The technique is based on the support system of fixed reference stations, such as SWEPOS. The so-called correction data is calculated at the SWEPOS command centre and sent to the user's GNSS equipment. The user can then get a position in the reference system SWEREF 99 with uncertainty at the centimetre level.

The equipment used during the expeditions consisted of a Leica Viva GS15 rover with built-in 3G modem on a 2.5-meter-high carbon fibre rod and a Leica CS10 field computer. Long-term measurements (at least 15 minutes at each site) utilizing the RINEX format (**R**eceiver **In**dependent **Ex**change format) are performed. This technique is very useful in areas with poor mobile coverage. The GNSS equipment borrowed directly from Leica Geosystems Sweden was then used to obtain data for the fix points on the surface obtained by radiolocation. The measurement information from the field computer was transferred nightly to an Excel file with X, Y and Z values in SWERREF 99 TM format. Depth value and time for the measurement were also included. GIS software ArcGIS® from Esri was used to visualize the points on an aerial photo of the area.

Data for six new fix points was obtained with the GNSS during the 2016 Expedition, which together with previously obtained points resulted in 21 different GNSS measured values along the Dolinsjö cave. Five weeks after the expedition, we received the post-processed GNSS data from the National Land Survey. The XYZ values of the points were measured/calculated with an accuracy of +/- 50 centimetres thanks to the correction of the data. The Swedish National Land Survey through Metria AB is planning to perform laser scanning (LiDAR) of the area in 2017. When the scanning is performed it will be possible to measure the depth of all dolines (sinkholes) using GIS and build a 3D surface model of the terrain above the cave.

Loan of advanced equipment from Leica Geosystems Sweden and post processing of data from the National Land Survey enabled us to achieve the desired accuracy in determining the position of the cave in relation to the ground surface. During 2016 this enabled us to achieve the best measurements so far. Half of the measurements are better than 1 centimetre in the XY-plane and better than 10 centimetres in the Z-direction (depth). Geo-referencing in three dimensions was able to be performed. Certain terrain features (deep valleys) made the data analysis complicated. It has been difficult to get so called fix solutions. Fix solutions can provide us good measures down to the cm-level. Code solutions provide lower accuracy values, at the dm-level up to the meter-level.

5. Medical and risk perspective

During a project with the size and complexity of Expedition Bjurälven there are always many risks to consider. A careful safety analysis of the entire expedition includes everything from the car trip up to the North to hygiene during meals. The main focus is on preventing accidents and injuries, but also on establishing plans in case of an accident. There are four main activities where the risk of injury or accident is high: cave diving, vehicle transport, snow mobile transport and dry caving. Long exposures to extremely cold water during diving, alternated with dry caving, are the special features of the diving during Expedition Bjurälven. The fact that a rescue mission has to be carried out in multiple dry and wet passages makes planning a rescue a tough challenge.

Some risks during diving are caused by technical problems such as failure of a breathing regulator due to freezing. Freezing of a diving regulator most often leads to a free flow, which can quickly deplete the supply of gas (Bantin, 2014). In Bjurälven, there have been recorded numerous cases where freezing of a diving regulator led to the opposite, namely a complete stop of the gas flow. This phenomenon was established to originate from the moisture in the breathing gas, which at very low temperatures can form ice plugs in the breathing hoses. This problem was solved through extra filtration and drying of air filled into the diving tanks. Another risk is puncturing a glove or a drysuit. Rapid loss of body temperature poses a considerable threat in the conditions the expedition operates in (Sterba, 1990). During the 2016 expedition, an incident where a diver ripped his dry glove inside the first dry passage happened. This event led to a rapid cooling of the diver, who was nonetheless able to exit the cave on his own, diving through some 450 meters of the first sump. On the surface, he could change to dry warm clothes and ingest hot food, which stabilized the situation. No additional measures were required. Decompression sickness, the risk most often associated with diving (Buzzacott, 2012) is less pronounced during the Bjurälven due to the relatively shallow passages and the small amount of nitrogen absorbed by the body during a typical dive.

One of the most important ways of preventing accidents and injuries is to make sure that everyone involved in the expedition has a sufficient level of training and knowledge for subarctic cave diving. It is also of the utmost importance that all the equipment is tuned in for this kind of diving (Cave Diving Group of Britain, 2005). This could involve, for example, tuning the breathing resistance in the regulators up so that the risk of freezing is minimized. Safety tanks are placed in the cave to decrease the risk of running out of breathing gas in a situation where the on-board breathing gas is lost. The dives in Bjurälven start from a hole in the ice. In order to make the start and end of each dive as safe as possible a special platform has been built and is installed in the hole. Divers can stand in waist-high water on the platform and adjust their equipment instead of floating on the surface. For safety we have a dive manager to keep track of the divers and their dive plans. There are also always safety divers that have their equipment ready in case someone in the cave requires assistance. In 2016, two-way communication was established between the first dry chamber and the base camp using a HeyPhone borrowed from the Norwegian Caving Federation. As the explored length of the cave grows, so does the length of each dive. Two-way communication is becoming increasingly important.

In the base camp there is a heated tent and hot beverages and food. There are also first-aid kits with equipment to deal with minor injuries as well as moderate trauma. To enhance safety of the divers in case of emergency in any of the dry parts of the cave, a watertight emergency canister is now placed in the first dry passage during the expedition. This canister contains dry clothes, spares, heating devices and painkillers. Using this, an injured diver might be able to improve his chances of safely getting to the surface without outside assistance. Careful preparations and drills contribute to increasing the safety of the expedition. Particularly emergency drills, e.g. transporting an injured diver inside dry and water-filled cave passages and rescue from the ice hole, are important.

Acknowledgements

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Sump Diving Exploration In Mammoth Cave, Jenolan Caves, Nsw Blue Mountains

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Abstract

The Australian Jenolan Caves have a geologically dynamic and complex history. Cave exploration in this area began in the early 1800s and has been almost constant since the 1950s, including underwater investigation. These subterranean passages present unique challenges that require unusual and creative cave diving techniques and equipment configurations. The caves have revealed surprising finds, often resulting in additional questions and mysteries. This paper will focus on past and present cave exploration in Mammoth Cave, Jenolan Caves, and comment on various key facilitators for success in these pursuits.

Keywords: Cave Diving, Sump Diving, Exploration, Logistics, Safety, Rescue

1. Introduction

The Jenolan Caves are located in the New South Wales (NSW) Blue Mountains, approximately 900m above sea level. The caves lie within a valley terrain that is littered with gum trees and active with native animals. Jenolan has been internationally renowned for cave tourism ever since a cluster of caves were found and developed for visitors in 1838.

The Jenolan Caves were known of for many thousands of years before, reported to be called a name similar to 'Binoomea' in the local indigenous Gundungurra language which referred to a prominent mountain peak, and possibly meant high and/or dark places (Smith 2014). Early reports indicate that Aboriginal people travelled great distances across the rugged mountains to visit the bright blue pools of water within what is now the tourist cave complex (Mathews 1908, Trickett 1899). The caves here have been consistently explored by Australian caving clubs such as the Sydney University Speleological Society (SUSS) for nearly 70 years.

The caves lie within a narrow band of limestone around 3km long which has been folded and fractured, now resting in an almost vertical orientation. The caves here are typically maze type passages that descend through series of low crawls and squeezes with multiple larger collapse chambers, many spectacularly decorated with formation. The aptly named 'Mammoth' cave is one that still holds mysteries despite decades of exploration. Its current map, created by SUSS, shows over 9km of surveyed passages, however much more is believed to exist. In the past few years exploration cavers have successfully focused on the caves' submerged passages, with some surprising finds.

2. A Brief History of Cave Diving Exploration at Jenolan Caves

The first documented cave dives in Australia occurred within the Jenolan tourist caves in 1952, followed by a dive attempt of 'Lower River' in Mammoth Cave the following year. This coincided with the earliest American cave dives, and occurred some 75 years after the earlier attempts by the French (Horne 2007, "They Swam in," 1953). These early dives were conducted by University of Sydney student cavers who were using homemade equipment including modified car headlights, a bellows pump, and thick woolen clothing for warmth. Dive training was almost non-existent at the time and financially out of reach for student cavers. Diving techniques used were rudimentary, for example, they wore heavy boots and walked along the silty floor on the bottom of the dive passage. These initial efforts at underwater exploration were largely 'trial and error', but over the course of six years the group was able to bypass several shallow sumps each with large walk-along streamway passage in between. Having identified communication with the divers as a problem they installed a telephone line between sumps which they successfully used to communicate with dry cavers awaiting their return ("They Swam in," 1953).

Further Jenolan diving attempts were made again in 1979 to 1981 by a small group of adventurous and experienced cave divers from South Australia (SA). By this time there was an active cave diving scene in Mount Gambier SA and on the Nullarbor in Western Australia. In response to a number of safety incidents and fatalities a group, named the Cave Diving Association of Australia (CDAA), had formed there six years earlier in order to introduce a structure of standards to increase safety. There were no formal cave diving courses at this time, but divers were able to learn via mentoring, club, or dive shop training, followed by an independent assessment by CDAA Examiners. Diving equipment had become more readily commercially available and affordable, and divers had been gaining cave diving experience by exploring locations all over Australia.

CDAA founding member Ian Lewis and NSW cave diver Ron Alum led these Jenolan expeditions and over the course of several trips the group rediscovered the already explored submerged passages, then extended their underwater exploration into new territory. This included initial dives in two pools of water in Mammoth Cave; Ice Pick Lake and Slug Lake. In Ice Pick Lake the divers found around 70m of narrow rift passage and in Slug Lake they descended steeply down for about 70m to a depth of almost -30m (Lewis 1981). Diving equipment technology had improved dramatically at this stage but divers were largely using unmodified ocean diving equipment and techniques which are now regarded as largely unsuitable for these harsh cave environments. These Jenolan divers were using one large scuba cylinder of air worn on their back which often limited advancement due to the diver's inability to fit through small or flat passages. In 1988 the hypothesised source of the Jenolan underground river was confirmed by dye tracing, as well as its path through Mammoth Cave (Kiernan 1988). The river resurgence into the Blue Lake, famed for its colbalticity, was spectacularly confirmed when the fluorescein used temporarily recolored the lake green.

Another period of diving in the 1990s saw the exploration and mapping of river passage under the tourist cave system by cavers adopting British style 'sump diving' techniques. Around this time the cave managers insisted that all cave divers hold appropriate cave diving certifications from recognised training agencies, leading many divers to seek formal cave diving training for the first time despite having dived the caves for many years. Concurrently, a group of trained 'technical divers' were beginning to explore deeper cave passages within Mammoth Cave. This included the early use of decompression tables for dive planning, and mixed gases which allowed deeper or longer dives with less decompression and reduced narcosis. The use of mixed gasses was controversial for many in the diving industry at the time (even referred to as devil gas) but it is now mainstream and considered best practice from a safety perspective. Both groups (sump and technical divers) were using redundant air sources which were mounted on the sides and removable, to allow movement through a variety of cave passage size and shapes.

The key achievement at this time was diver Ron Allum reaching a depth of -96m diving in Slug Lake. Allum was supported by commercial diver Rod Obrien who had received his cave diving training from Ian Lewis. Divers returned here for several trips in the early 2000s where they searched for leads in shallower passages and began mapping these immense chambers, however no one has returned to Allum's depth or beyond.

Another impressive achievement was the initial exploration of Lower River in Mammoth Cave. Reaching the underground river involves around 1-2 hours of climbing, crawling, squeezing, and climbing, before eventually reaching the impressive sight of an entire river bursting with force from a hole in the wall the size of a car tyre. The water emerging from this hole runs along the surface for a short distance before disappearing again into an unexplored underground passage. This location is exciting for divers as this is the first time this river is seen after it flows into a surface sink in gravel nearly two kilometers away. Between the two locations there are multiple large caves, most of which take immense amounts of water in flood, but no passage to the underground river has ever been found. Diving upstream from this point has the potential to unlock a lifetime's worth of new cave exploration. Dye tracing shows that this same river flows into Slug Lake, and then appears in Spider Cave, before flowing through Imperial Cave and eventually reaching the Blue Lake on the surface (Kiernan 1988).

The size of the passage in the upstream Lower River dive is very small and the force of the flow is extremely powerful. Many early attempts to dive it resulted in incidents including backed up water pressure causing rocks to hit the divers underwater, and divers facing difficult backwards retreats where they were unable to turn around upon exit. In each instance exploration was thwarted by water pressure.

3. Summary of Recent Cave Diving Exploration and Discovery in Mammoth Cave

In 2014, these diving exploration efforts were resumed with a systematic approach. A list of dives was compiled with the divers uniting to methodically explore each of them one-by-one. This focused approach proved successful with new passage explored and mapped in nearly every instance of exploration. Key discoveries were made throughout Mammoth Cave including 1. Lower River, 2. Ice Pick Lake, and 3. Slug Lake.

Lower River is perhaps the most promising dive lead at Jenolan as successful exploration upstream has the potential to unlock many kilometers of virgin cave passage. In recent drought conditions the flow of Lower River reduced to potential historic lows reducing the water pressure flowing from the dive site entry. SUSS divers were able to map the dive passage more than tripling the explored length. The passage remains very small for its entire length, requiring divers to edge in feet first dragging their gear behind them. It was hoped that the passage would ascend into dry cave after a short distance. Curiously, the cave continues downwards via a series of vertical shafts separated by horizontal flatteners. At a depth of -34m this intersected a downwards sloping flattener with an encrusted cobble floor. This floor was dug over a series of decompression dives, with divers reaching -45m at which point the floor became a steep sandbank. Progress was slowed as multiple cylinders containing various gas mixes needed to be staged through the cave. The divers also required larger cylinders to dive to these depths which made both the dive and carrying gear to and from the dive site more arduous. Exploration was eventually halted by the unstable sand bank which has the potential to pin a diver to the roof (in a reverse buried alive scenario). The passage was seen to continue to around -55m. A small stalactite formation was found underwater confirming that dry cave is present further upstream of this dive. The small size of the passage indicates that the original river pathway was blocked and this may be much younger passage, possibly formed by water forcing its way up along a crystal vein or existing fracture.

Ice Pick Lake is another exciting dive location as its passage is heading off the map of known cave and deep into the hillside. Access to the dive site is arduous as it involves multiple obstacles including many difficult climbs and some confronting vertical squeezes. The dive itself is along a keyhole shaped section of a tall and narrow rift. The bubbles from each exhalation travel around 10m up this rift dislodging a large amount of silt that makes visibility poor. The dive passage was explored to a previously known air chamber, with new passage discovered via a difficult side passage ending in a second air chamber. Climbing attempts were made above each air chamber revealing a continuation of the rift passage up at least another 15-20m in dry cave. The dive passage funnels to a tight hole which is silt filled and too confronting for most divers to contemplate. Some have attempted this underwater squeeze but no one has passed it. This exploration is not yet complete as climbing the dry cave above the airbells may lead to dry passage that bypasses the current end of the underwater passage.

Slug Lake captured the attention of divers and dry cavers around Australia when its depth surpassed all expectations.

Reaching almost 100m below water the passage continues out of sight in every direction. In 2016 divers returned to Slug Lake however this time their efforts were focused on a dry aven accessed via a relatively short dive to 30m. This aven was bolt climbed to a height of around 30m above water level where a dry passage was entered leading to an upper level of development with high rifts, decoration, large rockfall chamber, and another lake found at the bottom of an abseil. These passages as well as other promising leads visible further up the main aven continue to be explored.

4. Facilitators for Success in Cave Diving Exploration

There are multiple key facilitators contributing to cave diving exploration success. These include;

1. Equipment,
2. Training,
3. Cave Rescue Considerations,
4. Access Policy, and
5. Project Management.

Equipment. Diving technology is constantly improving with increased safety features and reliability. Equipment is also becoming more affordable including rebreathers which are now commercially manufactured by many companies and recreationally available. Rebreathers allow divers to routinely reach limits in diving that would have been considered impossible only a decade ago. Many modern day divers have a more in-depth understanding of gear functioning, limitations, and maintenance requirements than in the past. Even seemingly simple advancements such as easy access to bifocal or prescriptions diving masks has had a large impact. Cave exploration also benefits from technology such as electronic cave survey instruments and small unobtrusive waterproof video cameras such as the GoPro.

Training. Modern day divers are likely to seek out and remain current with modern techniques. This includes continually up skilling via online training, attending relevant conferences, participation in online forums, and undertaking advanced or specialised courses. Easy access to educational material such as accident/incident reports and diving related research findings is granted via globalization where divers worldwide can share ideas and experiences (including mistakes) on online networks. This allows the diving community to learn from the experiences of others and remain abreast of the latest knowledge. This culture of shared learning encourages shunning ego in favour of self-improvement which may have the added benefit of reducing a 'macho' culture of glorified risk taking and limit pushing. Modern day training is superior to courses taught in previous decades including more refined training in buoyancy and anti-silting techniques which are important for exploration cave diving. The popular use of GoPro cameras means that divers have the opportunity to view footage of themselves and self-identify where improvements can be made.

Cave Rescue Considerations. Jenolan presents divers with a variety of additional risks when compared to other locations. The caves themselves are silty, complex, and sharp. They are at around 900m altitude above sea level and are reasonably cold with an average of 14° Celsius water temperature, both factors which increase the risk of decompression illness (DCI). Additionally, divers here are more likely than normal to exert themselves during and immediately after dives, exacerbating DCI risk. The remoteness of the dive sites means extreme care must be taken to eliminate or reduce these risks wherever possible. Risk mitigation is achieved via an accredited trip leader system, fitness training, community education, first aid training, and specialised cave diving rescue training.

Access Policy. Only those with a valid National Parks authority permit are able to access the caves beyond the guide led tourist trips. The process is for a recognised caving club to submit a written application for caves they wish to visit and the purpose for each access, as well as emergency contact details. Clubs maintain relevant insurances for land owners and injury which they demonstrate with yearly certificates of insurance currency. If approved, a signed permit is received which the cavers present at the tourist complex to sign for access to relevant road and cave gate keys. For divers, permits are more difficult to obtain as all diving activity is expected to be achieving a purpose such as exploration or documentation, and recreational cave dives are rarely permitted. Current guidelines prohibit the use of closed circuit diving, and mixed gas or decompression dive plans need to be justified by the dive team before approval.

Project Management. Successful project management is perhaps the most important facilitator for any exploration project. Examples include recruiting and overseeing a competent team, ensuring ongoing and sustainable motivation, and continually assessing and upgrading goals. Continued assessment of team members allows the identification and exclusion of unsuitable divers, for example those motivated by thrill seeking or publicity, or lacking a longer term commitment to the project goals.

5. Summary

Mammoth Cave was the site of Australia's earliest cave dives and continues to lure generations of explorers with the promise of potential discovery lurking around each new bend. This review of cave diving exploration approaches over the decades highlights the effect of advancements in diving technology, training, education, and culture. This paper suggests numerous facilitators for cave diving exploration success, the majority of which are modifiable factors. This is an interesting area which would benefit from a qualitative survey of exploration divers. Such a review could identify additional facilitators and also explore key barriers to cave diving exploration. Future papers could also give additional consideration to the nature of and adherence to 'Golden Rules' of cave diving safety.

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(Abstract) Common characteristics of successful sump diving projects, a story of Main Drain Cave, Utah, U.S.A.

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Abstract

Cavers and hydrologists are intrigued by the great potential for unexplored passages between the terminal sump of Main Drain Cave and the resurgence to which it has been dye traced, Wood Camp Spring, Cache County, Utah, over 11 km away. Should these distant sites be connected, a system over 1200 m deep would be the deepest in the U.S.A. In 2016 cavers from Texas and Utah led a week of exploration efforts there, and found support for the practice of 'progressive penetration,' that is, introducing cavers to the system in shorter pieces rather than making the trip to the sump on the very first trip. The trip to the sump is difficult, with the entrance elevation at 2700 m, cave temperatures between 0 and 4 C, and 373 m of vertical plus 1.6 km of wet horizontal cave to traverse to reach the sump. Over 20 cavers, all vertically proficient but some with limited alpine caving resumes, helped haul 170 kg of equipment to the sump over five days. Equipment loans from the U.S. Deep Caving Team made these haul weights possible because of the use of high volume yet extremely lightweight composite tanks and high pressure regulators. Other massive savings of time and energy came by way of the driver to a team of horses and mules who volunteered his time to bring dive equipment and large sacks of personal kit to the entrance. By way of these efficiencies, there were four days left for exploration, during which time two sump divers made two dive efforts, and eventually broke the 125 m long sump to find 150 m of passage beyond. Cavers on the project enjoyed new challenges, long and difficult days, and the comradery of achieving things beyond themselves. Trip leaders attribute this success to not only strong cavers, but the large amount of preparation that included acclimatization trips, installation of warming stations set up at intervals to avoid the need for each person to carry extra insulation, monthly meetings to cover topics ranging from gear to training, lightweight gear such as composite tanks, and communication via social media, emails and phone meetings.

Cave Radio For Direction Finding And Communication

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Abstract

Mapping of caves is the base for further investigations underground. Compass is the tool commonly used in mapping. Especially when mapping under water, the proximity of large magnetic objects, such as tanks and lamps as well as high DC current in cables and heaters may lead to deviations in the compass readings. By the use of a vertical pulsating magnetic field from a transmitter located on a fixed point in the cave the position of that point can be located on the surface above. Coordinates of the position can then be determined using high grade GPS. Using this method, the cave map's accuracy can be improved.

The frequency of the magnetic field can be from kHz, giving low sensitivity/range but good accuracy, to MHz (in some cases). Depending on the electrical conductivity in the ground the magnetic field is considerably attenuated at high frequencies and tends to follow cracks in the ground. High frequencies give better signal from the antenna and therefore it is a delicate decision to choose the working frequency of the system. A lot of equipment works at 87 kHz or 32 kHz. Direction finding from the surface can be used when mapping or just to follow cavers and cave divers. In an emergency situation it can be of great value to know where and when everyone is in the cave, as well as what has happened. An inductive communication system can work in both directions and telephony or Morse code can be used. The Morse approach gives longer range than telephony. However sources of disturbance can reduce the practical communication distance. Antenna size, location and direction can reduce the problem as well as reduced bandwidth in the electronics involved.

It is important to have the right type of equipment operated by skilled persons, to get good results. It is not economical to make equipment for a very small market with very high cost for tests (meaning a CE certification) because the customers have low budgets. The techniques though are not very complicated and should be interesting for people already involved in ARDF (Amateur Radio Direction Finding) or amateur radio. There are some groups in the world specially interested in cave radio. In those groups there usually are some active radio amateurs. It is a very challenging project to design, build and test equipment for direction finding and communication underground.

Keywords: Cave Radio, Direction Finding, Communication, Transmitter, Receiver, Antenna

1. Introduction

Cave radio can use magnetic or radio propagation. The distances are often small and mostly within the range where magnetic behaviour, rather than radio propagation (range < wavelength/2 x pi), is dominating. An early example of the use of magnetic communication were the first world war battlefields (Bedford 2008). This paper will concentrate on the use of low frequency magnetic field in the range 1 kHz to 100 kHz (wavelength 300 – 3 km). The goal of this paper is to provide a starting point for work with cave radio for those who normally are not involved in such things. A lot of the content in this paper is common knowledge among specialists. Cave radio can be very useful in many ways but to get the full potential out of it some technical aspects must be understood. Cave radio can be a very interesting subject for radio amateurs and other people interested in electronics.

2. Theory

A magnetic field is created by a pulsating current in a wire, often arranged as a single or multi-turn circular loop (Figure 1). The decay of the field strength of such a magnetic field is proportional to the third power of distance. That means that for direction finding or communication over a doubled distance it is necessary to increase the power eight times. The strength of the magnetic field from a transmitting antenna is proportional to the electrical current, the number of turns and the area of the circular antenna. If the antenna is big the magnetic field will also be big and therefore it will be detectable from a longer distance. The most efficient form of the antenna is the circular loop. An oval loop or a loop formed as a narrow rectangle will create a small and strong magnetic field that over a short distance will be attenuated to a level below the noise in the receiver. A small antenna with a strong magnetic field can also cause problems in other electronics equipment near the antenna. The signal from a receiving loop antenna is proportional to the magnetic field passing through it as well as the frequency. A magnetic field parallel to the loop plane does not pass through the loop, it just touches the loop and therefore will give no signal in the receiver. This "zero" in the receiver is very sharp and can be used to find the direction of the magnetic field. In this "zero" position the plane of the loop antenna has the same angle of the magnetic field in that position.

The orientation with as much magnetic field as possible through the antenna loops is used for communication. The orientation of the loop in this case is not as critical as direction finding. For best performance the underground and the surface antenna loops should be parallel and on the same geometrical axis. This is the situation when the loop on surface is horizontal and located at "ground zero".

3. Direction Finding Or Radiolocation

Direction finding can be used to help or check mapping and to search for possible entrances or connections in a cave. Often

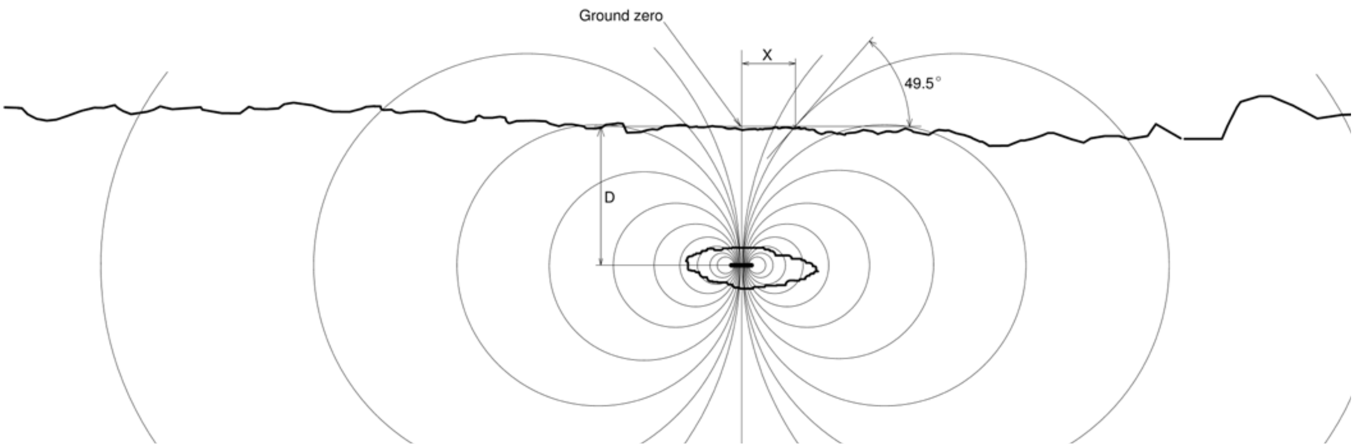

Figure 1. Direction Finding (DF) / radiolocation of "ground zero" and depth measurement.
$D = 2X$ is a special case for $\alpha = 49.5^{O}$, when $(8 + 9\tan^2\alpha)^{½} - 3\tan\alpha) = 1$ in the standard depth equation, $X/D = ((8 + 9\tan^2\alpha)^{½} - 3\tan\alpha)/2$

the transmitter antenna in the cave is set up as to give a vertical magnetic field right above the antenna. The point where the magnetic field is vertical can be found using a direction finding (DF) receiver on the surface. If the DF is moved from that point the magnetic field will lean outwards more and more until it is horizontal. A weak vertical magnetic field (the return field) can be detected at an even longer distance from the "ground zero". The area on the surface where the magnetic field is pointing against the ground zero has a radius that is 1.4 times the vertical distance to the transmitting antenna in the cave (Glover 1976).

By measuring the angle of the magnetic field and the distance from where this is done to the "ground zero", the depth to the transmitter antenna can be calculated. An easy way to do that is to search the point where the field angle is 49.5 degree and from that point measure the horizontal distance to "ground zero" and multiply that measure with two to get the depth to the transmitter in the cave (Figure 1).

The coordinates of "ground zero" can be found by using a high end differential GPS equipment (Gorski et al. 2017). The operating frequency of the DF equipment is important for the range and accuracy that can be reached. Low frequency in the kHz region gives a possibility of long range and high locating accuracy. This is due to the fact that the magnetic field at low frequency is not following such variations in the ground as cracks and joints between different mineral layers with different electric or magnetic conductivity very accurately. Use of DF equipment may be impossible if high magnetic or electric conductivity is present in the ground. This is a typical situation for a mining area. The noise in the receiver itself plus noise picked up by the loop antenna are critical factors since the DF is operating by searching the smallest signal. Atmospheric noise is broadband but man-made noise varies a lot with frequency and location. Examples of man-made noise are LORAN navigation system transmitters and VLF transmitters that can be a problem in large areas. Local man-made noise can come from digital cameras, GPS, computers, communication radios, wristwatches, LED regulators, chargers. The list can be long! The maximum range and accuracy of a DF is limited by the signal/noise ratio and therefore also by how much noise a DF operator can tolerate when listening to very weak signals.

4. Communication

Speech and Morse code communication via magnetic field is possible. It is also possible to transmit data. Speech communication can utilize the audio frequency (AF) signal that is amplified and feeding an antenna. This works for short distances but for long range communication, for practical reasons, the speech must be sent via a higher carrier frequency. A range between 10 and 100 kHz can be used to avoid self oscillation in the highly sensitive receiver. The carrier is then modulated by the speech. Modulation type can be Double Side Band (DSB), Single Side Band (SSB) in the form of Lower Side Band (LSB) or Upper Side Band (USB). The old fashioned Amplitude Modulation (AM) is not used because of its high power consumption. An operator listening to Morse code (CW or Continuous Wave) on a single frequency can tolerate a lot of man-made and atmospheric noise. The noise can also be very much reduced by utilizing a narrow band pass filter for the CW frequency. A speech transmission (SSB, LSB, USB) is more broad band (200 – 2700 Hz) and in this case more noise can pass through the receiver and cause a very bad signal to noise ratio. Data transmission or digitally coded speech can use narrow filters and therefore perform well in a noisy environment.

The working frequency of many cave radios is 87 kHz due to historical reasons – the Molefone from 1970s used USB on that frequency and the HeyPhone as well as the Nicola System used today are compatible with that (Bedford 1994). Carrier frequency 32.768 kHz is used with DSB in the cave radio M-85 (Lenander 1987) and newer transceivers in Sweden. The 32.768 kHz reference is the very cheap quartz tuning fork that can be found in almost every wristwatch and it is accurate enough for a DSB system.

5. Transmitter

The CW transmitter is the easiest one to build. It consists of just a keyed oscillator followed by an amplifier. The DSB transmitter can also be very simple. It consists of an oscillator, a balanced mixer and an amplifier. The SSB, LSB, USB approaches are much more complicated. Here the unwanted side band must be attenuated in some way (Figure 2). Data transmission must involve a computer. The CW transmitter, when used as a beacon, can be keyed with a cheap micro processor.

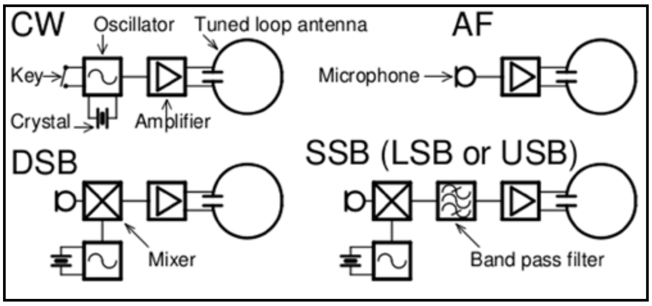

Figure 2. Block diagrams of different cave radio transmitters. Continuous Wave for Morse code, Audio Frequency feeding an antenna. Double Side Band and Single Side Band (either Lower or Upper).

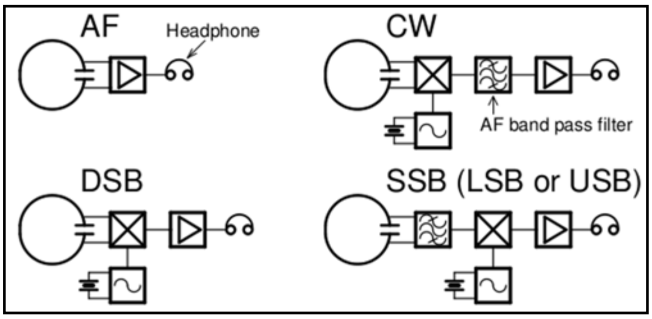

Figure 3. Block diagrams of different cave radio receivers.

6. Receiver

The most important task for a receiver is to deliver a message that is above the noise level. Reducing the band width with a band pass filter can be very useful, especially when working with CW on a single frequency. SSB (LSB/USB) can pass through a 200 – 2700 Hz wide filter. DSB must use even broader bandwidth – more than double that for SSB. In a broad filter a lot of man made and atmospheric noise will pass through to the headphones. A good CW filter will have a pass band of say 50 Hz (Figure 3). The receiver shall have a low noise level when no antenna is connected.

7. Antenna

The antenna shall pick up as much as possible of the wanted signal. Therefore, the area and the number of turns in a loop antenna are important. The antenna can be tuned to the operating frequency with a capacitor to get a narrow band width to reduce the noise and improve the sensitivity. The best shape for a loop antenna is the circle but a square shape can also be used. The loop antenna can be wound on a ferrite rod to make it smaller but at the cost of much lower sensitivity. The loop is the antenna for DF/radiolocation. The earth antenna (Gibson 2003) gives more signal for long range communication compared to the loop. The earth antenna is also a kind of a loop where the current is floating in a horizontal wire between two earth connections and through the earth under the wire in return, forming a big vertical and not very well defined loop, perhaps in a D shape. The wire in the antenna in the cave and the wire in the surface located antenna should be in same compass angle for best performance. Both wires shall be perpendicular to their common magnetic field to achieve the highest signal level. The horizontal wires can be one or two with a length together of 10 – 100 meters. Feeding the earth antenna requires high voltage to get enough current in the "loop". A transformer can step up the output impedance and voltage of a transmitter. See Figure 4.

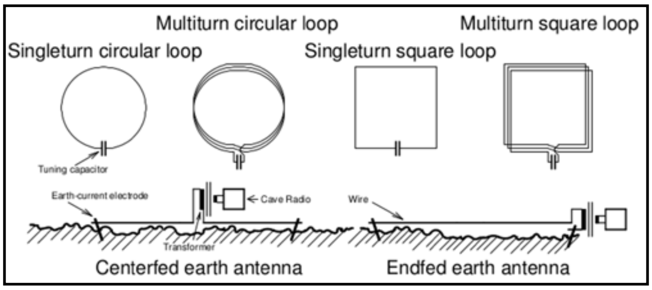

Figure 4. Cave radio antennas.

8. Electromagnetic Compatibility (EMC)

In many countries it is necessary to obey the EMC rules: Do not disturb! Do not be disturbed!

When transmitting, the transmission shall be only on the used frequency and not on harmonics of that frequency. To reduce the receiver noise the receiver shall not be sensitive to harmonics . A simple way to be on the right frequency only is to tune the antenna and associated circuits to the operating frequency. Strong magnetic fields can be a health risk. Therefore, try to transmit with as low power as possible (also good for the batteries!). A person with pacemaker has to be careful near a transmitting antenna (Rabson 2006). Electronic equipment near a transmitting antenna can be disturbed. To avoid this - try to increase the distance to the antenna.

9. Organisations With Cave Radio On The Program

Cave Radio & Electronics Group, http://www.creg.org.uk, with The CREG Journal can really be recommended. So can also Communications & Electronics Section of NSS, http://www.caves.org/section/commelect/drupal, with the journal Speleonics. In both organisations radio amateurs are involved and during the years they have really made great progress in the field of cave radio and radiolocation.

10. ARDF And Ham Radio

Amateur radio is popular in most countries. Google "amateur radio" or "ham radio". Amateur Radio Direction Finding (ARDF) is most concentrated to the former "eastern countries" and to those countries where the sport orienteering is popular. Google "ARDF"

11. Conclusions

Choose as simple equipment as possible to start with. Try to engage skilled technical people/operators for best results. Radio amateurs and ARDF competitors are familiar with the technology used in cave radios and are also skilled in operating such devices. The cave environment is very tough and demanding for the equipment, sometimes so tough that it calls for the military-grade requirements. Low budget projects require cheap and simple equipment. To build a cave radio can be a very interesting and challenging task. Let radio people accompany you on the next caving trip! Hopefully they will become interested in doing something with cave radio.

Acknowledgements

Thanks to all inspiring discussions with cavers and radio amateurs during forty years with cave radio. Without their help with field testing and use of different cave radios and without the existence of the Expedition Bjurälven project in Sweden this paper could not have been written (Suhonen and Apunen 2016)

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(Abstract) **International Cave Search and Rescue Team Slovenia**

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Abstract

When caving, we also have to keep cave rescue in mind. In Slovenia, cave rescue is provided by the Slovenian Cave Rescue Service (SCRS) operating as a part of the Speleological Association of Slovenia. SCRS was established in 1959. It is run by volunteers and is co-financed by Republic of Slovenia Ministry of Defence - Administration of the Republic of Slovenia for Civil Protection and Disaster Relief (ACPDR). As well as managing national cave rescue, CSRS is also one of most active teams in the field of international cave rescue collaboration. The Cave Rescue Service of Slovenia, together with partners from South East Europe developed the International Cave Rescue Training (CRT) Programme in 2008 to provide rescuers with a basic knowledge of cave rescue. Since then a CRT runs annually as one of the trainings of Disaster Preparedness and Prevention Initiative for South Eastern Europe (DPP SEE) and is financial supported by ACPDR. Training focuses on specific procedures and the organization of work of cave rescue teams involved in accidents or exercises. Cave rescuers are trained to work with a single rope rescue technique in cave conditions (abysses, meanders, rivers, etc.). The next important SCRS step in international collaboration was the EU Proteus project supported by the European Commission - Directorate General for Humanitarian Aid and Civil Protection - Civil Protection Prevention, Preparedness and Disaster Risk Reduction Unit Office. In the years 2012-2013 SCRS, together with Croatian Mountain Rescue Service (CMRS), run the project to enhance the awareness and preparedness of cavers and to improve the preparedness and effectiveness of cave rescuers as well as to establish basics for international cave rescue organisation. In 2013 the European Cave Rescue Association (ECRA) was founded and nowadays operates with 17 Member States.

SCRS next goal was to design and develop a cave rescue unit and to start a procedure for the registration of an international cave rescue team for operating in major rescue operations in cave related emergencies. In 2016 SCRS managed to register the first Cave Search and Rescue (CSAR) Team Slovenia as a part of Other Resource Capabilities in the European Emergency Response Capacity (EERC) in the EU Civil Protection Mechanism system. Twelve days of international rescue operation in Riesendinghöhle (Germany in 2014) is a prime example of how an internationally organized cave rescue system is crucial in case of major cave rescue operations.

Exploration of the Cliff Caves of the Nullarbor

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Abstract

The Bunda Cliffs of the Nullarbor are unique, reaching up to 100m above sea level for a 173 kilometre stretch in a semi-arid coastal region; they present a unique opportunity to investigate relatively recently exposed karst features. Around 15,000 – 18,000 years ago sea levels were around 100m lower than today's levels and since then, rising sea levels and erosion has resulted in retreat of the cliffs exposing the caves.

The majority of caves at the foot of the cliffs are formed by wave action, but there are exceptions; the most interesting caves however, are found between 30m and 70m depth in Abrakurrie and Nullarbor limestone, and are typical of caves discovered inland on the Nullarbor, with the key difference being that there are no modern-day surface entrances.

The prospects are fascinating, especially as it is possible that when the sea level was lower, the modern-day cliffs were accessible from the surface or from low-lying land (now eroded away), much like the escarpment above the Roe Plain to the west. In the Bunda Cliff caves there are remains of extinct animals; heightening the possibility that evidence of human activity might also be discovered.

To date over 60 karst features have been explored in the cliffs, but the cavers have barely covered 10% of the cliff face. Caves are up to 250m long, spacious, and full of fine calcite, gypsum and halite formations, and have significant deposits of bones of small and large animals. All work carried out on the Bunda Cliffs is under permit, including the collection of specimens.

In spite of the use of aerial video footage, locating the caves is difficult in the relatively featureless terrain, and dropping down cliffs over a cave entrance to within a few metres is a major challenge. Weather can be an issue; as onshore winds can bring waves that can crash up to half-way up the cliffs.

Long-forgotten evidence of human activity at the top of the cliffs has been discovered and shown to Elders of the Mirning People. The Bunda Cliffs are in an area of outstanding natural beauty, with plentiful flora and fauna. This paper will present some of the key findings, and describe new caving techniques.

Following the 17th International Congress of Speleology in Sydney, a handful of congress members will join the 2017 expedition to investigate and explore new cave targets.

Keywords: Nullarbor, Bunda Cliffs, Shallow Caves, Exploration, Techniques

1. Introduction

The Bunda Cliffs start at the eastern boundary of the Nullarbor, at the Head of Bight, and continue unbroken for 173km to the west near the SA/WA Border near Eucla, and rise up to 100m above sea level. In the east, the Nullarbor Limestone overlays the Wilson Bluff Limestone, and in the west the two limestone layers are intersected with Abrakurrie Limestone.

The majority of caves at the foot of the cliffs are in the Wilson Bluff Limestone and are formed by mechanical action of the sea, waves and wind; but there are exceptions to this. The retreat of cliffs, however, has exposed shallow caves (relative to the surface) in both Abrakurrie and Nullarbor limestones (Fig 1); these caves which have previously not been documented, are similar to shallow caves discovered inland on the Nullarbor, with the key difference being that there are no modern-day surface entrances, and that a few cliff caves occasionally behave as resurgences.

These recently exposed caves present a unique opportunity to investigate cliff retreat processes, to investigate undisturbed caves, to describe past habitation by animals and potentially to note past human activity.

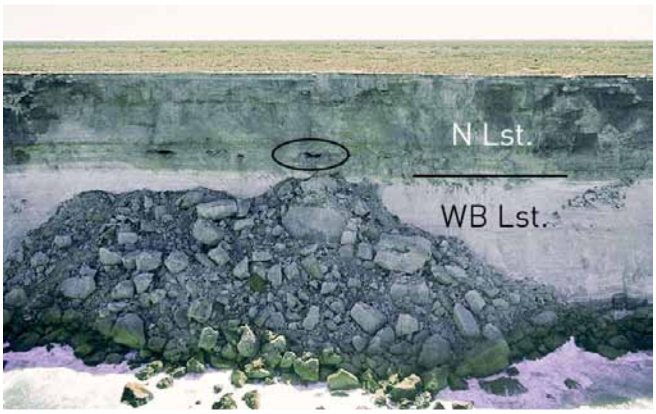

Figure 1. This aerial photograph taken at Longitude 129.6E shows the exposed cave entrance of N6722 (Charade Cave), a 250m long cave formed in Nullarbor Limestone (N Lst.). The white layer beneath is Wilson Bluff Limestone (WB Lst.); the height of the cliff at this location is approx. 100m.

Figure 2. The exposed cave entrance of N6701 (Lejeg Cave) is approx. 20m wide and 3m high; it is a complex but spacious cave in Nullarbor Limestone with significant calcite, gypsum and halite formations.

Figure 3. Mirning Elders evaluating a putative cliff top dew pond. Photo courtesy P Gregory.

2. History of Exploration

In 1988 members of the Cave Exploration Group of South Australia (CEGSA) hired a light plane to fly along the Nullarbor Cliffs to record images of the cliffs to document the caves. They recorded a number of large features at the base of the cliffs, but unfortunately these were not accessible either by boat or from the surface of the Nullarbor Plain (Meth 2000).

The prospects were fascinating, especially as it is possible that when the sea level was lower, the modern-day cliffs were accessible from low-lying land (now underwater or eroded away), much like the Hampton escarpment to the west. Around 15-18,000 years ago, sea levels were approximately 100m lower than today's levels (Gornitz 2007) and since then rising sea levels and erosion has resulted in retreat of the cliffs and exposure of karst features.

Following consultation with relevant Government Departments, the Aboriginal Community, and the SA Museum, experienced climbers and cave explorers undertook the first focussed field trip to explore the cliff caves in November 1999. That team, comprising members from CEGSA, the SA Museum and from the Victorian Climbing Community was successful in entering a few caves using modern climbing techniques (Milner 2000a); the key finding was the greater proportion of caves in the cliffs were short caves formed principally by erosion by the sea at the foot of the cliffs (Milner 2000b).

In 2003, a second aerial mapping flight was undertaken (Oswald-Jacobs 2003). In addition to the improvement in video resolution the images were synchronised to the longitude data. At face value, the flight confirmed that the vast majority of caves seen were large erosion sea caves at the foot of the cliffs. It was not until 2011 however, when the data was re-examined, that it was realised that a number of dark shadows observed in the images of the cliff face above the Wilson Bluff Limestone layer may be natural solution caves typical of shallow caves discovered on the Nullarbor previously. The 2012 field trip was successful in that a 'proof-of-concept' karst solution cave was discovered (Fig 2). In addition, there were significant learnings and improvement of techniques and safety.

Building on discoveries made during the 2012 field trip (Milner *et al.* 2013) the team returned to the Nullarbor in 2013. During this field trip the team confirmed that the majority of caves at the foot of the cliffs were short caves formed by erosion of the sea, and that the caves mid-cliff were karst solution caves exposed or intersected by retreat of the cliffs. Nine new significant caves were found with lengths up to 250m, but notably with spectacular calcite, gypsum and halite formations and numerous bone deposits including a complete raptor skeleton and a small dog-like animal (Milner *et al.* 2015).

In 2015, for the first time, Mirning Elders joined the field trip to observe, learn and share information. An unusual feature observed at the top of the cliffs in 2012 was confirmed to be a small water collection pond much like a 'dew pond' seen in limestone areas in Europe; while degraded, it was evident that the circle of stones would have been packed with earth to create a raised dam; the feature was referred to as 'gabi', meaning water (Fig 3). The focus of the 2015 trip was to complete detailed cave surveys and to investigate an additional 25 caves; again numerous bones were observed, including those of now extinct animals including those of a thylacine (Tasmanian tiger; Milner *et al.* 2017).

3. Techniques

The principal method of identifying caves was aerial photography using material gathered in 1989, 2003 and 2014. Approximate cave locations were confirmed using Google Earth by aligning satellite imagery with aerial photographs, which was later confirmed in the field. Accuracy of locating drop-off points for abseiling down to the caves in the field improved to be within 10m of the target; this is a considerable feat considering that the vast majority of caves explored could not be observed from the surface.

Owing to the friable nature of the cliff edge, techniques were developed to safely evaluate the drop-off points and to make safe loose rocks. Dual ropes and vertical access techniques were employed to ensure safety of personnel; there is complete redundancy of equipment and readiness for cliff rescue should it be needed.

All cavers adhered to the Australian Speleological Federation guidelines for caving and exploration; bone specimens were packaged and labelled at the site of location; and surveys were completed using a Suunto compass and clinometer with a laser distance measure, or using a Disto-X. GPS locations were collected using handheld Garmin devices, and all data was recorded in the field using work packs for each individual cave target.

Figure 4. Large cave found near sea level in Wilson Buff Limestone (N6741, Dorcas Dreaming)

All bone samples collected were lodged with the SA Museum in accordance with permits. Each of the caves discovered was surveyed, photographed and locations recorded, and all data is lodged on the Cave Exploration Group of South Australia / Australian Speleological Federation database called OzKarst.

4. Results

To date 60 Bunda Cliff caves have been investigated. They may be categorised as either having been formed by mechanical processes or by karst processes, and secondly categorised as being deep or shallow, as follows:

Deep Caves (in Wilson Bluff limestone) – the majority of the caves found at the foot of the cliffs are formed by action of the sea; the erosion cuts into the soft Wilson Bluff limestone undercutting the cliffs and resulting ultimately in collapse of the cliff above. There are numerous examples of cliff rock falls obscuring, or partially obscuring the cave that weakened the cliff; thus caves become sheltered and a haven for marine mammals such as sea lions.

Such caves are often associated with the exposure of significant flint deposits, sometimes set in a conglomerate, or a hard red clay-like material. Notwithstanding the difficulty in accessing the foot of the Bunda Cliffs, the environment is harsh and no evidence of human activity has been noted, in spite of the desirability of large quantities of flint for indigenous peoples' use.

While the majority of Bunda Cliff deep caves are formed by the sea, one exception has been discovered, designated as N6741 (Dorcas Dreaming; Fig 4); this cave is typical of deep caves found inland, and is formed in Wilson Bluff Limestone. The cave has passage dimensions up to 30m wide, 8m high extending over 200m in a straight line in a north-westerly direction.

Shallow Caves (in either Nullarbor or Abrakurrie limestone) – over twenty significant karst features have been explored, with seven of these being over 200m in length; one of these is presented in Fig 5. Notably in the caves there are extensive calcite, gypsum and halite formations (many active), numerous animal bone deposits including birds, raptors, fish, and small marsupials; evidence of large mammals including dingo and the now-extinct thylacine. Many of the caves exhibit contemporary bat colonies and nesting birds.

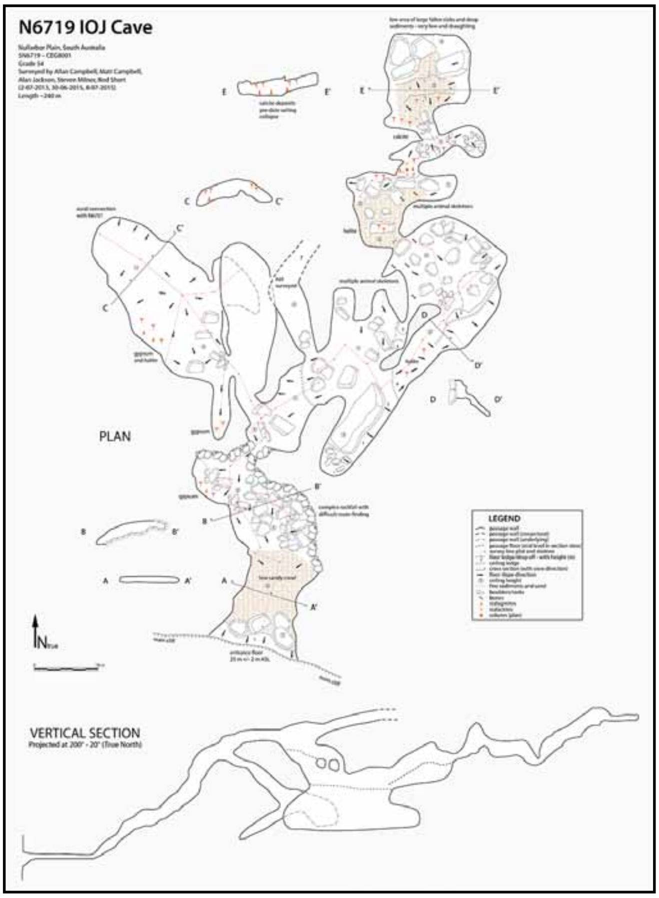

Figure 5. N6719 (IOJ Cave) is a shallow cave which has bones of animals now extinct on the Nullarbor at its highest point (approx. -20m depth). It is likely that the animals were trapped, or died in the cave at a time when the cave was accessible from the surface, however, no trace of the early cave entrance can be observed at the surface today.

Some of the larger caves exhibit calcite formations influenced by algal growth near the entrance, and two have evidence of water flows, presumably after heavy rains. One small cave has been noted at the interface between Abrakurrie and Wilson Bluff limestone, which is almost certainly a result of wind action (N6723).

5. Summary

To date 60 cliff caves have been investigated. Surveys of large caves including Lejeg Cave, IOJ Cave, Charade Cave, Raptor Cave, Dry Eye Cave, N6736, Jharbilla Cave, Dorcas Dreaming and numerous other small caves were finalised and digitised. The field work has informed the understanding of cave formation, and cliff retreat. Numerous bones were collected from animals no longer present on the Nullarbor, including those of a Thylacine. A fine example of large deep cave was discovered (N6741 – Dorcas Dreaming), which is reminiscent of deep caves inland on the Nullarbor. No evidence of human activity in any of the cliff caves has been observed.

Objectives for future field trips include the completion of detailed surveys; collection of calcite to support palaeoenvironmental studies; completion of exploration in several caves; exploration of new targets; and the rediscovery of five purported 'climb-downs' used in the past by indigenous people.

The next expedition to the Bunda Cliffs is immediately after the 17th UIS Congress in Sydney, 2017.

Acknowledgements

We are indebted to the Mirning People, the Far West Coast Aboriginal Corporation, Yalata Land Management, the Department of Environment, Water and Natural Resources, National Parks and the Nullarbor Co-management Group, the South Australian Museum, and the Cave Exploration Group of South Australia (CEGSA) for their continued involvement and support of the investigations on the Bunda Cliffs.

We are also indebted to and acknowledge the passionate team of cavers, climbers, explorers and supporters from the 1999, 2012, 2013, and 2015 field trips who have given their time freely to build knowledge of the Nullarbor's Bunda Cliffs. We thank: Marty Bulle, Rowan Cameron, Bonnie Campbell, Dee Campbell, Matt Campbell, Daryl Hughes, Alan Jackson, Meike Polman-Short, John Russell, Terry Reardon, Cameron Richardson, Travis Shaw, and Dave Whitam.

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Cave Exploration In Xiaonanhai Karst Area, Shaanxi Province, China

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Abstract

Thanks to a detailed study of satellite images, a new extensive karst area was discovered south of Hanzhong City in Nanzheng County, Shaanxi Province. Speleological project was established in May 2016 and during the first reconnaissance visit of the area, several new cave entrances and large dolines (tiankengs) were discovered.

A speleological expedition in October 2016 was organized in cooperation with the Shaanxi Geological Institute from Xi ´an and more than 7 km of new caves were explored and surveyed. The Guanyindong Cave with total 3,024 m of corridors and 445 m of depths is the longest and deepest cave discovered in the area. Boniukeng (1,386 m long and 187 m deep), Xiaoxuidong (777 m long) and Diao Dong (762 m long and 45 m deep) are the other significant explored caves. Exploration in the all above mentioned caves as well as reconnaissance and study of the new promising locations in the Shaanxi Province will continue in the next years.

Keywords: Shaanxi, Xiaonanhai, Guanyindong, Boniukeng, Diao Dong, Cave exploration,

1. Shaanxi Project

First idea to explore the unknown karst areas in Shaanxi Province started during the year 2014 when Z.M. and M.F. studied satellite images of many karst regions in China and found several promising karts phenomena (especially blind valleys, dolines, etc.) in several more or less separated adjacent areas in the Shaanxi Province. An initial pilot step to realize the speleological project in China was made in autumn 2015 during the second Asian Transkarst conference in Lichuan in China, where all authors of this paper first met together and seriously discussed a possibility to visit the mentioned areas.

The first expedition took place in late May 2016. The team consisted of 5 members – Michal Filippi, Libor Matuska, Zdenek Motycka, Roman Sebela and Zhang Yuan Hai. The aim of the expedition was reconnaissance in three interesting karst areas selected using a Google Earth application (GE), however, for two areas it was not possible to visit. One area is not allowed for foreigners and second because of a slope-failure that destroyed the access road. Therefore our main focus was aimed on a karst plateau south of Xiaonanhai village in Hanzhong District (for results see below).

Second expedition took place in October of the same year with the following participants: Jiri Bucek, Radoslav Husak, Miroslav Kotol, Libor Matuska, Stepan Matl, Tomas Mokry, Zdenek Motycka, Jan Sirotek, and Zhang Yuan Hai. The main purpose of this expedition was to continue in exploration and documentation of the karst phenomena in the Xiaonanhai area.

2. Description of the study area

Hanzhong City is located in the Nanzheng County on the Han River in the southwestern part of the province Shannxi in central China. Geologically, the whole area spreads in the transitional zone between the Yangtse Plate and the Qinling

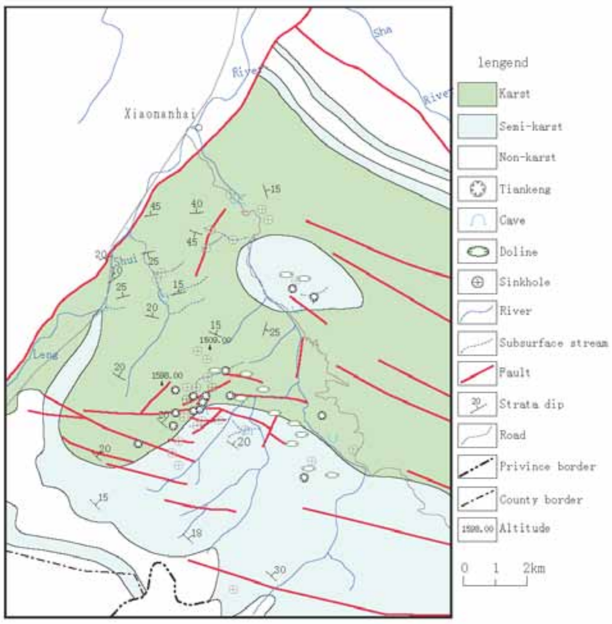

Figure 1. Karstological map of the Xiaonanhai area, Shaanxi, China
Author: Zhang Yuan Hai

orogenic belt system. The whole area covers about 5,000 square kilometers of carbonate rocks that form morphologically different types of surface from undulating to mountainous terrain, through karst plateaus to medium-developed cone karst. Karst forms are ubiquitous, but usually covered with dense vegetation. Typical landforms are blind valleys, canyons, cave portals, abysses and sinkholes of various proportions (called tiankengs). (Fig1.) The highest summits of the local mountains reach usually 1,500–2,100 meters above sea level. Limestone of Wujiaping Formation of a Permian age is the most common rock in the region, alternating with clays,

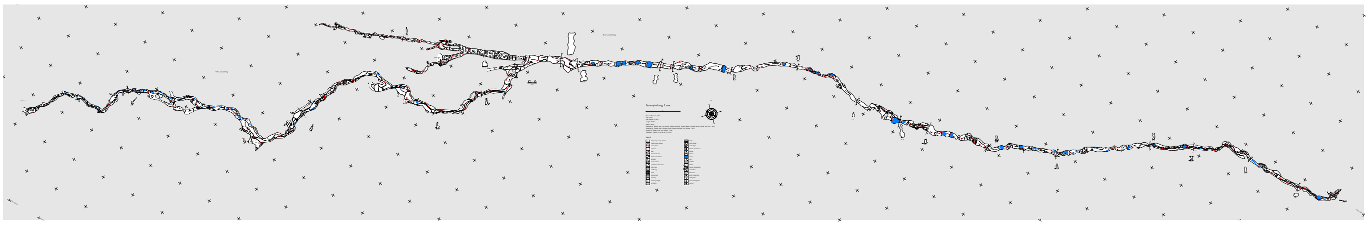

Figure 2. Map of the Guanyindong Cave, Shaanxi, China

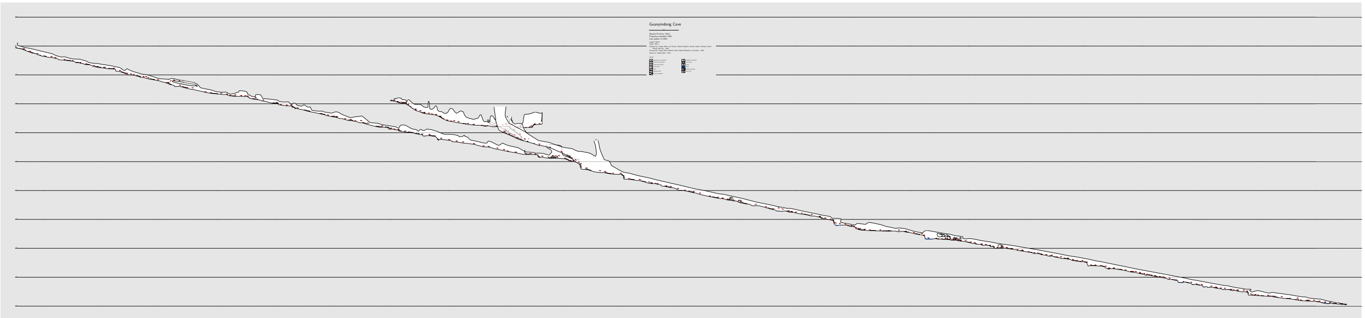

Figure 3. Profile of the Guanyindong Cave, Shaanxi, China

shales, dolomitic limestones, cherts and other layers or interbeds of sedimentary rocks of Permian to Jurassic ages.

Climate in the area is mild to subtropical. Average temperatures reach 26 °C in summer and 4 °C in winter, but in the mountains it is cooler, with average winter temperatures below freezing-point, which means that snow is relatively common. However, the mean annual precipitation in general is not abundant, if compared to (by tourists much more visited) southern China and it usually reaches 700–1100 mm. A long-term drier climate is also reason why the cone karst of central China is not as well-developed here as in the Guilin area in southern China with cones and towers up to 300 m high. The study area is located southeast of the village Xiaonanhai. It consists of a north to northeast dipping limestone plateau (or even a relic of a much larger plateau) with an area of about 7 × 5 km, which is on the south and west limited by an incised valley flanked by mountain ranges and high rock cliffs towering above the otherwise relatively flat surrounding landscape.

In the north and east of the plateau is a wild mountainous karst landscape with deep valleys and canyons. The plateau is gently undulating to flat with a complex network of shallow valleys with permanent or intermittent streams, which mostly terminate in sinkholes with cave portals or in abysses up to several tens of meters deep. The whole plateau is only minimally populated, covered with dense subtropical forest. Only a small portion along the roads is deforested where tobacco and other crops are grown.

3. Materials and methods

3.1. Cooperation with the authorities

Our work in China are undertaken in a valuable cooperation with several Chinese institutions and local authorities. We coordinate our work with representatives of the Institute of Karst Geology of Chinese Academy of Sciences in Guilin and Shaanxi Geological institute in Xi´an. Very important support was provided by representatives of local authorities from Nanzheng County, Hanzhong city and Xiaonanhai village.

3.2. Cave mapping and data processing

All explored caves were surveyed using a paperless technology. Basic data of cave polygons and walls contours were collected by a DistoX device and immediately transferred to a PDA with a specialized Pocket Topo software. While the data are displayed in the PDA, cave walls and all important details of caves are drawn separately. After the exploration trip in the caves, all data from the Distox and PDA are downloaded to a PC and processed by a Therion software to draw the final maps (using data from the Pocket Topo).

4. Main speleological discoveries

4.1. Guanyindong Cave (length: 3,024 m; depth: -445 m)

The cave starts in an inconspicuous entrance portal (10 × 4 m large) at the bottom of an elongated doline densely covered by vegetation. Gently descending and meandering passage with stream and small steps continues next approximately 300 meters. The stream has other tributaries. Then, a relatively large cave space named Birds Hall (25 × 10 m) opens. Approximately 800 m behind the entrance, the passage continues via a 10 m deep step as a huge tunnel (up to 10 m wide and up to 30 m high). The upper part of the cave until the tunnel is named Old Guanyindong and the large following parts are named New Guanyindong. The tunnel has a flowing stream. The upstream part is ascends steeply and after ca. 100 m collapses to the surface occur. Downstream, the tunnel continues approximately 500 m but its height is decreasing (except two larger spaces) and after next several hundred meters (1.5 km from the cross with the Old Guanyindong part), the cave finishes in an impassably narrow space. Chert layers exposed from the limestone are typical feature of this cave. (Fig 2. Fig 3. Fig 4.)

Figure 4. Waterfalls in the New Guanyindong passage, Guanyindong Cave, Shaanxi, China
Photo by: Stepan Matl

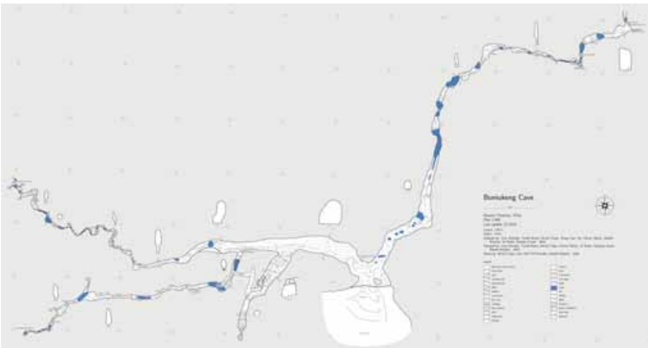

Figure 5. Map of the Boniukeng Cave, Shaanxi, China

Figure 6. Large tunnel in downstream passage of the Boniukeng Cave, Shaanxi, China
Photo by: Radek Husak

4.2. Boniukeng (length: 1,386 m; depth: -186 m)

This cave starts at the base of a large collapse doline of 80 × 50 m in size and 80 m of depth. A relatively large passage continues in both directions, following the underground stream (lower part with passages 2–20 m high and 2–5 m wide) and against the stream (upper part with passages 2–30 m high and 2–5 m wide). The lower part is technically difficult with small but deep lakes and steep steps up to 17 m high. The passage continues towards the unknown cave space.

The upper part consists of a passage (lately branching) of decreasing size from 15 × 30 m up to 1 × 8 m (width × height). Several chimneys were found there up to 70 m high. A fossil level with some artificial artifacts was found in this part of the cave. (Fig 5. and Fig 6.)

4.3. Xiaoxuidong (length: 777 m; depth: -25 m)

The cave portal (40 m high) is situated at the end of a blind valley close to the Xigou village. A zigzag shaped horizontal passage of the same height but only 3 to 5 m wide opens to a huge – 100 m long, 20 m wide and 53 m high cave hall with some windows at its ceiling. Then the cave continues via passage 8 × 15 m, slowly decreasing and containing two small steps (3.5 m a 2.5 m high). After the next 200 m a second much smaller hall opens. Behind this hall, the passage again becomes smaller and after 100 m a lake fills the whole profile. The flooded passage continues for 120 m and then a small hall with a lake (30 × 6 m large) opens. Free space of the cave is finished by a sump behind this lake. (Fig 7. and Fig 8.)

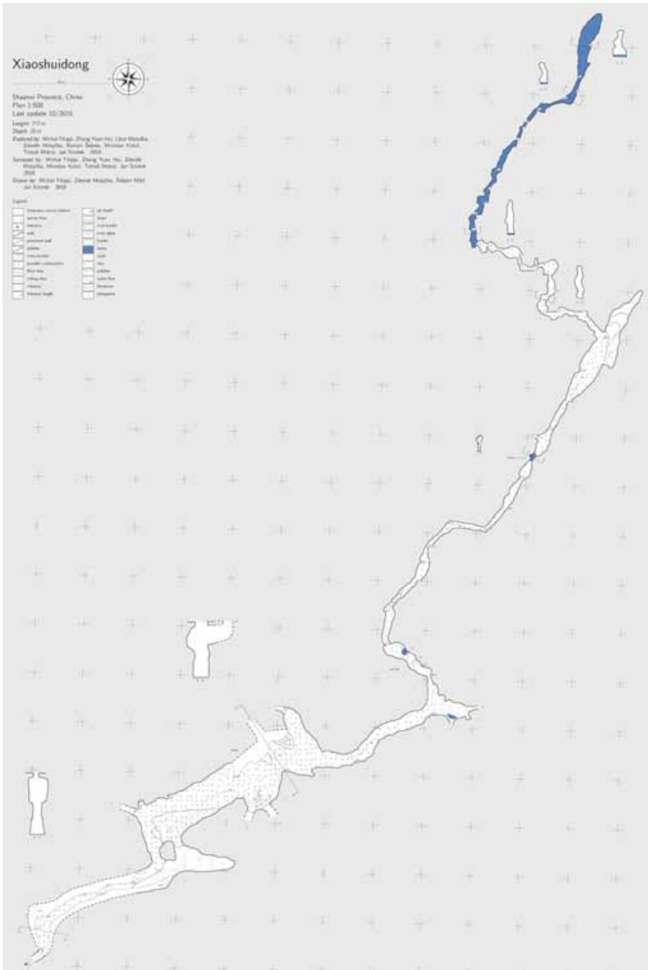

Figure 7. Map of the Xiaoxuidong Cave, Shaanxi, China

Figure 8. Large hall with ceiling window in the Xiaoxuidong Cave, Shaanxi, China
Photo by: Zdenek Motycka

4.4. Diao Dong (length: 704 m; depth: -45 m)

Diao Dong Cave is opened via 18 m deep and 20 × 5 m wide vertical shaft with a waterfall on its wall. At the bottom, a cave passage (up to 5 × 10 m in size) starts down- and upstream, the tributary part ends in a small dome and not surveyed step with a waterfall. The "main" downstream passage is larger reaching approximately 15 × 20 m in a cross-section. After an approximately 20 m deep rock step, the passage changes into a relatively narrow but up to 40 m high narrow space with small cascades. This part was named as the Turbines because of the characteristic noise of the present waterfalls. (Fig9. and Fig10.)

4.5. Other Caves

Dragon Cave (length 895 m), **Cave Resurgence 1** (length 338 m) and **Three Cigars Cave** (length 48 m) are other caves discovered and mapped.

5. Summary and Future Expeditions

Speleological research in unexplored karst areas nearby Xiaonanhai village south of the Hanzhong City in central China (Shaanxi Province) started within the last year. Already two expeditions were realized – first aimed as a reconnaissance exploration of the most interesting sites with karst features previously found via a Google Earth Application and second focused on mapping of the discovered caves. During the both expeditions, several large dolines (tiankengs) and promising caves were discovered and their mapping started successfully. More than 7 km of new cave passages were mapped and photo-documented. After the first expedition, a detailed drone scanning was realized by geologists from the Shaanxi Geological institute in Xi´an in this and adjacent areas and a lot of new sinkholes were revealed and photo-documented (see also paper: The significance of the Tiankeng Group discovery in Hanzhong of Central China). Some results were already presented by world media.

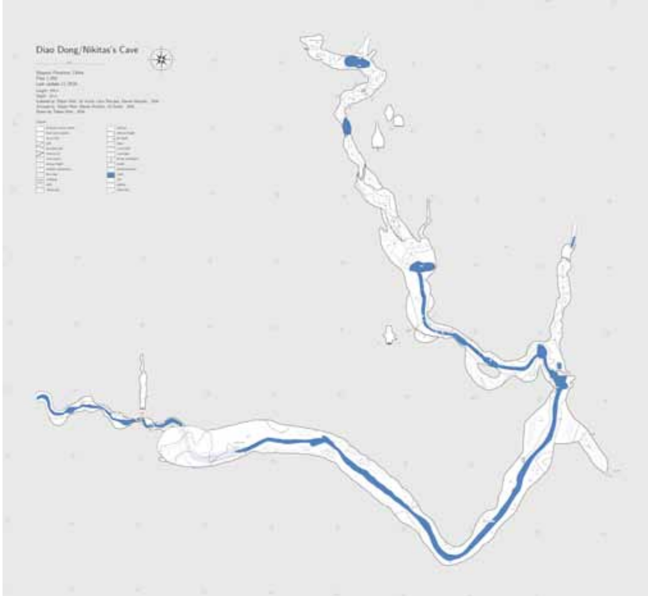

Figure 9. Map of the Diao Dong Cave, Shaanxi, China

Figure 10. Waterfall in entrance shaft of the Diao Dong Cave, Shaanxi, China
Photo by: Zdenek Motycka

Exploration continues since the potential of this area and other karst areas in the province are more than promising for future exploration.

Acknowledgement

Authors (Z.M, M.F.) would like to express their great thanks to co-author Zhang Yuan Hai from the Institute of Karst Geology of the Chinese Academy of Sciences for his great job with managing of the expeditions in China. Exploration of the karst was also supported by the Institute of Karst Geology of the Chinese Academy of Sciences, by the Shaanxi Geological Institute in Xi´an and by the Institutional research plan No. RVO 67985831 of the Institute of Geology of the Czech Academy of Sciences. Working in the field and reliable partners were all the above mentioned participants of the expeditions.

New Exploration In Underwater Cave Systems In Riviera Maya, Mexico

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Abstract

During speleological expeditions in 2014, 2015 and 2016 the members of Czech and Slovak Speleological Society continued their project for exploration and documentation of underwater cave systems on the Yucatan Peninsula, which has been running since 2003. They discovered new cenotes in the NW and SW from the known parts of the K'oox Baal Cave system, which is now the third longest underwater cave in the world and was explored by the Czech and Slovak speleologists from 2006 to 2012.(Motycka, 2013). Another new area located about 4 km NE of the K'oox Baal Cave system was explored and many new cenotes discovered there. Some of them was lately connected to new cave system Sac Kay, which is now 11 551 m long. Totaly 17, 5 km new passages was discovered and documented.

Keywords: Sac Kay, K´oox Baal, underwater caves, cenote, Yucatan, Xibalba

Figure 1. Decorated passage in K'oox Baal Cave system, Mexico
Photo by: Radoslav Husak

Figure 2. Entrance chamber in Cenote Axh Puk
Photo by: Zdenek Motycka

1. New challenges

In February 2014 the members of Czech Speleological Society continued their project (Project Xibalba) for exploration and documentation of underwater cave systems on the Yucatan Peninsula. Project Xibalba has been running since 2003. The area of interest is located in Mexican state Quintana Roo, N from city Tulum, near the village of Akumal. In 2014 over 14 days they discovered two new cenotes in the NW and SW from the known parts of the K´oox Baal Cave system, which were then explored by them from 2006 to become the 4th longest underwater cave system in the world in 2012 (Fig1). In the new cenote Shoot's Hool they discovered 589 m of new passage and in the cenote Wa Ba'ax Yan total of 1176 m of new corridors. During an inspection dive in cenote Chak Ha, they discovered 354 m of new passage and connected Chak Ha in to the cenote Zebra, (discovered in 2015) which reached the total length of 2443 meters. The main result of this expedition was the reconnaissance of a new area, located about 4 km NE of the K´oox Baal. Here they discovered 8 new cenotes with 2 km of new corridors with potential for their continuation and connection to a larger system.

2. Behind the gate of dreams

In February 2015 project members focused their exploration in the new cenotes discovered in 2014, which are located about 4 km NE of the K'oox Baal Cave system. Over two weeks they discovered 3,2 kilometers of new corridors and connected four of these cenotes; cenote Tu, cenote Nautilostotl, cenote Paachil Nah and cenote Beh et Óox Ha to one system with total length 5 271 m.Two more cenotes were separately explored in the area. The first of them; Ash Puk is 650 m long and second one named Carita is 350 m long. (Fig 2. Fig 3.)

Figure 3. Deep lake in Cenote Carita, Mexico
Photo by: Zdenek Motycka

3. Sac Kay

In January and February 2016 three groups of cavers from the Czech and the Slovak Speleological Society continued the project for exporation of underwater cave systems on Yucatan Peninsula. Over 5 weeks they discovered new underwater tunnels in cenote Nah Baak and the new cenote Mariposa. Altogether they discovered 5 km of new passage and connected most of cenotes in the area to one system called Sac Kay. The total length of the system is now 11 638 m. (Fig. 4) New corridors they also discovered in cenote Luuk Hool, which is now 872m long. A surprise for them was the discovery of two new dry caves; Xul In, 546 m long and ZBK which is 753 m long. (Fig. 5) In the last days of expedition they also surveyed and mapped new passages in K´oox Baal Cave system, which is now 90 km long and it is actually the third longest underwater cave in the world.

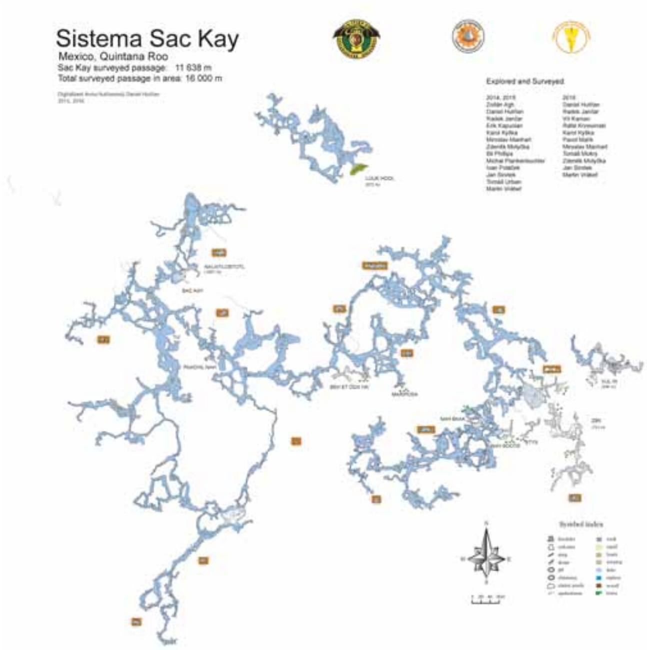

Figure 4. Map of the Sistema Sac Kay, Mexico

4. Summary

Sac Kay is new underwater cave system on Yucatan Peninsula discovered, explored and surveyed by members of Czech and Slovak Speleological Society from 2014 till 2016. The total length of the system is now 11 638 m. During three expeditions a total of 17.5 km of new passage was discovered and documented in the area. The people who participated are: Daniel Hutnan, Radek Jancar, Vit Kaman, Karol Kyska, Rafal Krzewinski, Miroslav Manhart, Pavol Malik, Tomas Mokry, Zdenek Motycka, Jan Sirotek, Martin Vacek and Martin Vrabel.

Figure 5. Lake ´s hall in Sac Kay cave system, Mexico
Photo by: Zdenek Motycka

Acknowledgement

Special thanks to Bil Philips, Jim Coke, Jorge Gonzales Pacheco, Jacobo Pacheco, Robbie Schmittner, Nadia Berni and David Sieff for their support, help and friendship.

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Characteristics Of Limestone Caves In The West Of Khuvsgul Lake, Northwestern Mongolia

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Abstract

Khuvsgul Lake is a freshwater Lake, located in northwestern of the Mongolia south of the border with Russia. Carbonate rock is distributed around Khuvsgul Lake and some caves were discovered in this region. Three joint expeditions of Japan and Mongolia were carried out to find out the cave distribution and to survey the structure of the caves in the west of Khuvsgul Lake from 2008 to 2014. Each expedition occurred between the end of August and the middle of October.

This expedition found and surveyed 6 caves, which are located at the altitude of 1,700 meters to 2,110 meters ASL. Urkhet Cave, the longest cave of them, has the total length of 227.2 meters and the depth of 64.4 meters. These caves in this region are not of complicated structure, but of simple passages and chambers; moreover, the total length of these caves is short. Most entrances of these caves are ponors or crevices with vertical entrances. The temperatures in these caves are around 0oC; therefore, there is not groundwater flow, and the floor and the wall of these caves are icy. One of the surveyed caves, White Rock Cave has ice pillar 7 meters tall. This region belongs to the subarctic zone, and there is little precipitation, so it appears that the current expansion is due to corrosion.

Keywords: limestone caves, Mongolia, Lake Khuvsgul, subarctic zone

1. Introduction

Mongolia has numerous caves, and Avirmed, (2008) classified and documented them. Around Khuvsgul Lake is one of the typical karst landscapes. Khuvsgul Lake is one of several freshwater lakes and located in northwestern of the Mongolia south of the border with Russia. Carbonate rocks cover more than 16,500 square kilometers, which is largest in Mongolia (Avirmed, 2008). However most of them aren't surveyed and do not have maps.

Japanese and Mongolian groups including the authors visited around Khuvsgul Lake to explore and survey caves three times between 2008 to 2014. Each expedition was spent around 11 days in the field, and we surveyed six caves during all expeditions (e.g. Morizumi et al., 2009). We report here the caves which we surveyed in Mongolia.

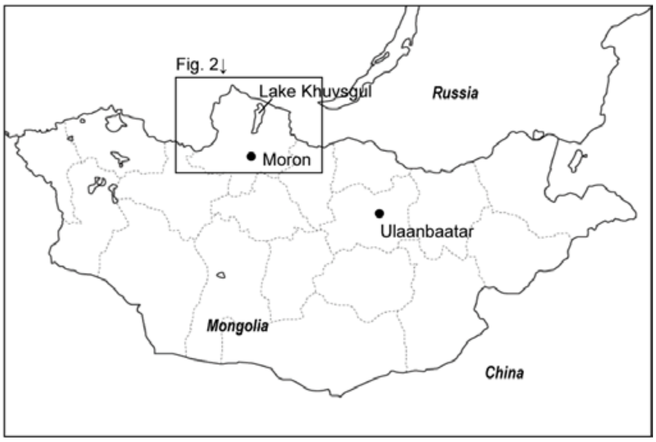

Figure 1. Location map

2. Regional Setting

Khuvsgul Lake is located in north-western Mongolia, and occupies a depression in the Baikal Rift Zone (Fig. 1). The climate zone of Mongolia is subarctic or Semi-arid climate, around Khuvsgul Lake belongs to subarctic zone. The amount of rainfall is lower and there is a very widel noon-night temperature difference. As Mongolia is located in central Asia, the altitude of Khuvsgul is around 2,000 meters ASL. The Hangay range is in central Mongolia. There is mountainous topography, a coniferous forest zone, a plateau region, and an endorheic basin, and a river, around Khuvsgul Lake.

Mongolia is located in Central Asian Orogenic Belt between the Precambrian Siberian Craton in the north and the Tarim and Sino-Korean Cratons. This is a complex of fold belts which is composed of Precambrian to Paleozoic gneiss, schist, sandstone, shale, limestone and volcanic rocks (Tumurtogoo, 1997; Badarch et al., 2002). The geological setting of the

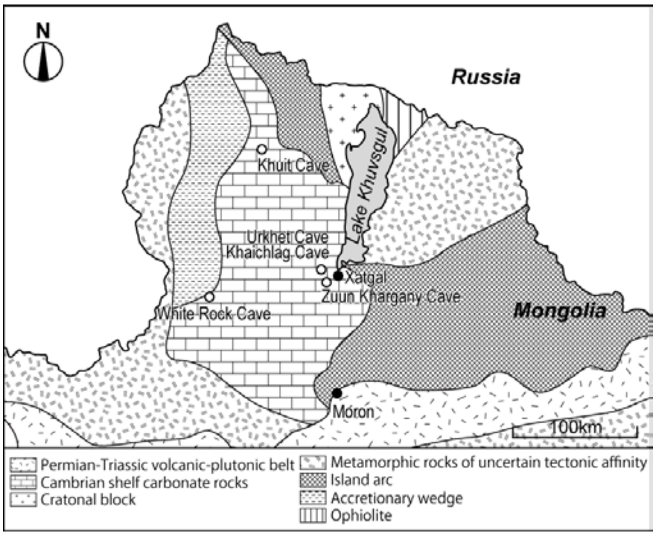

Figure 2. Geological map around Lake Khuvsgul (modified from Badarch et al., 2002)

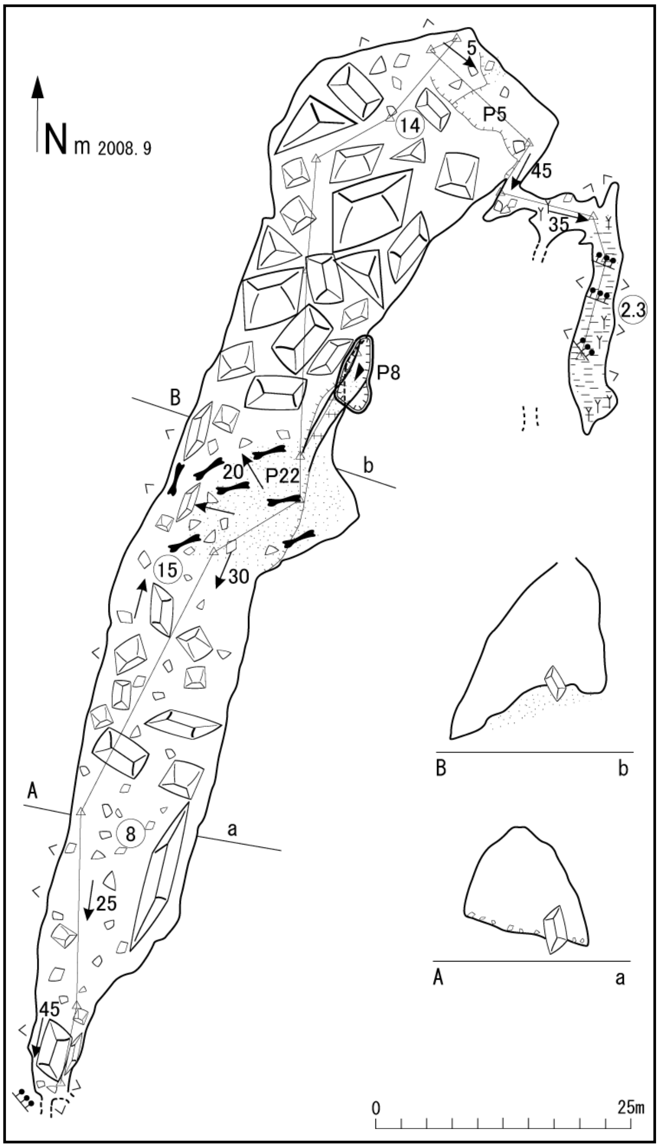

Figure 3. Survey Map of Urkhet Cave

west of Khuvsgul Lake is composed of Cambrian carbonate rocks (Fig. 2), all caves we surveyed are located in this region (Badarch et al., 2002).

3. Cave Survey

3.1. Outline

The authors found and surveyed 6 caves to the west of Khuvsgul Lake where the Cambrian carbonates are located(Table 1). Most of them are complexes of vertical and horizontal caves, consisted of simple passages and chambers. All are ponors or crevices with vertical entrances except Khuit Cave. The longest cave, Urkhet Cave is 227.2 meters in length. The longest cave around Khuvsgul Lake is Dayandeerkh, at 224.0 meters. However, the length of caves is measured by maximum width, not total length of traverse lines in Mongolia, it is possible that these caves we surveyed are shorter than Dayandeerkh

The temperature in these caves are around 0 oC. There are icicles and parts of the cave floor and the wall are icy in these caves. Moreover, there is no groundwater flow. Caves are not forming actively now.

Figure 4. White colored-hall in northwestern side of Urkhet Cave

Figure 5. Human bones in Khuit Cave

3.2. Urkhet Cave (Fig. 3)

Entrance of this cave is located on the mountain slope. The relative elevation between this entrance and river is about 50m. This entrance is in doline, and the depth of this vertical passage is around 30m. The temperature in this cave is 0 oC and the floor and wall of the doline is icy.

There is a huge hall under the doline, which the trends north and south, and dips to the south. The floor of this hall consists of mud, sand, and huge rocks, and there are some bones and dead bodies which are thought to be cows. The height of this hall is 15-20m. Although the northern end of this hall has a small passage, that has not been surveyed. At the far south of this hall the cave inclines and the deepest point is 60m below the entrance. The end of this passage has many white-colored speleothem and helictites (Fig. 4).

3.3. Khaichlag Cave

Khaichlag Cave is 6.3 km to the northeast of Urkhut Cave, Khaichlag Cave is only a pit. The width of the entrance is about 3m and the depth is about 18m. There is ice on the wall and floor because the temperature of this cave is about 0 oC. The end of cave is narrower than other parts, and we couldn't go in. There is no water or speleothems.

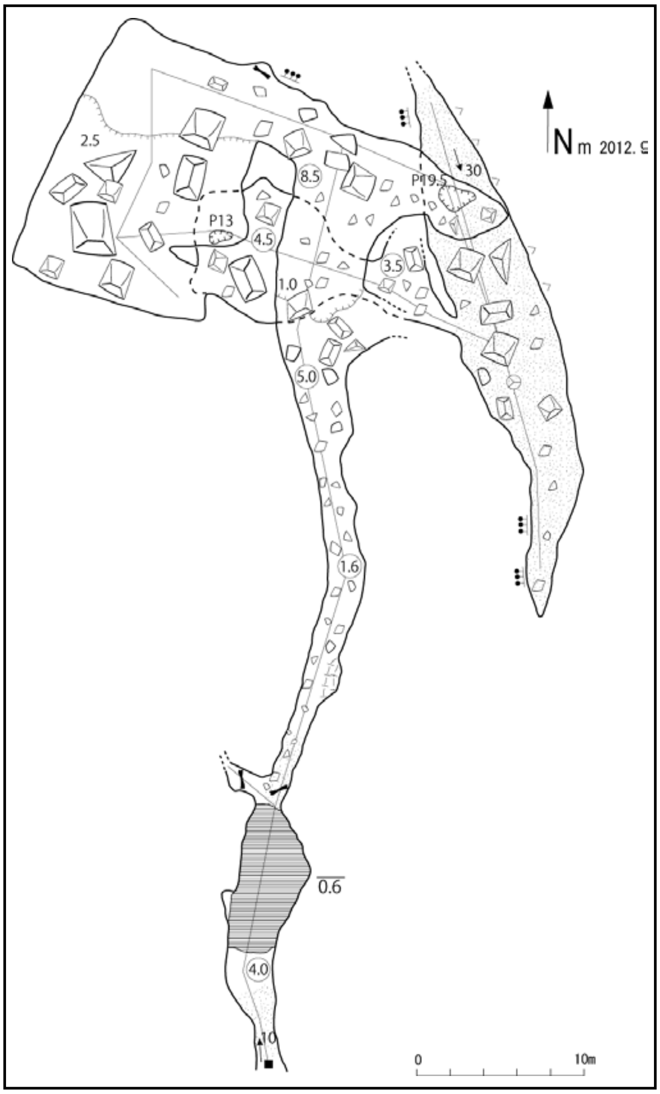

Figure 6. Survey Map of Khuit Cave

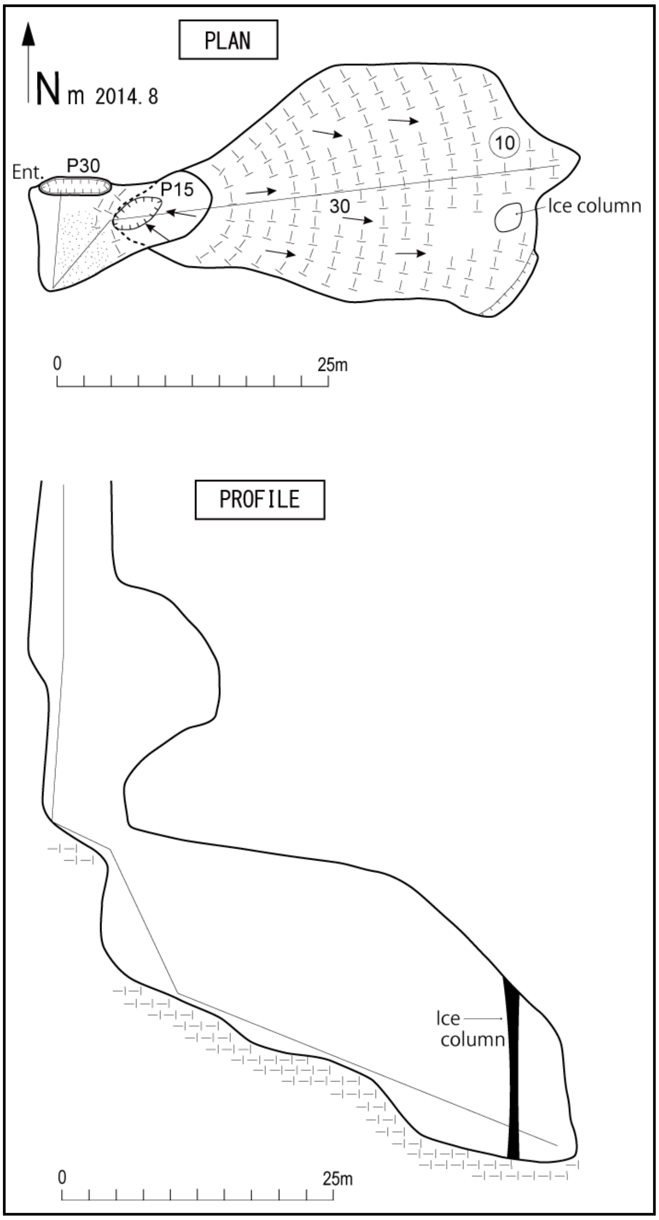

Figure 7. Survey Map of White Rock Cave

3.4. Khuit Cave (Fig. 6)

Most of passages of Khuit Cave are horizontal. The entrance is 2m by 1m and located on the mountain slope. Snow remained on the ceiling beyond a pool which is under the entrance, therefore we can infer that this passage will be blocked by snow in winter. Around a meter down, this passage forked and on the left (west) side, there is a hall 10m wide and another passage heads down to east side. At the end of this passage, there is another hall in an eroded fracture system, toward NNW and south. The right (east) side of the branch, there is 19.5m deep vertical passage. The bottom of this passage connected to the same hall which is eroded fracture system too. There is a human cranial bone in the hall (Fig. 5).

Near Khuit Cave, there is another cave (Khuit Cave No.2) too. There is a lot of bird guano on the floor. This cave has possibilities to connect to Khuit cave, although we couldn't find it.

3.5. White Rock Cave (Fig. 7)

White Rock Cave consisted of two pits, both around 30m deep. The temperature in this cave is approximately 0 oC, and there is ice from a few meters deep to the bottom. The passage shape of the 1st pit presents is oval measuring about 6m by 1.5m. At 10m down, there is a hall whose width is about 10m. The north wall and part of floor are icy. The 2nd pit entrance is on the east side of this hall. At 10m down, there is a huge hall and slope down which is thickly ice-covered. At the base of this cave, there is an iced column about 8m high(Fig. 8).

3.6. Zuun Khargany Cave

This is a horizontal cave which is an eroded fracture system trending west-northwest and east-southeast. The entrance side of this passage slopes down and part of the floor is covered by ice. The back of this cave is level, with sand on the floor. There are some bones which is thought to be mammals present.

4. Conclusion

As a result of this exploration, we found and surveyed 6 caves to the west of Khuvsgul Lake which is located Cambrian carbonate rocks. These caves are located at around 2,000 meters ASL. The longest and deepest cave of them, Urkhet Cave has the total length of 227.2 meters and the depth of 64.4 meters. Study area belongs to subarctic zone, the temperature in these caves are around 0 °C . Therefore, there is not groundwater flow, and cave development is inactive at present.

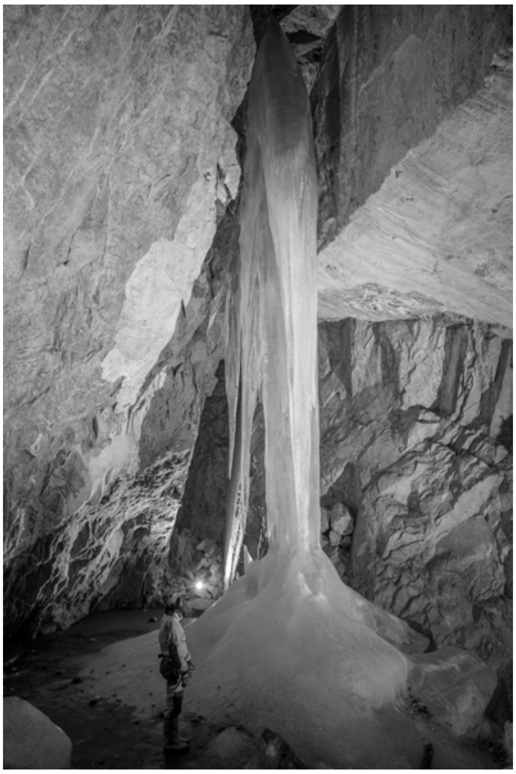

Figure 8. Iced column in White Rock Cave

Acknowledgement

Choijindash Avirmed and Sandagdorj Avirmed joined and supported these expeditions. Ryo Mastuzawa, Tomoko Kuroda (Tokyo Speleo Club), Riei Akamatsu, Misato Jonishi (Osaka City University Exploration Club), Donghwan Yi joined each expedition and surveyed these caves together. Dr. Davaabayar coordinated these expeditions. We are deeply grateful to them.

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Table 1. Survey Caves List

Name	Location	Altitude	Length	Depth	Surveyed
Urkhet Cave	N 50°29' 01.8" E 100°01' 08.9"	1,889m	227.2m	64.4m	2008/9/4
Khaichlag Cave	N 50°30' 58.9" E 100°05' 31.3"	1,976m	34.0m	18.0m	2008/9/5
Khuit Cave	N 51°18' 19.4" E 99°21' 25.3"	1,736m	190.1m	32.7m	2012/9/11
Khuit Cave No.2	N 51°18' 20.0" E 99°21' 25.1"	1,736m	11.9m	1.1m	2012/9/11
White Rock Cave	N 50°29' 00.23" E 98°44' 55.04"	2,110m	95.0m	61.1m	2014/8/28
Zuun khargany Cave	N 50°23' 42.55" E 100°04' 17.54"	1,721m	25.5m	10.1m	2014/8/30

Fort Stanton Cave: World-Class

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Abstract

Fort Stanton Cave is located in the Sacramento Mountains of south-central New Mexico, USA. Originally known as Government Cave, documented evidence of visitation goes back to the designation of nearby Fort Stanton in 1855. Major portions of the cave were mapped in 1877 by the Wheeler Survey, a military expeditionary force that preceded the U. S. Geological Survey.

The cave remained a popular recreational site through the mid-1900s. It was compared to Mammoth Cave of Kentucky and home to unusual and substantial deposits of selenite needles.

In the 1960s the cave attracted the attention of the organized caving community, and efforts began to map the cave with modern (at the time) survey techniques. A group of cavers, who came to be known as the Fort Stanton Cave Study Project (FSCSP), organized the effort. Documentation went beyond survey and mapping, and extended to conservation and scientific study.

In 2001, the Snowy River passage was discovered, and exploration and documentation intensified. This passage proved to be unlike anything else known in the world, partly due to the 18 kilometer long white crystalline floor deposit and also due to the extraordinary and abundant microbiology. Along with other new passages found, Snowy River expanded the known cave (at present) to over 50 kilometers, as well as leading to the most remote cave passages known in the world.

In order to understand and experience this remarkable cave, members of the FSCSP developed a 3-D avatar based simulation program, Caver Quest, (http://www.fscsp.org/CQ6/), which continues to set benchmarks in cave interpretation and education. In 2013, in recognition of its exploration and documentation work at Fort Stanton Cave, the UIS recognized the Fort Stanton Cave Study Project with its Most Significant Exploration Award. We received that award for combining record-setting exploration with high levels of science and conservation, an obligation we feel we owe to this world-class cave.

Keywords: Exploration, Microbiology, Biosignature, Paleoclimate, Footprint, World-Class

1. Introduction

In 1855, the US military established Fort Stanton in the Bonito valley of the Sacramento Mountains of south central New Mexico. Soldiers from the fort visited the nearby cave and left their signatures on the walls of the cave. In the 1870s the US Government sent out military surveying teams under the leadership of Captain George M. Wheeler, assigned to survey and map the unknown lands of the southwestern United States west of the 100th meridian. In 1877, one of his teams was surveying the area of the Sacramento Mountains. They chose to include Fort Stanton Cave in their survey and produced a map of the cave, shown below. (Wheeler 1877) This was the second cave west of the Mississippi River in the United States to be mapped.[1]

Fort Stanton Cave began to acquire a reputation as the "Mammoth Cave" of the west. Indeed, the comparison has merit. Unlike many other caves in the western United States, Fort Stanton Cave is considered a typical epigenic limestone cave, with relatively large passages, some with periodic streams. Most passages end in breakdown collapses and show the influence of flowing water. Indeed, the Wheeler Expedition named one portion of the cave the "Water Passage".

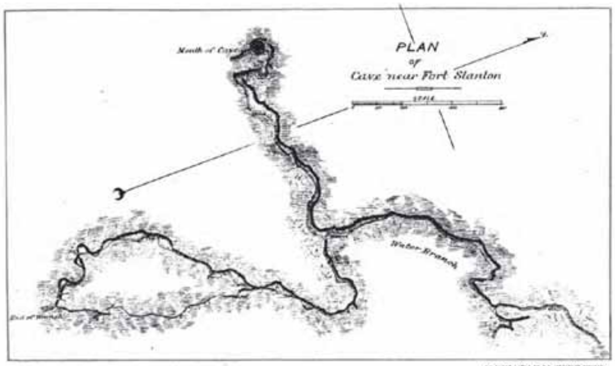

Figure 1. Map of Fort Stanton Cave from the 1877 Wheeler Expedition

2. Modern Exploration

The pace of exploration of Fort Stanton Cave picked up in the late 1950s when sport caving in the United States became more popular. New portions of the cave were discovered, often by digging through the breakdown collapses that blocked the ends of some of the passages. In the late 1960s a serious mapping effort was begun to document the cave. By 1970, the cave was protected by the US Bureau of Land Management with an exterior fence around the entrance sink and interior gates. Digging, discoveries, exploration, and mapping continued up to 2000 when the surveyed length of the cave was around 12 km.

1 The first cave to be mapped was Cave Valley Cave in Lincoln Co., Nevada, also mapped by this same team earlier in their expedition.

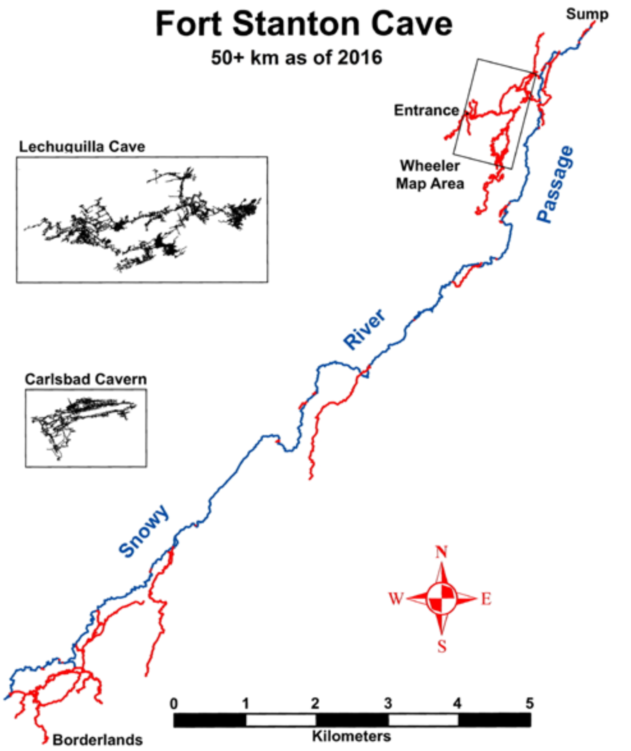

Figure 2. Fort Stanton Cave plan map compared to Lechuguilla Cave and Carlsbad Cavern at the same scale. The area covered by the 1877 Wheeler Map is also shown.

In 2001, a dig from the 1970s was revived by an ardent digger, Lloyd Swartz. After only a few digging trips, he and a team that included John McLean, one of the long-time explorers in Fort Stanton Cave, managed to dig over the top of the breakdown collapse pile and down the other side to a passage that led to a connection with a larger cross passage. The passage, unlike anything they had ever seen before, was named "Snowy River", for the pristine white crystalline floor deposit that extended as far as they could see in both directions. (Davis, 2004)

This Snowy River passage has now come to dominate the map of Fort Stanton Cave. The historical portion of the cave, what was known before the discovery of Snowy River, is just a series of side passages at the lower (downstream) end of Snowy River. To date, the Snowy River passage, by itself, is over 18 km long and while it sumps at the downstream end, the upper end has yet to be found! It is now known that the Snowy River passage periodically floods. The water resurges at the surface in a spring in the Rio Bonito. We believe that the major source for the stream in the Snowy River passage lies at least an additional 7 km beyond the current explored portion of Snowy River.

Surveys of Snowy River passage and its side passages and additional survey in the historical part of the cave have brought the surveyed length of Fort Stanton Cave to over 50 km. We believe that much remains to be discovered and a potential length of over 100 km is reasonable.

3. What makes Fort Stanton a world-class cave?

Optimističeskaja, Gouffre Berger, Huantla, Mammoth, Jenolan, Lascaux, Villa Luz – what do all these caves have in common? They all have characteristics or features that are superlative in some fashion among the thousands of caves of the world. They are "world-class" caves. So, what are the characteristics or features of this cave that put it into this class?

Figure 3. Figure 3: Cavers on Snowy River; Photo by Pete Lindsley, courtesy of the BLM

4. The Snowy River Deposit

The immediate reaction to the discovery of the Snowy River passage in 2001 was that this unusual white crystalline floor deposit may extend for a few thousand meters. No one would have predicted that it would continue almost continuously for 18 kilometers! (The formation is assumed to be continuous, but is not accessible in some locations where the floor of the passage is interrupted by breakdown.) When the first exploration team set foot on the deposit in 2003, there was serious concern about the nature of the deposit, and whether it would support the weight of cavers walking on its surface. (Because the Snowy River deposit takes up the entire floor of the passage, for the most part, there is really no alternative to walking on it in order to explore the passage.) Was it a thin crust that would be easily destroyed, or crushed by repeated footfalls? Fortunately, it was found that the surface was solid and with the adoption of certain protocols, could withstand the impact of cavers walking on it.

The nature of the Snowy River floor deposit proved to be a very porous laminated calcite crystalline deposit, with nearly 500 individual layers, some as thin as 0.01 mm. (Spilde, Boston, et.al, 2008b, Spilde, Northup, et. al., 2009, Spilde, Kooser, et. al., 2010. Spilde & Boston, 2013) Initially it was thought that the deposit must be very old, perhaps laid down during the last ice age, but Dr. Lewis Land took some core samples of the deposit, dating the lowest layers of the deposit at only ~850 years bp, +/- 100 years! (Land, Polyak, et. al. 2007) In 2007, the Snowy River passage was found to be flooded, up to the edge of the Snowy River deposit, confirming that the deposition was not old, but was an active process, continuing to the present. (It has flooded several times since the 2007 event.)

Why does this deposit extend, almost continuously, for the entire length of the known extent of the Snowy River passage? It would appear that it relates to the extremely low gradient of the passage itself. The average gradient of the passage is on the order of 0.2%. That is, it only drops perhaps a meter or two for every kilometer of its length. This gradient has not changed significantly over the entire 18-kilometer length. When the passage does flood, water flows very slowly down this only

Figure 4. The amazing Snowy River passage with the crystalline white floor deposit and biologically active walls and ceiling! Photo by Kenneth Ingham, courtesy of the BLM

slightly inclined passage. Essentially, the Snowy River deposit is a very long, narrow pool deposit.

Visually, the Snowy River deposit is stunning. In contrast with the darker mud and bedrock walls of the passage, it appears to be white as snow – hence the name. When compared with a truly white reference, it is seen to be more of an off-white cream color. The 18 kilometer long formation is considered to be the world's longest known cave formation. (Spilde, Kooser, et. al., 2012)

5. Microbiological Laboratory

While the Snowy River floor deposit is the most impressive aspect of the Snowy River passage upon first sight, what has become even more significant to many scientists, are the walls and ceiling of the passage. The first exploration teams noted that in many locations throughout the passage, there appeared a dark colored deposit on the walls and ceiling.

When this deposit was sampled by scientists, such as Dr. Penny Boston, formerly of NM Institute of Mining and Technology and now the Director of NASA's Astrobiology Institute, and Dr. Diana Northup, of the University of New Mexico, it was found to be a mineral deposit made by micro-organisms that were living on the bedrock of the cave, in an environment where photosynthesis has no part in the life cycle. (Spilde, Boston, et. al., 2008b, Northup, 2011, Spilde, 2014, Morgan-Edel, Boston, et. al., 2015)

Figure 5. Dr. Diana Northup sampling micro-organisms on the wall of the Snowy River passage. Photo by Pete Lindsley, courtesy of the BLM

Indeed, these organisms were extremophiles, adapted to living in extreme environments on Earth! Continuing DNA studies have revealed many families of organisms in the cave that occupy a completely different domain, Archaea, neither bacteria, plant or animal. These Archaea play critical roles in cycling nitrogen within the cave ecosystem.[1] Snowy River passage provides an unparalleled opportunity to study microbial-mineral interaction in a pristine low-energy environment.[2]

6. Extraterrestrial Biosignature Analog

In 2012, scientists from New Mexico State University (NMSU) and New Mexico Tech began development of tools that could be used to distinguish the origin of mineral samples, whether that origin was biological in nature or strictly mineralogical. They needed an "extreme" environment in which to test those tools and Fort Stanton Cave provided that environment. (Chanover, 2014, Uckert, 2014) Dr. Kyle Uckert, now with Jet Propulsion Laboratory, was an astronomy doctoral student at NMSU involved with that project.

Dr. Uckert explains: "Fort Stanton Cave is an ideal extraterrestrial biosignature analog site due to its relative isolation from surface organisms, the presence of undisturbed microbially altered samples, and the variety of speleothems and minerals contained within. Caves not only offer a sheltered habitat to extant life forms but can also serve to preserve ancient microfossils and biominerals that would otherwise be rapidly degraded under harsher conditions at the surface. Additionally, management and conservation efforts by the Fort Stanton Cave Study Project (and the BLM) protect this unique field site and facilitate collaborations among scientists to provide context to individual studies."[3]

7. Paleoclimate Analog

Drs. Victor Polyak and Yemane Asmerom, Dept. of Earth and Planetary Sciences, University of New Mexico, and Dr. Matthew Lachniet, Dept. of Geosciences, University of Las Vegas,

1 Kimble, J; unpublished study; Northup, D; E-mail message 21 January 2017
2 Spilde, M.; E-mail message, 15 January 2017
3 Uckert, K.; E-mail message, 6 January 2017

have been conducting paleoclimate studies at Fort Stanton Cave for many years, first publishing results in 2010 in the journal Nature Geoscience (Asmerom, Polyak, et. al., 2010, Polyak, 2011, Polyak, 2012a). Their research involves utilizing broken stalagmites to reconstruct past climate changes using carbon, oxygen, uranium and thorium isotopes preserved in the calcite. The stable isotopes of carbon and oxygen measured every mm along the stalagmite's growth axis are tied to 67 uranium-series ages to produce those climate proxy time-series that correlate very well with the oxygen stable isotope time-series from the Greenland ice cores for a period from 6,000 to 11,000 years ago. A later study published in 2012 focused on the climatic backdrop of Pleistocene megafauna extinction. (Polyak, et. al., 2012b) This work was published in the journal Geology, and suggests that our climate in the SW USA was drying rapidly during the period that many important megafauna went extinct.

According to Dr. Polyak, "the stalagmites in Fort Stanton Cave contain sufficient uranium for measuring accurate and precise dates, and grew continuously for long periods of time. Results included in their first two papers show that samples from Fort Stanton Cave have potential to produce the most significant highly resolved and accurate paleoclimate records in the world. Already, their results are used by scientists globally."[1]

8. Extent and Footprint

One of the significant aspects of Fort Stanton Cave is its extent and footprint. For our purposes, we define the extent of the cave as the greatest linear distance from one "end" of the cave to the other. For Fort Stanton Cave, this value is a little over 12.7 kilometers. Researchers have defined footprint in different subjective fashions; however, we will define footprint objectively as the size of the smallest convex polygon that encloses the horizontal representation (map) of the cave. Fort Stanton Cave's footprint, using this definition, is over 18 sq. kilometers. In the United States, only Mammoth Cave and Kazamura Cave have footprint values larger than that. The map of the cave above shows how the extent and footprint of Fort Stanton Cave compares with two other well-known caves in New Mexico – Lechuguilla Cave and Carlsbad Cavern.

9. Remote Passages

Finally, we consider the remote quality of some of the passages of Fort Stanton Cave. The cave has only one known entrance, and the lower end of the 18 km long Snowy River passage is relatively close to that entrance. This means that the upper explored end of the Snowy River passage is quite a distance from the entrance of the cave. The most remote known point in the cave is in an upper level side passage of Snowy River called "Borderlands". The furthest explored part of that passage is 18.3 kilometers from the entrance, by survey.

The far end of the Snowy River passage is 18.0 km from the entrance. We know that the actual travel distance to these remote points is somewhat more than that, since the cavers travel on the Snowy River deposit, which meanders in the passage. For that reason, the book on the exploration of Fort

Figure 6. A caver looking into the darkness in the most remote known cave passage in the world – the frontier of the Snowy River passage (January, 2017). Note the Snowy River deposit continuing on the bottom right. Photo by Rene Ohms, courtesy of the BLM

Stanton is titled "12 Miles from Daylight". (12 miles = 19.3 km) These are considered to be the most remote known cave passages in the world!

10. Summary

It should be obvious that these characteristics or features of Fort Stanton Cave, some of them superlative in nature, should give Fort Stanton Cave the qualities that place it in that category of "world-class".

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Caving Expedition To The Humpata Plateau, Angola

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Abstract

In July, 2010, two Portuguese caving clubs organized the first speleological expedition to the African nation of Angola. The aim were the caves of the Humpata Plateau, near the city of Lubango, of which some reports were known but had never been explored nor surveyed.

Most caves in this plateau lie in dolomitic limestone. These limestone strata comprise the upper series of the Chela formation (which dates from the Cambrian period to the Silurian), and lay over quartzite rock that is also partly karstified itself over a narrow stretch, near the escarpment overlooking Lubango.

The major highlights are: i) Tchivinguiro cave system: this spring cave has been known and visited for decades, but the real extent of this subterranean maze was yet unknown. Several new entrances were discovered and the system was partly mapped, adding up to 1.700 m; and ii) a complex of caves in quartzite rock, with 23 entrances located so far, was mapped to a length of 1.200 m. More entrances are expected to be found by expanding the search area on the surface.

In total, 45 caves were registered in the plateau, but only a very small part of its area was prospected.

Keywords: Africa, speleology, Angola, Huíla province, Humpata plateau, caves

1. Introduction

In July 2010, two Portuguese caving clubs, Núcleo de Espeleologia da Universidade de Aveiro (NEUA) and Liga para a Protecção da Natureza – Centro de Estudos e Actividades Especiais (LPN-CEAE) organized a caving expedition to the Angolan province of Huíla. The Humpata Plateau, near the city of Lubango, was the chosen territory to prospect and start a cave and karst spring inventory.

Despite having few references to local caves and karst landforms, a vast area of the plateau was visited by car and also several journeys were made by foot in order to identify the real limits of this limestone massif and major geomorphological karst landforms that could indicate the presence of subterranean voids. Several caves were surveyed but many others were just registered. The presence of quartzite formations on the plateau was also a motive of interest with the expectation of finding karstified quartzite with caves.

This expedition had also the opportunity to introduce speleology to the students of a local university (Universidade Privada de Angola - UPRA) by organizing several easy cave visits.

Figure 1. Outline of the Huíla province with the location of the Humpata Plateau.

2. Humpata Plateau

The Humpata Plateau is located in the Huíla province, southwest of the city of Lubango and facing the Namibe province to the West. The Humpata Plateau rises above the flat surrounding territory between 1.000 and 1.500 m and is an imposing step on Angola's Southwest landscape.

Between the villages of Leba and Cangalongue, the plateau is mainly formed in dolomitic limestones. These dolomites lay in horizontal and sub-horizontal layers and they comprise the upper series of the Chela formation which dates between the Silurian and Cambrian periods (Amaral, 1973). These strata lay over quartzite rock that is also partly karstified itself over a narrow stretch, near the escarpment overlooking Lubango. There were expectations to find cave systems both in the highly karstified Dolomite outcrops and also, in a lower degree, in the quartzite rock.

3. Previous speleological explorations

Previous to this expedition few references exist pertaining to caves in the Humpata Plateau. No speleological explorations or systematic cave records are known to exist. Inscriptions we found on several of the visited caves witness the activity of some adventurous people, especially during the 20th century. The main references to caves and karst were on the geographic surveys performed by Portuguese geographers during the last years of the colonial occupation. More recently, archeological and paleontological studies were also made in the caves of the plateau.

4. Expedition main results

A vast area of the Humpata Plateau was prospected in order to identify karst landforms and caves. Due to the vast area of the plateau, prospection was made with an off-road vehicle where possible and by foot to reach the least accessible areas. Contact with locals was essential to locate many of the caves found and surveyed. In total 45 cave entrances were registered, but just a few caves were surveyed. For lack of time, in some caves only the coordinates were recorded. Below is an exhaustive list of the registered caves.

Most of the effort in this expedition was made in the Tchivinguiro cave system and the quartzite cave complex found near Lubango, due to their relative greater development.

5. Tchivinguiro

Tchivinguiro cave is one of the best known caves of Angola. It is mentioned in several geographic references and internet sites. Due to its easy access this cave has long been visited by curious people, boy scout groups and students.

This spring plays a major role as a main source of drinking water for the population established around the spring and Nandimba river margins. During our visit (June 2010) the water flow from the spring was estimated to be approximately 160 l/s. This is representative for the dry season.

Tchivinguiro cave lies in a dolomitic limestone convex hill, isolated by erosion, which is a pattern in regard to the lime-

Table 1. List of cave entrances and karst springs registered during the expedition (all coordinates WGS84)

Ref.	Lat.	Lon.	Description	Altitude (GPS)
001	-15.16750	13.32088	Gruta do Tchivinguiro (Nandimba spring)	1666
002	-15.16374	13.29464	Tchivinguiro school spring (near agricultural school)	1641
003	-15.16758	13.32339	Nandimba shaft	1685
004	-15.16747	13.32310	Impenetrable doline	1713
005	-15.28339	13.46160	Gruta de Cangalongue	1585
006	-14.94009	13.45493	Quartzite rock cave system	2085
007	-14.93941	13.45509		2090
008	-14.93890	13.45479		2094
009	-14.93862	13.45511		2094
010	-14.93862	13.45522		2091
011	-14.93806	13.45517		2098
012	-14.93822	13.45504		2097
013	-14.93834	13.45514		2097
014	-14.93837	13.45528		2093
015	-14.93755	13.45510		2101
016	-14.93768	13.45499		2101
017	-14.93909	13.45438		2095
018	-14.93873	13.45489		2095
019	-14.93936	13.45457		2092
020	-14.93923	13.45452		2095
021	-15.16827	13.32358	“Boi que cai e não sai” shaft	1720
022	-15.16865	13.32267	Rift	1713
023	-15.16664	13.32149	Candimba Cocofima	1699
025	-14.93880	13.45439	Quartzite rock cave system	2098
026	-14.93897	13.45456		2094
027	-14.94105	13.45490	Quartzite rock cave system - unexplored entrance	2083
028	-14.94147	13.45491		2080
029	-14.94165	13.45502		2080
030	-14.94173	13.45502		2066
031	-14.94184	13.45492		2070
032	-14.94104	13.45475		2087
033	-15.08341	13.25949	Gruta da Leba (Forno da Leba)	1754
034	-15.08228	13.25639	Small shaft	1795
035	-15.08463	13.26786	Shaft	1808
038	-15.12700	13.26972	Tchiua spring (impenetrable)	1672
039	-15.10932	13.26090	Ondimba da Tartaruga	1809
040	-15.10407	13.25757	Shaft with human bones	1811
041	-15.12402	13.28016	Shaft	1734
042	-15.12012	13.29946	Shaft (large chamber)	1747
043	-15.13199	13.29516	Small cave with child burial	1727
044	-15.13324	13.29746	Small rift cave	1732
045	-15.12039	13.29663	Small cave in abandoned quarry	1702
047	-15.13597	13.36411	Small spring (needs diving equipment)	1776
048	-15.13161	13.36268	Spring in abandoned quarry	1788

Figure 2. Partially flooded gallery in Tchivinguiro cave (Photo: P. Pinto)

Figure 3. Tchivinguiro spring seen from the cliff (Photo: R. Andrade)

stone's superficial appearance. This subterranean horizontal network hosts several large breakdown chambers and galleries, some of them flooded. Formations are abundant.

Several other caves were registered and surveyed in the same hill of the Tchivinguiro spring cave. Their proximity and similar morphological pattern strongly suggest that all are part of the same cave system. Also small digs allowed us to discover and connect new passages to Tchivinguiro cave. Approximately 1.700 m of extension were surveyed in that system. Nonetheless, exploration is not complete.

6. Quartzite caves complex

Karstification of quartzite rock was also expected on the Humpata Plateau. The most noteworthy discovery on this rock formation was a very interesting subterranean network near Lubango, with 23 entrances located so far. It was formed by multiple interconnected crevice-type caves. On this cave complex we surveyed a total of 1.200 m, at depths between 15 to 20 m. Several of the entrances found were not explored and more entrances are expected to be found by expanding the search area on the surface.

7. Cave biology

The expedition did not include a biology specialist, however, in most caves we found biology. It was quite common to find caves inhabited with big bat populations which naturally created large amounts of guano deposits. Several insects (such as ants, crickets), arachnids (such as whip spiders) and even reptiles (such as snakes) were also seen inside caves.

Figure 4. Cave map of Tchivinguiro cave system georeferenced to a Google Earth image.

Figure 5. Cave map of quartzite cave complex georeferenced to a Google Earth image.

In Tchivinguiro cave, fish and crabs were found in the flooded areas near the cave's entrance. However, it was more significant to observe a population of discolored skin frogs in a large pool inside Nandimba shaft, 300 meters away from the system's spring.

8. Archeology

Several archeological remains were seen inside the caves of the area. It was very common to find artifacts such as pottery and human bones.

9. Conclusions

Due to the large area of Humpata Plateau, just a small part of the plateau was covered during the expedition. New caves are likely to be found by future expeditions. Several of the entrances found were neither explored nor surveyed.

The Tchivinguiro cave system was not entirely explored or surveyed and new passages are expected to be discovered in this system.

With regard to the quartzite cave complex, several entrances were just registered and not surveyed. More caves on this rock formation are expected to be found in future expeditions.

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Cave Exploration in Sangkulirang-Mangkalihat Peninsula, East Kalimantan-Indonesia

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Abstract

Sangkulirang-Mangkalihat Peninsula is located in East Kalimantan, Indonesia. Covering an area of 1.867.676 ha, an Oligocene-Miocene limestone within the area exhibits an unique geomorphological karst features. Pinnacle karst and numerous cave systems are among the uniqueness of the area. Exploration by French and Indonesian cavers has been conducted in the past two decades. However, only few caves have been explored, the large portion of the area is still unexplored. The paper documented here is a report of cave exploration conducted in 2016 under the scheme of Tropical Forest Conservancy Act (TFCA-Kalimantan) program. This exploration aimed at providing cave data, especially its importance in bid of promoting better management plan of the area. Sangkulirang-Mangkalihat karst consists of separated and isolated block of karst areas, namely Merabu, Gergaji, Ambulabung, Tondayan, Suaran, Batuputih, and Tabalar block. Different cave characteristics and degrees of development are found within the different blocks as a result of different geological, geomorphological, hydrological controls. 61 new caves were explored of which the 59 caves were mapped using BCRA Grade 5 technique.

Keywords: Cave survey, Cave mapping, Exploration, Sangkulirang Mangkalihat

1. Introduction

Sangkulirang-Mangkalihat Peninsula is an Oligocene-Miocene karst. Administratively, it is located in two regencies of Berau and Kutai Timur (East Kutai) in the province of Kalimantan Timur (East Kalimantan). Sangkulirang-Mangkalihat Peninsula has a lot of unique and fascinating karst features. Not only showed the geomorphological uniqueness, it also contained high-dense archaeological aspects (Samodra, 2006;). This peninsula divided the South-East and North-East part of Borneo with a limestone with less than 1000 m thickness (van Bemmelen, 1949).

This area exhibited a numerous significant karst characteristics. Because of the tectonic and the structural setting of the area, Sangkulirang-Mangkalihat peninsula was divided into several blocks. Sea-level rise and erosion were also significant processes which form current morphological situation in the peninsula (van Bemmelen, 1949). The blocks are: Tebo – Kulat, Suaran, Ambulabung – Tutunambo, Tondayan, Aji – Gergaji, Inaran, and the coastal region such as Batuputih, Biduk-biduk, and Teluk Sulaiman- Teluk Sulaiman block. Each block showed particular features. However, the most karstic landform was the pinnacle karst. It provided high tower karst with a very steep slope.

Sangkulirang-Mangkalihat Peninsula and the karst area within held an important and crucial role in providing ecosystem services and habitat (TNC, 2016). The roles it had were extended from hydrological aspects as the water reservoir, ecological as the provider of habitat for certain species like *Pongo sp*. And also providing cave for bat's habitat (Saroni, 2005), cultural aspects with the richness of rock art and rock shelter, and also as the carbon reservoir. Caves, as the inherent part of the karst cannot be excluded from the significant aspects of the Sangkulirang-Mangkalihat Peninsula and the karst within.

Figure 1. Borneo and Indonesia

2. History of Research

Through the last two decades, explorations had been conducted to explore the speleological aspects on Sangkulirang-Mangkalihat Peninsula. Federation Francaise de Speleologie (FFS) had done three exploration since the beginning of the 2000. In 2002, FFS explored four caves in 2 different blocks (Degouve & Lips, 2002). They mapped Gua Kambing which is one of the largest cave systems in Sangkulirang-Mangkalihat Peninsula with more than 5 km length. In 2007, FFS explored caves in Merabu and Pengadan village (Lips, et al., 2007) where they mapped more than 20 caves. FFS then came back again in 2010 to explore Merabu and Merapun villages (Lips et al., 2010). From Indonesia, Lawalata conducted exploration in Merabu Villages at 2014. They captured not only the speleological features, but also biological and social-cultural aspects (Viedela, Kharismadewi et al., 2015)).

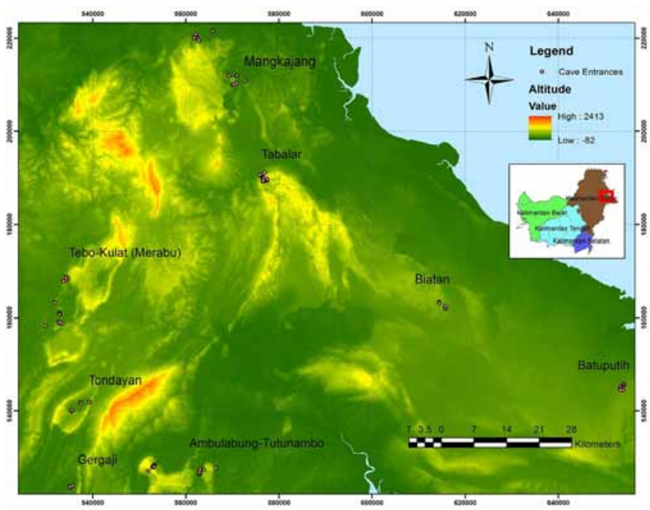

Figure 2. Spatial Distribution of Cave Entrances

3. Materials and Methods

The exploration was done in two terms. The first term was held on August 2016 and the second term on October-November 2016. Each term took three blocks to be surveyed and each block took one week to be done. The speleology team was divided into two different groups. Therefore, in one terms there were six different regions surveyed.

The survey was divided into two categories; they were surface survey and subsurface survey. The surface survey was designed to create the spatial distribution of cave entrances and the setting where the cave entrances were located. The result is the Geographic Information System for the speleology features. To find the entrance, team used local people to guide the team into the cave. However, some entrances were found incidentally while exploring some region.

Sub-surface survey was conducted to capture the spelomorphology aspect of the cave. Team measured the dimensions of the cave to produce speleomorphometry. The results were cave maps as the most important cave exploration product (Kambesis, 2007) and the speleology features such as speleothem, spelogen, and the tabular data. The dimensions were measured using Leica disto ® D510 and Suunto Tandem®. In mapping, team used BCRA Grade 5.

4. Results

There were almost a hundred cave entrances discovered. Most of them were well known by the people in the village and the local guide. Imposed to the limitation of time and the weather condition, not all of the caves are explored and mapped. Some of them were only plotted while others were only explored. Table 1 showed the list of the cave surveyed. There are various characters in every cave surveyed. The characteristics were related with karst geomorphological condition and surrounding environmental settings. One of the characteristics profoundly related is the location of cave entrances found.

Caves were found in the top-hill where the geomorphology was pinnacle with a lot of pinnacle or tower karst. Ambulabung – Tutunambo is the block where most of the caves were located in mid to the top hill. If the geomorphological conditions were plain, most of the caves were found in the base of the hill with enormous hydrological conditions such

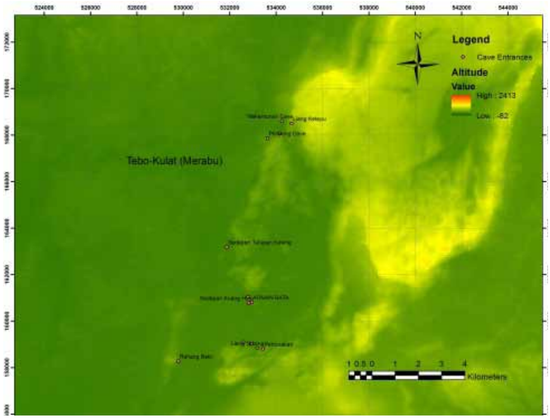

Figure 3. Spatial Distributions at Tebo-Kulat

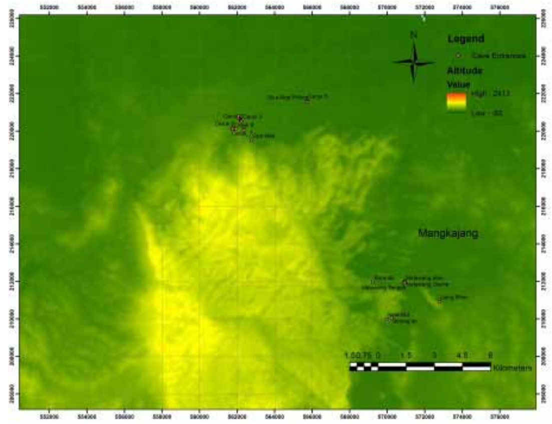

Figure 4. Spatial Distribution of Cave Entrances at Suaran and Mangkajang

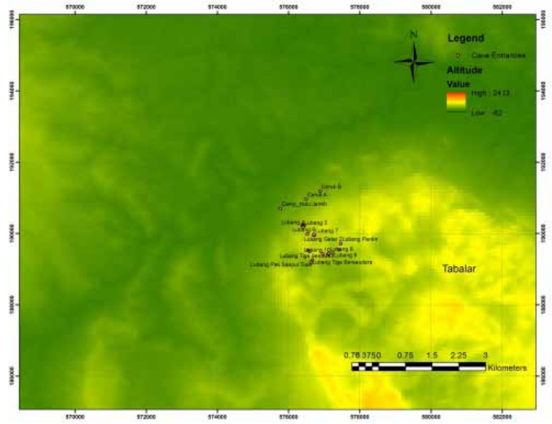

Figure 5. Spatial Distribution of Cave Entrances at Tabalar

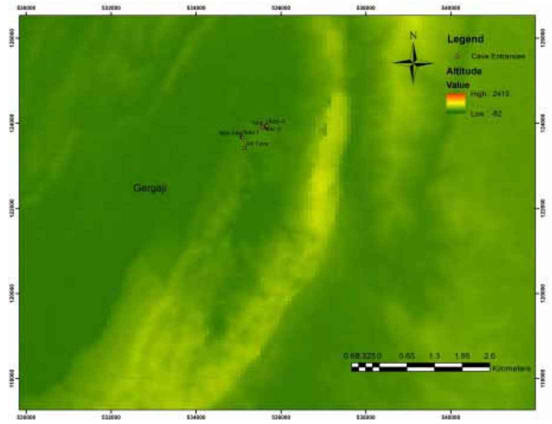

Figure 6. Spatial Distribution of Cave Entrances at Gergaji

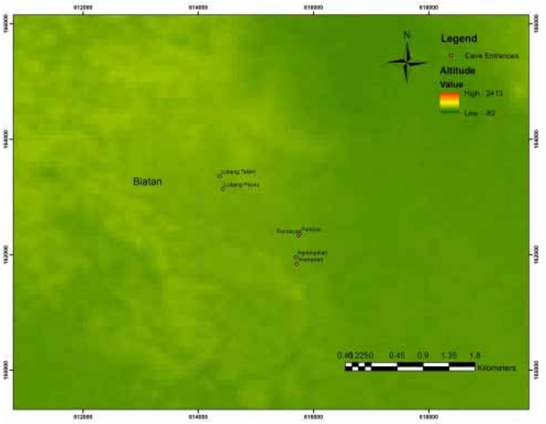

Figure 7. Spatial Distribution of Cave Entrances at Biatan

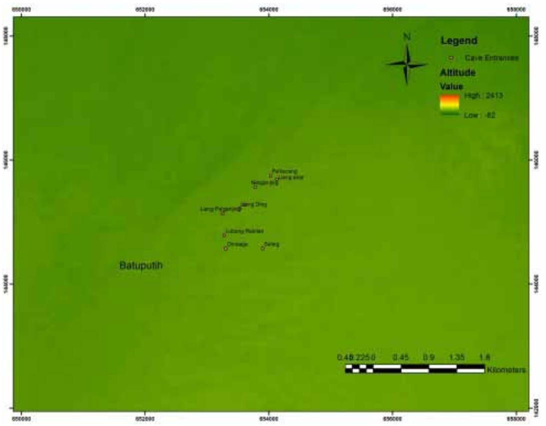

Figure 8. Spatial Distribution of Cave Entrances at Batuputih

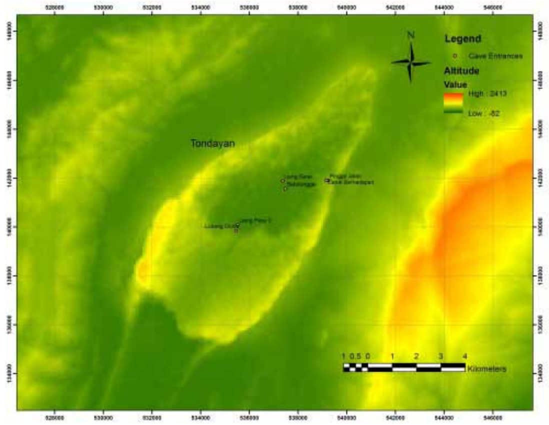

Figure 9. Spatial Distribution of Cave Entrances at Tondayan

Figure 10. Gorge-shaped passage at Liang Kandar, Mangkajang

as underground river or spring. Mangkajang, Kulat and polje of Tondayan are the example of this condition.

Another caharacteristics is the dimension of the cave, whether it was horizontal or vertical. Most of the caves did not have deep vertical shaft. It was related to the location of the survey which took the plain where the hydrological base level had been reached. Therefore, there was no vertical movement of the water as the primary factor which formed the vertical shaft (Bogli, 1980).

Most of the caves were situated in the fresh water phreatic conditions once. The indications for that is the morphology of the passages which exhibited laminar view and the presence of cupola and solution pocket (Ford and Williams, 2007). The presence of the cupola brought swallows into the caves to make nests (Saroni, 2005; Samodra, 2006). Swallow nests collecting became very economically rewarding. They were very highly valued and so many people collected and resold the nest. Almost every cave in the study area was filled with swallow's nest. Therefore, the cave deposits were mostly filled with organic material from the swallow.

The sizes of the caves were relatively enormous. Massive dissolution was happened because the high rainfall and the high density of land coverage. The biggest system explored was Kambing Cave which had been mapped by FFS previously with more than 60 meters high and 50 meters width. Another gigantic system was Lubang Dunia, located in Tondayan block with 40 meters high ceiling. With this size, it is concluded that the karstification rate was in the mature stage because a lot of conduit system was present.

Most of the caves were developed under the control of bedding plane. It was able to be seen from the elliptical form of the cross section of passages (Bogli, 1980). The elliptical passages therefore triggered the incision of the passage. Therefore, a lot of breakdown was discovered inside the cave. An exceptional form of cross section can be seen at Kandar Cave on Mangkajang block where it exhibited gorge passage. It is related with the "deepening in vadose condition" (Bogli, 1980: 153).

5. Conclusion

Almost a hundred caves were discovered and most of them were mapped. The characteristics of caves are related with the massive dissolution and controlled by structure of bedding plane. For the recommendation, exploration should be continued further inside the block to capture the unexplored area not yet investigated.

Acknowledgements

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Figure 11. solution pocket and structure-controlled passage at Punbulu Cave, Biatan

Figure 13. Underground River at Liang Selung, Mangkajang

Figure 12. Bedding plane-controlled passage at Batutunggal Cave, Tondayan

Figure 14. River of Melangan get into a cave, Kulat

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Table 1. List of caves surveyed

1	Kulat	Tutupan Kalang	531863	163188	118	Kaki Bukit	mapped
2		Sedepan Melangan	532594	199088	135	Kaki Bukit	mapped
3		Liang Nikong	533173	158839	220	Mid-hill	mapped
4		Sedepan Koang Ilir	532792	161045	127	Kaki Bukit	mapped
5		Rahang Babi	529772	158278	147	Mid-hill	mapped
6		Areman Bata'	532951	160812	128	Kaki Bukit	explored
7	Tebo	Wakernunuk	534245	168607	0		mapped
8		Kelelawar	534168	168068	0		mapped
9		Ketepu	534663	168501	0		mapped
10	Tutunambo	Gambar Layar	553036	128222	371	mid-hill	mapped
11		Lubang Angin	553156	128069	322	mid-hill	mapped
12		Bunbe'	553293	128147	351	mid-hill	mapped
13		Unmul					mapped
14		Kambing				doline	explored,
15		Turis	551923	127133	443	mid-hill	mapped
16		Berhadapan	553183	128253	333	mid-hill	mapped
17		Atas Lombok	553284	128558	249	mid-hill	mapped
18		Namkul				mid-hill	mapped
19	Ambulabung	Blethok	563876	127381	0		mapped
20		Tenane	563043	127487	0		mapped
21		Kelelawar					mapped
22	Tondayan	Pinggir Jalan	539239	141900	0	mid-hill-cekungan	mapped
23		Liang Serai	537370	141874	0	kaki bukit-dataran	mapped
24		Liang Pesu	535522	140091	136	kaki bukit-dataran	mapped
25		Batutunggal	537484	141566	0	kaki bukit-dataran	mapped
26		Lubang Dunia	535460	139842	0	mid-hill	mapped
27	Gergaji	Arit	535137	123415	0		mapped
28		Tebo Atas	535086	123666	0		mapped
29		Tebo					mapped
30		Tebo 3	535642	123905	0		mapped
31	Batuputih	Liang akar	654129	145688	226	doline	Mapped
32		Pa'kacang	654026	145747	225	doline	Mapped
33		Niniganjing	653775	145563	218	doline	Mapped
34	Batuputih	Lubang Payau	653603	145276	226	mid-hill	Mapped
35		Liang Ding	653523	145214	231	doline	Mapped
36		Seling	653899	144572	226	doline	Mapped, CUE
37		Liang Pa'ganjing	653252	145139	217	doline	Mapped
38		Lubang Rakitan	653278	144784	227	doline	Mapped
39		Omsaga	653304	144573	232	doline	Mapped
40	Biatan	Purinayan	615743	162328	250	doline	Mapped
41		Imanawan	615708	161841	258	doline	Mapped
42		Ingrempihan	615690	161959	250	doline	Mapped
43		Punbulu	615763	162362	218	doline	Mapped
44		Lubang Taken	614372	163363	294	mid-hill	Visited
45		Lubang Payau	614425	163140	262	mid-hill	Visited
46	Mangkajang	Melawang Tengah	570854	211903	72	mid-hill	Mapped
47		Melawang Utama	570933	211996	64	mid-hill	Mapped, CUE
48		Melawang Tengah	570916	211957	78	mid-hill	Mapped

49	Mamkajang	Melawang atas	570924	211936	56	mid-hill	Mapped, CUE
50		Kelencut	569963	209982	120	mid-hill	Mapped
51		Selung air	570221	210050	68	doline	Mapped, CUE
52		Liang Kandar	570854	210305	82	doline	Mapped
53		Kurandji	569227	211953	109	mid-hill	Mapped
54		Liang Bram	572764	210915	99	mid-hill	Mapped
55	Suaran	Gua Nunuk	562065	220793	0	Mid-hill	Mapped
56		Gua Burakat	562077	220708	0	Mid-hill	Mapped
57		Gua Mak	562753	219514	0	Kaki bukit	Mapped
58		Gua Akar Pohon	565716	221563	0	Kaki bukit	Explored
59		Ceruk 1	562182	220609	0	Mid-hill	Explored
60		Ceruk 2	562209	220551	0	Mid-hill	Explored
61		Ceruk 3	562234	220527	0	Kaki bukit	Explored
62		Ceruk 4	562374	220225	0	Kaki bukit	Explored
63		Ceruk 5	562342	220045	0	Kaki bukit	Explored
64		Ceruk 6	565729	221612	0	Kaki bukit	Visited
65		Ceruk 7	561938	220113	0	Mid-hill	Explored
66		Ceruk 8	561737	220163	0	Kaki bukit	Explored
67		Ceruk 9	561775	220083	0	Mid-hill	Explored
68	Tabalar	Gua Pak Musa	577415	189538	507	Top-hill	Mapped
69		Gua Pardin	577463	189718	596	Mid-hill	Mapped
70		Lubang Dua Bersau-dara	576959	189431	455	Top-hill	Mapped
71		Lubang Jernih Tua	576536	189529	559	Mid-hill	Visited
72		Lubang Pak Saepul Tuah	576670	189253	562	Mid-hill	Visited
73		Lubang Tiga Bersau-dara	576625	189198	424	Mid-hill	Visited
74		Lubang Tiga Sekawan	576592	189496	542	Top-hill	Visited
75		Ceruk A	576488	190964	264	Kaki bukit	Explored
76		Ceruk B	576881	191187	294	Kaki bukit	Explored
77		Lubang 1	576380	190234	433	Mid-hill	Visited
78		Lubang 2	576436	190238	418	Mid-hill	Visited
79		Lubang 3	576410	190212	446	Mid-hill	Visited
80		Lubang 4	576391	190192	399	Mid-hill	Visited
81		Lubang 5	576407	190174	455	Mid-hill	Visited
82		Lubang 6	576525	189982	599	Mid-hill	Visited
83		Lubang 7	576714	189949	436	Top-hill	Visited
84		Lubang 8	577238	189457	477	Mid-hill	Visited
85		Lubang 9	577126	189441	356	Mid-hill	Visited
86		Lubang 10	577103	189419	402	Mid-hill	Visited
87		Lubang Getar 1	576703	189949	436	Top-hill	Visited
88		Lubang Getar 2	576705	189970	537	Top-hill	Visited
89	Teluk Sulaiman	Gua Sigending				Mid-hill	Mapped

La Venta Association, 25 years of exploration projects and discoveries

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Abstract

The Association La Venta was founded in 1991 with the aim of organizing and running geographical exploration projects with particular attention to the underground world. In 25 years of activity, La Venta has undertaken explorations in several countries, involving over hundred speleologists and researchers. Such projects are carried out using a multidisciplinary approach, developing new ideas and using new research and documentation strategies. In more than 100 expeditions, this association has documented some of the most unique underground environments around the world, such as the Naica Giant Crystal Cave, the quartzite karst of the tepuis of Venezuela and Brazil, glacier caves in the Alps, in Patagonia and on Antarctica, tropical caves in Mexico, Myanmar and in the Philippines, halite caves in Chile, and high altitude caves in Uzbekistan and Iran. One of the main goals of the projects carried out by the La Venta team is to promote the conservation of the areas in which the expeditions take place and to raise public awareness in the local inhabitants. The La Venta members carry out caving activity in a true "geographical" way, trying to understand the archaeological, historical, anthropological and physical aspects of caves, also involving partnerships with local institutions and UNESCO.

The exploration results have allowed La Venta to be known and appreciated all over the world, both through publications and films, collaborations and advisory activities with governments and cultural and scientific institutions. This article summarizes and discusses the main projects and results of La Venta during its 25 years of life, as well as the current frontiers of exploration projects in progress.

Keywords: speleological expeditions, multidisciplinary research, documentation, speleological association

1. Introduction

In the early 1980s, after some decades of exploration in the karst areas of the Alps and the Apennines, Italian cavers began venturing further away starting a fruitful period of expeditions to remote countries like the Philippines, Mexico, and Pakistan. In 1989, this momentum reached a climax when an international project to explore caves in Uzbekistan ("Samarcanda 89") was finally realized in cooperation with Russian speleologists. On that expedition, explorers reached over 1300 meters of depth in Boy Bulok, the deepest cave known in Asia at that time (Bernabei and De Vivo, 1991).

Building on the success of the Samarcanda expedition, La Venta Geographic Exploration Association was founded by part of this Italian leading group in 1991 with the aim to study other unexplored karst areas around the world. The name 'La Venta' was chosen after the first exploration of La Venta Canyon and its caves in north-western Chiapas (Mexico), during the first official expedition of the team (Fig. 1; Bernabei, 1990). This exploration was an epic geographic discovery that joined adventure, speleology, archaeology and environmental research leaving an indelible mark on the five Italians involved in this first descent. This small group of friends founded the association without imagining that after 25 years it would have grown to over 70 members, from 7 countries (Italy, UK, Spain, Mexico, Venezuela, USA, Argentina), including a wide variety of professionals, like geologists, archaeologists, biologists, filmmakers, renowned cave photographers, rescue technicians, medical doctors, journalists, etc.

Figure 1. The group of explorers and founders of La Venta during the first descent of La Venta Canyon in Chiapas in 1991 (photo T. Bernabei/La Venta).

2. An integrated exploration/research structure

During La Venta's first expeditions to central Asia, southern Mexico, Brazil, and Patagonia, the Association established new standards in cave exploration by changing the focus from depth-records to diversity of cave systems, and from exploration exploit to research. Continuing in this tradition, La Venta expeditions today are based on an interdisciplinary approach to exploration with the goal of finding geographically, ecologically, and socially important underground environments, especially where they are most important for cultural heritage, most at risk and in strong need to be preserved. Exploration is only the first step to allow scientists from universities and research institutions to reach unknown and remote environments that otherwise would be logistically inaccessible or dangerous. In this way La Venta endeavors to expand the commonly held concept of "caves" by discovering and studying speleogenesis in the Earth's most remote and diverse environments. La Venta expeditions are based on the principle that underground exploration is much more than simple geographical mapping or adventure; it's a frontline survey of planet Earth's modern day frontiers, exploring the limits of human curiosity, and promoting the need of "speleological" conservation. By working with local communities, regional and international institutions and universities, and producing books, films, and exhibitions, La Venta intends to serve as a voice for this new era of underground exploration and for the long-term study and protection of the inner side of our planet.

3. The scientific outreach

During the 25 years of La Venta's activity, an increasing attention to scientific investigation has been paid. If the first projects were mainly devoted to exploration of cave systems, the last ones have a strong scientific profile. This trend is well emphasized by the figure 2A, which shows the number of articles published by La Venta members in scientific journals or presented to international congresses.

In the period 1991-2015 the number of scientific publication has been 95, 2/3 of which in the last ten years. The two major peaks in the graph correspond to the years of the international congress of speleology held in Kerrville (Texas, 2009) and Brno (Czech, 2013), testifying a high divulgation strength in international scientific contexts.

A number of these publications are detailed reports on field investigation results and are mainly of speleological interest, but several papers concern high-level scientific researches performed in collaboration with university and scientific institution worldwide (France, Germany, Switzerland, USA, Mexico, Australia, etc.). Researches deal with several topics in earth sciences, in particular hydrogeology, geomorphology, mineralogy and geochemistry, and with archeology, mainly regarding pre-Hispanic cultures in central e southern Mexico. The scientific impact of the main La Venta projects is testified by figure 2B, which shows the number of citations (by Google Scholar) for each of them.

The network of collaboration with universities and research institutions, which la Venta has built over these 25 years, is now a good guaranty for obtaining very interesting results in the project presently in progress.

4. Environmental protection and ethic approach

La Venta operates within environments that are usually of enormous natural value, from the biological, geological and cultural prospective. Some of these sites have already been

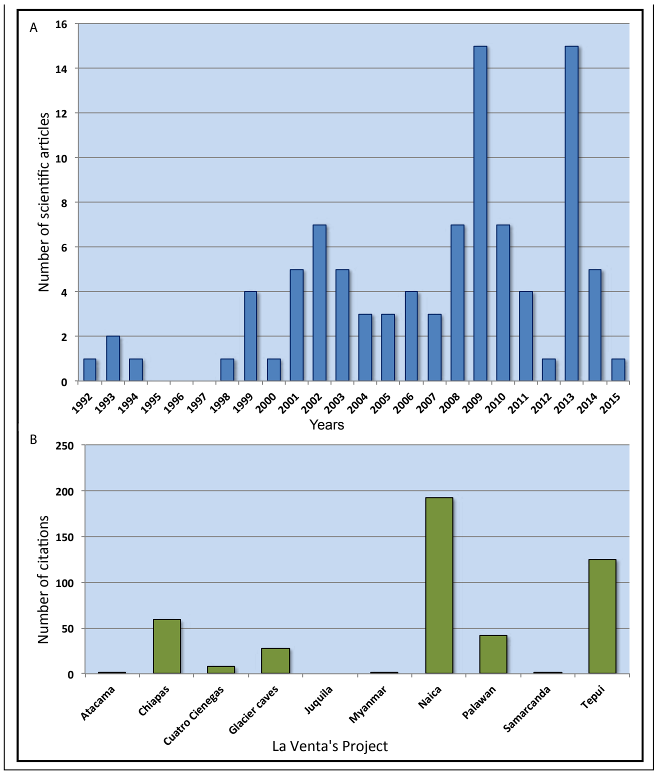

Figure 2. A) Number of scientific publications per year. B) Number of citations (source Google Scholar) for each La Venta project; most citations (192) are those concerning the Naica mine-caves (Mexico), due to the uniqueness of this exceptional hypogenic environment; several citations (125) regard also the project on the quartzite highlands of the tepuis (Venezuela and Brazil), where La Venta had performed exceptional speleological discoveries and detailed studies on the processes that allow the formation of huge cave systems in a so low soluble rock; the third project, for number of citations, is that carried out in the Chiapas state of Southern Mexico since the born of the association, mainly for what concerns the archeological topics. Another important contribution has been that on the glacier caves and englacial water drainage, but the spreading of the results in scientific context is actually not sufficient.

included in UNESCO's World Heritage List, and some have been recognized as park or reserve areas thanks to our activities, such as the Reserva de la Biosfera El Ocote in Mexico (Badino et al., 1999) or the Saint-Paul Underground River in the Philippines (https://www.new7wonders.com).

The team has a long experience in management of pristine and fragile cave environments, in order to avoid human contamination, like in the cases of the Giant Crystal Cave of Naica in Mexico or the ancient quartzite caves of the tepuis in Venezuela. In these years the association has developed some of the most effective protocols to avoid environmental contamination and has served as consultant to minimize the human impact on caves used for tourism purposes by local stakeholders.

A fundamental step of our research and documentation activities is to involve local people in the research and exploration and, when needed, give educational support to them. People living in these karst areas are often not aware of the importance of the resources they are surrounded with. This includes the direct, and equal, involvement of local speleological associations, as specified in the "Casola" ethic code for foreign expeditions that was proposed by La Venta itself for the first time in 1999.

5. Main projects and expeditions

So far, La Venta has organized 94 speleological expeditions and 31 preliminary recognitions to 21 countries in 6 continents, including Antarctica. In total, almost 200 km of caves have been mapped in the most diverse lithologies (limestone, quartzite, gypsum, salt, ice) and environments (tropical forests, deserts, glaciers, high altitude mountains, mines). The main projects of La Venta are focused in areas with high scientific potential. Usually a series of expeditions to these sites is needed to comprehend the whole significance in terms of karstology, environmental and cultural heritage and to propose protection plans for local stakeholders and institutions. The main projects, grouped on the base of different cave environments, are listed here below.

5.1. Tropical karst: Rio La Venta, Palawan, Myanmar

La Venta has devoted most of its efforts to the exploration, documentation and study of tropical limestone karst regions, mainly in Mexico, Philippines and Myanmar. The first project developed by the association was dedicated to the tropical highlands of the Rio La Venta and El Ocote region of Chiapas in Mexico. In 1993 Antonio De Vivo, the leader of the project, won the Rolex Award for Enterprise, starting a fruitful period of expeditions with funding and support from several sponsors and institutions. Starting with speleological and hydrological studies of the area (79 km of caves mapped so far) the researches have been focused in the late 90s also on the archaeological significance of these caves that were used by the ancient Zoque population as water reservoir and sacred burial places. After 25 years the project is still ongoing, with an account of 34 missions, involving over hundred cavers from different countries. Most of the area has been protected under the constitution of the Natural Reserve of El Ocote, and La Venta has acquired a small parcel of the karstic area, with some beautiful caves, in order to promote speleological and ecological education to the local communities. Two monographic books have been published regarding the researches and explorations in the area (Badino et al., 1999; Bernabei et al., 2014), and a register with more than 400 cave maps and locations has been provided to local institutions representing now the basis of the institutional cave list of Chiapas. La Venta has also promoted the foundation of a fully Mexican organization (CEKLAV, Centro de Estudios Karsticos La Venta) to protect and promote continuous researches in the area.

A similar approach has been applied also to other tropical karst areas of the world, like in the case of the Saint-Paul Underground River on the island of Palawan, Philippines. Here the explorations started even earlier than the foundation of La Venta in 1991, but with the arrival of the association a new period of collaborations with the local institutions have started (De Vivo et al., 2009). This cave represents an exceptional biological and geological site, with one of the most extensive underground estuaries of the world. In the last ten years the cave system has been mapped for 32 km of length, and an extensive project of sampling, monitoring, as well as training of local guides, has started in 2016 in collaboration with the Philippines Foreign Affair Ministry. Several scientific articles (Piccini and Iandelli, 2010, Coombes et al., 2015) and one monographic book, endorsed by UNESCO, have been published (De Vivo and Piccini, 2013).

Other explorations in tropical areas have been focused on the unexplored karst of Myanmar state. La Venta has been one of the first speleological organization to promote exploration in this nation of Asia, discovering and mapping several caves and studying the geology and biospeleology in these regions (Piccini et al., 2009).

5.2. Hypogenic caves: Cuatro Cienegas, Juquila, Hundido

During its 25 years of activity, La Venta often dealt with hypogenic karst phenomena. The first and more relevant project in this field was organized since 1999 to 2003 in order to find an explanation to the deep hydrothermal system that feed the several pools of Cuatro Ciènegas, in Coahuila (Mexico; Forti et al., 2003; Giulivo et al., 2007). The Cuatro Ciénegas plain, located in the Sierra Madre Oriental at the eastern edge of the Chihuahuan Desert, is a Natural Protected Area. Although it receives little rain, the plain has abundant subterranean water, which rises in a wide area to form hundreds of pools, marshes, rivers, large, temporary saline lakes and canals with a unique biota of great interest to the international scientific community and which is at serious risk of extinction. Springs and surface water create a groundwater-dependent ecosystem characterized by a high level of endemism and stromatolites. In this area La Venta performed a study which dialed with geomorphic aspects of karst landforms and caves, hydrogeology and geochemistry of groundwaters. During the five years of field investigation about 50 caves were surveyed and studied. Most of them testify to an ancient bathyphreatic regional flow of thermal and meteoric waters, probably similar to that which feeds the present springs (Forti et al., 2003. A monographic book was published about the project in 2004 (Badino et al., 2004). Recently, not far to the Cuatro Ciènegas area, two expeditions to the Hundido cave in the desert of Chihuahua (Mexico), a gigantic 180 m deep shaft in the desert of Chihuahua, have revealed probably the biggest sulfuric underground lake in the world with a surface of 40.000 m2 and a depth not in listof over 70 meters (Bernabei, 2010).

A second project about hypogenic caves was performed in the area of Sierra Mixteca-Zapoteca, south of Tehuacàn (Mexico). The most karstified area is the limestone plateau crossed by the Rio Juquila (or Xiquila) Canyon (Piccini et al., 2004). Four missions, performed between 2002 and 2006, have discovered more than 50 caves. In the area just to northwest of Santa Maria di Ixcatlàn, some caves of thermal origin have been surveyed during the last mission. These caves display dissolution features due to underwater processes, which probably attained during the rise of thermal waters.

5.3. Extreme hot caves: Naica and Kronio

In the year 2000, excavations in the lead-silver mine of Naica in the Chihuahua State in Mexico accidentally intersected one of Earth's underground wonders: the Cueva de los Cristales (Fig. 3). This is a cave whose walls are completely covered with gypsum crystals, some of which are longer than 10 meters. Since 2006, La Venta has been promoting the Proyecto Naica, organizing a total of 7 expeditions together with Mexican partners; the project aimed at documenting this extraordinary phenomenon, both in a scientific and in a popular way. In order to make this possible the team had to develop new

Figure 3. The exploration and study of the Giant Crystal Cave of Naica in Chihuahua remains one of the main milestones of La Venta (photo P. Petrignani/La Venta).

technological solutions that allowed to survive in the extreme operative conditions found inside the cave, with a temperature of 47° C and a humidity close to 100%. Research institutes from all over the world, including NASA, were involved in many science-related researches (Forti and Sanna, 2010). The Proyecto Naica allowed setting up conservation, protection and divulgation criteria for this system of caves, with micrometeorological analyses, environmental monitoring, evaluation of anthropic impact, studies of interaction with external meteorology and long-term drift of environmental parameters. The same technologies that allowed exploring Naica are now used by La Venta in other extreme exploration projects, like in the hot hypogenic cave of Mount Kronio in Sicily, rich of archeological remains from the Ancient Greek and Roman period.

5.4. Quartzite karst: Venezuelan and Brazilian Tepuis

La Venta has worked on the Tepuis of Venezuela since the early 90s as a pioneer in the exploration of cave systems carved in quartzite rocks. The "quartzites" project started to reveal how karstic cave networks could form within extremely hard and low solubility rocks. In these years, the explorations in these regions not only demonstrated the existence of large, complex underground systems that offer an enormous exploration potential, but also allowed to understand the speleogenesis in quartz-rich lithologies. The project reached its apex in February 2013 when La Venta, together with the Venezuelan team Theraphosa, discovered Imawarì Yeuta Cave, located on the Auyan tepui not far from the famous Angel Falls. This complex labyrinth of galleries and huge rooms is characterized by exceptional biomineralizations of opal and diffuse deposits of gypsum. During February 2014, with a multidisciplinary scientific mission, the cave system was mapped for over 23 km becoming the world longest cave in quartz-sandstone. For this discovery the project leader Francesco Sauro won the Rolex Award for Enterprise in 2014, the second member of the association to receive this honour.

The caves of the tepuis represent a real "window" open on the past because they are isolated from the rest of the world for millions of years. The study of biospeleothem formations, (such as stromatolites, but built with silica by bacterial communities) is providing new insights into the evolution of life on Earth. La Venta discovered also a new mineral for science here (a sulphate-phosphate named rossiantonite) (Galli et al., 2013) while other extremely rare minerals were documented, such as Sanjuanite. Biologists discovered also new cave animal species, such as a blind catfish that was trapped for hundreds of thousands of years in an underground river inside one of those mountains. Thanks to the Rolex Award support other three expeditions have recently been organized to the farthest tepuis of the Amazonas region, starting new explorations in massifs like Marahuaca (Venezuela, 2015), Aracà (Brazil, 2015) Sarisariñama (Venezuela, 2016) and Chiribiquete (Colombia, 2017).

5.5. Glaciospeleology: Alpine glaciers, Patagonia, Iceland and Antarctica

La Venta has been active on the world's glaciers for more than 20 years, studying the caves that form inside the ice. The research started in the Alps, then moving to Central Asia, Iceland and Antarctica, ending up focusing most of our efforts on the famous glaciers of Patagonia. Over the years, we have started to understand the processes that generate the caves and the internal drainage network of glaciers, exploring also the longest epidermic ice cave in the world in Perito Moreno (1150 m, Piccini et al., 2014), Argentina. At present we are trying to understand the dynamics of glacier karst in specific, "non-classic", cases, as well as returning to glaciers we explored years ago in order to understand how climate changes are affecting their deep structures.

In Antarctica we discovered different phenomena, in which the genesis of caves is due to cycles of sublimation in environments with a temperature below -20 °C, the coldest caves ever explored so far. Another interesting topic is the direct, scuba diving exploration of inner water pockets that, in the event of a sudden release, pose a threat for the populations living downstream the glacier. "Caves of the Sky", the book we published on these topics, was endorsed by UNESCO and won the Gambrinus Prize in 2005.

5.6. High altitude caves: Baysun Tau

One of the first projects carried out by La Venta was the exploration of high altitude caves in the Pamir-Alaj mountain range between Uzbekistan and Tajikistan in collaboration with the Caving Club of Ekaterinburg. This area was fascinating for the altitude of these caves, some of them at almost 3900 m a.s.l. and with great potential for extremely deep explorations. The most exciting result in the early 90s was the first descent of Boy Bulok, an "impossibly" narrow 9 km long meander, down to a depth of 1300 meters. It was the deepest cave in the whole continent and it remains one of the most challenging in the world.

Since 2011 La Venta has restarted the project in synergy with the Russian friends bringing new discoveries in the Dark Star cave (actually -930 meters of depth, 14 km of development) and searching for potential high entrances of the Boy Bulok system that could potentially extend the cave to other 2000 meters of total depth.

5.7. Salt caves: the Atacama desert

Following two scientific campaigns to Atacama in 2007-2008 with the Earth Science Department of Bologna (Italy), during which the importance of the halite caves near San Pedro de Atacama was ascertained, in 2016 La Venta decided to back up a speleological expedition organized together with the Commissione Grotte Eugenio Boegan of Trieste. The aim of this expedition was to document the variety of the salt caves in this area, and the speleological results obtained by the Trieste cavers over the past 10 years in this area. Over 50 caves are known in the Cordillera de la Sal, for a total development of more than 15 km (De Waele and Padovan, 2016). These systems, some of them among the largest halite caves in the world, host a very large variety of cave minerals and speleothem types, the origin and evolution of which has been studied in detail. This extremely interesting halite karst will be the object of further detailed explorations and especially scientific research, to unravel the genesis of the caves and their deposits, and understand their paleoclimatic and paleo-environmental significance.

5.8. Other projects

La Venta has dedicated some recognition and expeditions also to other unusual karstic environments on Earth, like the desert regions of Mongolia and the island of Socotra (Yemen, this project has been temporarily frozen pending the change in the security situation in the area due to political and religious crisis). Exploration has not been limited to caves but also to deep canyons, like in the case of the Durango project in the Sierra Occidental of Mexico where some of the deepest canyons in the world have been descended and documented for the first time. In June 2016 a new project has started with the aim to explore volcanic caves in the north of Isla Isabela in the Galapagos archipelago.

6. The Future

At the beginning of the third millennium, the total amount of cave passages which has so far been explored throughout the world amounts to barely 15,000 kilometers, most of those surveyed in the past thirty years. In reality, the total amount of cave passage potentially existing in the Earth's crust probably is a thousand times greater. We are at the beginning of the great age of underground exploration, and there are many frontiers left to explore.

This lack of knowledge about the underground world is also a call for conservation. Caves are fragile, endangered ecosystems with limited energy to recover from disturbance, yet they are vital to the health of our planet. In the years to come, the La Venta Exploring Team accepts the challenge of exploring and protecting this awesome underground frontier. Through interdisciplinary research and documentation, we intend to increase humanity's awareness of caves as a fundamental part of any natural environment and of every geographic endeavor.

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Ten Years Of Prospecting, Exploration And Documentation Of Caves At Bulha D'água Region And Surroundings, Brazil

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Abstract

Located in the high valleys of the Ribeira de Iguape basin, 300km south of the Sao Paulo City, southeastern of Brazil, the Bulha D'Água region comprises a complex karst system with caves, underground rivers, dolines and surface relief forms, rich fauna, archaeological and paleontological remains covered by the amazing Atlantic rainforest.

Characterized by the difficulty of access, long trails in the forest and use of advanced techniques of exploration the region was sparsely explored during the decades of 1970-1990, but only in 2004 did the systematic effort of exploration and documentation of caves in this region begin, leading to great discoveries of a huge complex of caves, new species of fauna and paleofauna.

The work intends to deepen the knowledge about the area and has already generated new research in adjacent regions, expanding the possibilities of discoveries. One of the current objectives is to contribute to its effective conservation and to studies to public use with benefits for the local economy and as an alternative work for the residents of the region.

Keywords:

1. Introduction

The Bulha D'água region is located in the upper valleys of the Ribeira de Iguape River Basin South of the State of São Paulo and is partially included in two important protected areas, the *Parque Estadual Turístico do Alto Ribeira* (PETAR) and the *Parque Estadual de Intervales* (PEI), which together receive more than 50,000 annual visitors in search of adventures in rivers, rainforests, waterfalls and caves. It is one of the main speleological regions of Brazil and one of the most studied and explored with more than 600 known caves and one of the initial areas of Brazilian caving.

This region is one of the most remote areas of these parks, presenting precarious access, dirt roads that part of the year are inaccessible and long walks. Visiting is restricted to the researchers, with minimal infrastructure, such as no electricity, telephone or radio communication.

The landscape of mountainous relief, deep valleys, limestone walls, rivers and waterfalls, holds a spectacular richness of caves, abysses, sinkholes, springs and other karst features covered by the fascinating Atlantic Rainforest. Sparsely explored in the 1970s, 1980s and 1990s, only from 2004 began systematic exploration and documentation work coordinated by the *Grupo Bambui de Pesquisas Espeleológicas* (Bambui Group of Speleological Research).

The exploration represents long journeys in the middle of the forest, overcoming falls over 400m and becoming more challenging during the wet season, with mud and fallen trees blocking the way; facing storms, mosquitoes, living together with the constant presence of jaguars watching us, snakes and venomous spiders lurking, risk of flooding, fatigue, discomfort and distant from a point of support with medical attention.

The caves are the dark continent and one of the last unknown frontiers of the Earth, which provide the possibilities of challenge and discovery. The exploration of caves is closely related to our curiosity and to our desire of adventure and it is an activity that, reconciles technical and scientific knowledge, physical and psychological preparation.

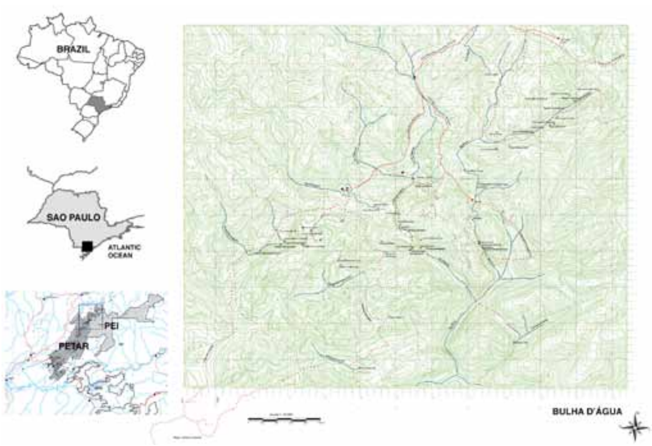

Figure 1. The Bulha D'água Region.

These characteristics make Bulha D'água a privileged place for speleological practice. It presents a most stimulating prospect; the exploration of caves. In relation to their condition, curiosity, persistence, techniques of exploration and friendship are the only components that are important for the discovery of new caves and passages.

Besides the region of Bulha D'água, the core of the expeditions, the work spreads throughout a larger region surrounding it like the Valley of Buenos, Caboclos, Fundão and Figueira Valley.

2. Main caves

Buenos I Cave - One of the largest caves in the region with 2,690 m of development and 47m deep, with large and ornate galleries (Image 2).

Buenos IV Cave - Discovered during the works of the Bambui Group in 2009 it presents one of the biggest salons of col-

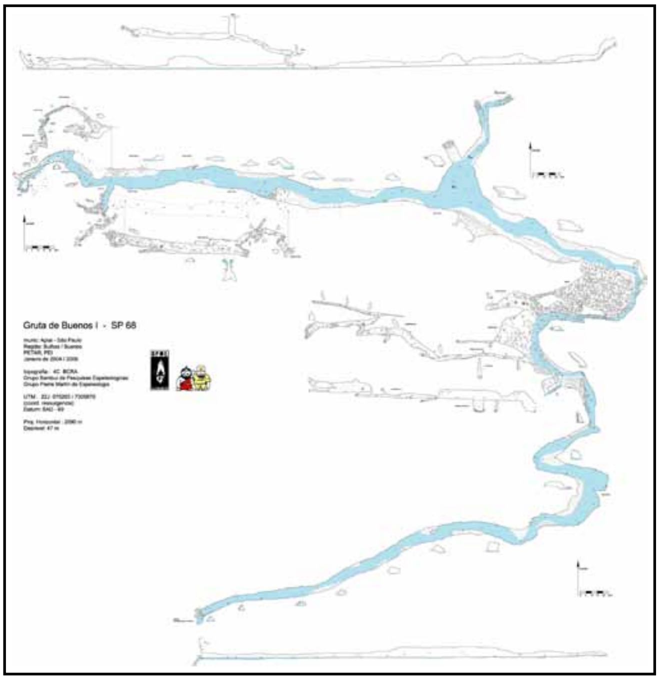

Figure 2. Buenos I Cave

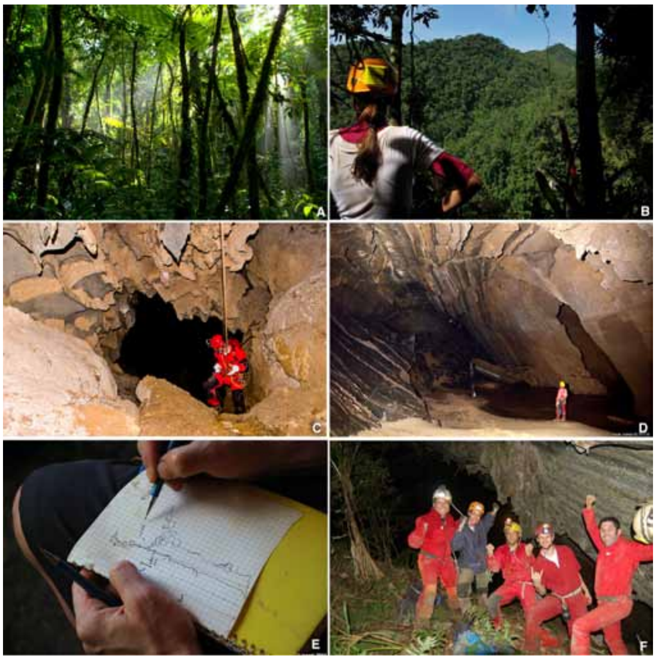

Figure 3. A Atlantic Rainforest (Marcos Silverio), B Karst Landscape (Alexandre Iscoti Carmago), C Vertical Exploration (Marcos Silverio), D Buenos IV Cave (Alexandre Iscoti Carmago), E Mapping (Alexandre Iscoti Carmago), E Buenos IV First Exploration (Alexandre Iscoti Carmago)

lapse of the region. It has almost all its limits explored, leaving some possibilities in superior galleries that are hard to access. During the exploration of its wet gallery a connection was found with the Buenos River and with the Buenos II Cave.

Ribeirãozinho III Cave, with 1,990 m of development, 180m deep and great volume of the galleries, is one of the great caves systems of the region being the resurgence of the River of Ribeirãozinho in the Valley of the Rio Buenos with its sink in the Ribeirãozinho II Cave and João Dias Cave and having the Los Tres Amigos Abyss among them.

Los Tres Amigos Abyss, is still under exploration at 212m deep and with huge galleries which requires the use of advanced techniques of vertical exploration. These are challenging the exploration teams finding good anchorages and safe exploration processes. It is the middle segment of the Ribeirãozinho II - João Dias - Ribeirãozinho III Cave system and a connection among them has been sought for almost 10 years.

In the last ten years, about 66 caves were mapped, 54 of which were discovered from a total of more than 100 known caves in the region, totaling more than 11,000 meters of topography and 30,000 meters of open and geo-referenced trails. In the systematic work carried out by more than 90 people in the field, led to new discoveries of subterranean fauna, archaeological and paleontological remains and interesting geomorphological features awaiting specialists from other areas are prepared to explore and explore the roads and trails in the middle of the Atlantic forest.

3. Field Activities

The field activities are characterized by the study of maps and aerial images of the region, prospecting with geo-referencing of trails, access and caves, and opening and maintenance of trails, exploration and mapping of caves, photographic documentation and publication of activity reports. Information on observations of relevant occurrences on the ecosystem, fauna, geomorphology, archeology, paleontology, etc. is collected and disseminated with the objective of supporting and encouraging and collaborating with specific research and in each of these areas (Image 3).

Field teams are usually restricted to a small fixed group with a floating number of occasional participants, who, with rare exceptions, never return because of difficulties.

The work received basic support from a local resident and friend, Zé Guapiara, a deep connoisseur of the region, cave lover and enthusiast of the exploration. He collaborates with the exploration, being responsible for several discoveries.

Due to the topographical characteristics and the locations of the tracks, the supply of water for consumption is not frequent, a condition that imposes the need to carry a supply of water and food for the journeys and camping in the middle of forest or in caves and need to carry all equipment to the points of exploration. With the progress of the work, the difficulties increased, new areas becoming increasingly distant and demanding more time and effort, with roads and trails with poor or abandoned maintenance making access more difficult.

4. Cave exploration

Although current techniques of vertical exploration, good lamps and equipment are used, the most important techniques responsible for the work progress are stubbornness, persistence and friendship. It is very important to keep the continuity of the work and the group united. Tight passages, crawls, fallen blocks, mud, climbing with precarious safety, frustrated walks in the middle of the woods, often returning without even an explored cave or after long and tiresome climbing efforts resulting in a great cul-de-sac is difficult but which often holds great rewards (Image 4).

Figure 4. *Photos (Alexandre Iscoti Carmago)*

Due to the difficulties of access there is a rule that we always follow; only what is mapped is explored. This always leaves the doubt of any continuation to encourage the return of the team.

5. Conclusion

Bulha d'água can be considered one of the last regions of the State of Sao Paulo where caving can be practiced as decades ago. It has a remote location and limited infrastructure, and caves to be discovered. It is the unknown that motivates the explorers and the friendship that keeps the group excited and united.

Bulha d'Água is a region that continues to be promising and challenging and will certainly require the dedication of many more hours of work by speleologists and researchers until we have a complete understanding of all the potential that it possesses. Frustrating or encouraging but never boring days.

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(Abstract) Cavity searching and 3D density mapping via muon tomography

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Abstract

Locating a totally unknown cavity is still a big challenge for the cavers, and also for the geophysicist, despite the increasing sensitivity of various techniques. The palette of applied methods is widespread: gravity measurement, geoelectric methods, seismics, or the one of the most recent development, the muon radiography or tomography, the using of high penetration cosmic muons similarly to the X-ray technology at larger-scale. We present here a density mapping and cavity searching project based on muon tomography above an artificial tunnel system in Budapest, capital of Hungary. There is also a natural cave starting from the middle of the tunnel system, and the area is very promising for finding unknown cavities either natural or hidden artificial ones. This place has been chosen to perform a detailed muon tomography project. The main goals were to test the whole data acquisition, evaluating and inversion process and also to find possible unknown caves. The muon tomography has been used in combination with geoelectric measurements and elaborated geodesy to provide detailed data for a fine scale geophysical inversion. The key tool, the high resolution, portable and low consumption muon detector has been developed and built by our group. The project was successful, we could locate unknown cavities. The measurements are still going on and we are planning the final validation by drilling, but the results qualify us for the strong hope that this method will be a particularly useful tool for the cave explorers.

(Abstract) Photographing New Zealand's subterranean wilderness

Marcus Paul Thomas

Affiliation: *New Zealand Speleological Society*

Abstract

In 2014 Neil Silverwood and Marcus Thomas shared a dream to create a book that showcased the best of New Zealand's caves. That project has taken them to some of the most remote places beneath New Zealand in an effort to photograph and document some of the wonders of exploration.

The creative challenge of photographing, writing and illustrating the book was a journey worth documenting in its own right. From leading and documenting an astounding dye trace beneath Mt Owen, to photographing unique formations at the back of Bulmer Cavern, Neil and Marcus were able to catch some rare footage of caving in New Zealand. Determined to document exploration underground at the sharp end the presentation contains images of major discoveries in New Zealand caving as they happened.

Topics covered in their book of images include the connection of Stormy Pot/Nettlebed NZ's deepest cave, the Mt Owen Dye trace from Bulmer Cavern to Blue Creek, and Moa and Haast's eagle remains in caves around Northwest Nelson.

This presentation is about the process of creating a photographic book on caving and some of the adventures they had along the way.

Exploring for New Caves on the Nullarbor Plain, Australia

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Abstract

The Nullarbor is a large limestone plain of some 200,000 km^2 (Webb & James 2006). The original cave exploration of the Plain used local knowledge gained from the Mirning aboriginal occupants, the pastoralists and kangaroo, rabbit and foxhunters to locate caves. Systematic cave exploration found most of the deep caves of the Plain that extend into the Eocene Wilson Bluff Formation by the 1960s. Detailed further exploration used interpretation of aerial photographs to locate new caves. Expeditions each year since 2000 using an ultra light plane by members of the Victorian Speleological Association (VSA) have been conducted searching for new caves and karst features.

Each year an area of up to 1,600 square km^2 was systematically flown recording features using a GPS. Search groups then ground truthed the sites. Over 2,500 new caves, blowholes, karst features and rockholes have been discovered through to 2016. The spatial distribution of caves is now better understood as well as their speleogenesis. Valuable deposits of extinct megafauna have been made together with their palaeoclimatic context and dates. Cave discoveries with artwork in the form of hand stencils have been found as well as numerous rockholes with evidence of indigenous use and these are adding to knowledge of indigenous use and travel on the Plain. Decreased biodiversity has been revealed from the examination of owl pellets from under feeding roosts within the caves. There is much further scientific work to be undertaken on the caves and their contents discovered during these expeditions.

Keywords:

1. Introduction

Just as the Great Barrier Reef or Uluru are iconic Australian places so is the Nullarbor Plain. The early post World War 2 period when transport was becoming better and there was a relatively large semi-permanent population on the Nullarbor Plain was when systematic cave exploration began. The early cave exploration relied on both local knowledge in locating caves and also from Joe Jennings of the Australian National University who systematically examined aerial photographs for the presence of caves. From this he prepared lists, which classed sites according to whether they were good, medium, or less likely to have open caves. A series of cave discovery expeditions through into the 1960s used this information to find new caves on the Plain. Most of the deep caves were discovered through this period although dive exploration really did not start until 1970.

The enigma of how blowholes formed and how many there were was a puzzle. Lowry (1968) estimated there were 10,000 – 100,000 which was reiterated by Lowry and Jennings (1974). These conjectures played on Ken Boland's mind, which led him to go bushwalking for 3 days only to find 9 small caves or blowholes. Ken decided to apply his gliding knowledge to the question, which led to the acquisition of an ultra light plane for the following year (Figure 1). With aerial spotting of sites possible the search for caves could extend away from existing roads and tracks and explore for caves and sites not visible from ground level (Boland et al 2009). The year 2000 was the first VSA expedition to the Nullarbor using the ultralight plane. This first expedition was extremely successful and expeditions have been conducted each year since then, with the exception of 2005, through to 2016 (Figure 2).

The objectives of these expeditions have been to find all features of interest and this embraces caves, dolines, rockholes or other karst features and to explore and document those found. Other environmental conditions have also been documented such as the owl pellet studies for biodiversity studies.

Figure 1. Ken Boland in Flightstar Ultralight Plane (Photo D. Carr)

Figure 2. Exploration blocks flown from 2000 to 2016

2. Methods

Exploration for new caves on the Nullarbor requires both time and persistence. The Nullarbor is a long way from modern support services and risk management is one of primary objectives in planning. Each year an area north of the

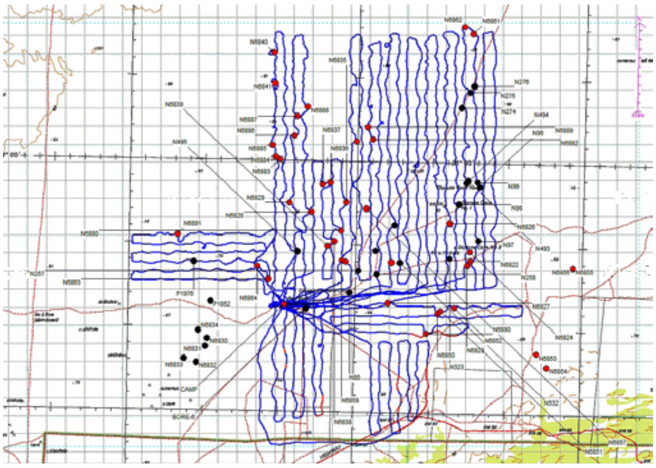

Figure 3. Flight paths of 2016 expedition showing red dots new caves and black dots known caves

tree line (for emergency landing purposes) up to 40 × 40 km^2 is selected for investigation near a reasonably accessed road or track The actual campsite is not determined until a reconnaissance flight is undertaken to find a grassy flat for an airstrip.

Expedition planning is for three weeks in camp with sufficient food, fuel, water and people to support the flying and on-ground exploration parties to ground truth the sites located from the aerial surveying.

Flight information consists of GPS points with a note whether the point is a blowhole, an entrance, a rockhole or a "village". Villages are normally pavements with a rockhole with animal tracks leading into the rockhole and on occasion there may also be a blowhole. This flight information was originally plotted on paper maps but is now entered into a laptop computer using the mapping program, Gartrip, which is used to plot the data. This data then forms the basis for downloading to GPS units for use by search parties (Figure 3).

Ken Boland undertakes a lot of preparation of the aircraft before each expedition. During an expedition he uses weather data to plan flying days, which are as calm as possible. He has aboard a UHF radio, emergency flares and an EPIRB, which notifies a central emergency base in Canberra, which can start a search. Each days flight plan is left in the camp and this restricts the area he is flying that day.

Initial expeditions relied on walking to sites or using vehicles. The 4x4 vehicles produce tracks that remain for years as well as getting many flat tyres that need fixing as bluebush (*Chenopodium sp*) produces very hard wood that punctures tyres easily. Bicycles were tried but were not much better than walking. More recently, ground search parties consist of walking groups for sites close to existing tracks or small motorbikes that leave minimal tracks and can cover long distances in a day.

3. Results

From year 2000, the rewards have been apparent as each flight logged new sites for ground checking. The ground search teams use the GPS site locations to find the sites. In nearly all instances sites were confirmed within a 30 m radius of the GPS location. Occasionally in very rough or windy flying conditions the search locations are further that 30 metres. Nearly all sites are confirmed as blowhole, cave or doline as specified

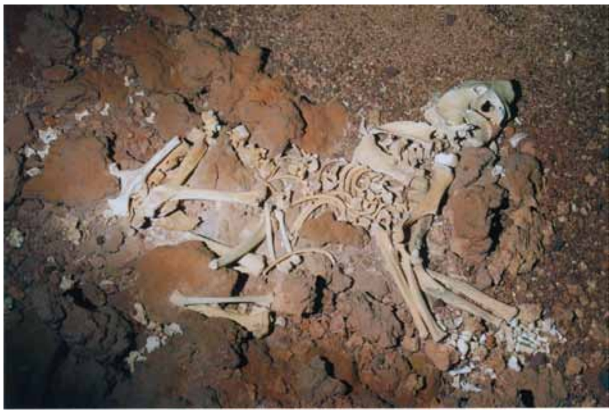

*Figure 4. Marsupial lion (*Thylacaleo carnifex*) in situ, Pliocene age (Photo K. Boland)*

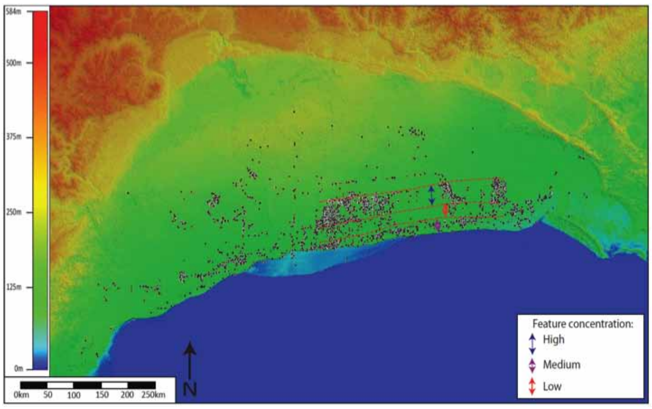

Figure 5. Distribution of caves on the Nullarbor (After Burnett et al 2013)

but occasionally wombat holes or animal diggings at the edge of pavements are not numbered.

The 2002 expedition was significant in that we found a large number of blowholes but also three shallow caves that had distinctive bones. These were of the extinct Marsupial Lion (*Thylacaleo carnifex*) (Figure 4). This discovery was reported to the Western Australian Museum and led to a series of expeditions to retrieve material and study the context of when the animals were on the Plain. The discovery has led to finding extinct species of tree kangaroos and bird faunas that are out of context for the current environment and point to much higher rainfall periods in the Pliocene into the early Pleistocene. (Prideaux et al 2007).

It was apparent to us after several expeditions that the blowholes we were finding were oriented in an east to west band. These blowholes were typically a few metres deep and in some instances had short lateral stream passages with occasional bell holes or domes. This east-west band of blowholes was extended as each expedition added to the data (Burnett *et al* 2013) (Figure 5).

Each year we moved the search area further east i.e. into South Australia and explored the Nullarbor Regional Reserve. These expeditions continued to be very productive in terms of new caves and blowholes found as well as evidence of indigenous use. In recent years, the land ownership has changed and the State co-manages the area with the aboriginal owners, the Mirning group. Mirning representatives have participated in several of our expeditions. Our discoveries of rockholes and of caves with red ochre hand stencils has added to missing

Figure 6. Thylacine skeleton (Thylacinus cyanocephalus) (Photo Steve Bourne)

knowledge as it is several generations since the Mirning lived on this part of the Nullarbor.

The 2015 expedition discovered a cave with Tasmanian Tiger (*Thylacinus cyanocephalus*) skeletons still with skin and whiskers intact (Figure 6). These were carefully retrieved during the 2016 expedition by a team of palaeontologists equipped to retrieve the DNA of the specimens. We still await results. The last living Tasmanian Tiger died in the Hobart Zoo in 1936. On the mainland the Thylacine did not survive the introduction of the dingo that was introduced about 4,000 years ago. Nullarbor cave specimens have been dated to several 1,000 years BP. The age and DNA from these latest specimens will be valuable in adding to our knowledge on the mainland Tasmanian Tiger.

For several years, we have collected owl pellets from the genus Tyto from feeding roosts within the caves. These pellets have been examined for dietary remains. The results are disappointing as the current diet consists of house mouse (*Mus musculus*) (Patricia Wooley, pers com). This is an introduced species but the bone piles under the cave feeding roosts have at least 18 mammal species. The biodiversity of the Nullarbor has been seriously modified by changes due to the introduction of predators such as the cat, fox and competitors such as the rabbit.

4. Discussion

These expeditions have proved productive and rewarding for everyone. They take careful planning not the least of which is Ken Boland's capability with the aircraft. He replaced the first plane due to age and obtained another one that needs to be kept in good condition with services and inspections between trips.

The discovery of caves with the Marsupial Lion skeletons initiated intensive scientific investigation by Prideaux who discovered a new tree kangaroo (Prideaux, GJ 2007). This put things out of context until Jon Woodhead's Uranium-Lead dating technique was validated for cave speleothems and this gave accurate Pliocene dates for material associated with the Marsupial Lion caves (Woodhead et al 2006). These speleothem studies have now been extended to examination of the pollen present and profiling the flora present during wetter periods in the Pliocene and Pleistocene (Sniderman et al 2016).

5. Conclusions

These expeditions have been extremely successful. The use of an ultralight aircraft to locate sites has meant we have investigated, explored and documented over 2,500 new caves and features. These have enabled a better understanding of speleogenesis in that there are at least four groupings of caves. The deep caves, the shallow caves close to the present coast, a band of caves attributable to a flank margin setting and a possible fourth group of caves at or north of the Transcontinental Railway (C. Brown pers comm). The 2002 finding of caves with remains of the Marsupial Lion, *Thylacaleo carnifex*, led to important scientific findings of other extinct megafauna that were completely out of context for the present climatic conditions of the present Nullarbor Plain.

Our findings of rockholes and caves with evidence of human use and travel routes provide knowledge that has been lost by the Mirning since European settlement The regional extinctions of the mammalian fauna due to introduced predators are a tragedy that is not restricted to the Nullarbor in Australia.

The use of an ultra light plane to find caves and features on the Plain during these expeditions may be replaced by higher resolution imagery and use of better satellite photography, Lidar or the use of drones. However, it has been the visual acuity of the human eye from a 200 m altitude that enabled this systematic search for caves and karst features on the treeless part of the Nullarbor Plain to be so successful.

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Extraterrestrial Caves

Speleology As An Analogue To Space Exploration: Five Years Of Astronaut Training, Testing And Operations In The ESA CAVES Program

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Abstract

Since 2008 the European Space Agency has studied the possibility of using caves as a natural platform for astronaut training, investigating analogies with space and with International Space Station (ISS) missions. With this purpose in 2011 a new ESA training programme named CAVES was launched, involving astronauts from Partner Space Agencies. During five editions of CAVES, from 2011 to 2016, 28 astronauts from space agencies around the world (ESA, NASA, JAXA, ROSCOSMOS, CSA, CNSA) have taken part in the training. CAVES has been recognised by all participant astronauts and, in particular, by experienced spacefarers, as a very realistic spaceflight analogue, providing unique multicultural operational team training opportunities, in one of the best space analogue environments available on Earth. The space community has thoroughly recognized the value of the experience that speleology is acquiring in cave exploration, to be applied for future planetary missions, both on current and future orbital and surface and subsurface missions on planetary bodies..

Keywords: natural caves, teaching, training, scientific experiments, science, technological testing, analogue environments, planetary exploration, human spaceflight, astronauts

1. Introduction

Space agencies are concerned with training of their astronauts for long duration missions, not only for current and future orbital missions but also for future human and robotic planetary surface exploration. Preparing for expeditions to other planets requires a realistic replication of environmental and situational characteristics of the extreme conditions of space in earth analogue platforms, where stressors similar to those encountered in long duration spaceflight are provided (Morphew, 2011).

The environments in which such training events are carried out must have realistic perceived risk and must enable the execution of complex technical tasks, as well as requiring group living in isolated and/or confined settings. This requires the identification of suitable terrestrial analogue environments and the design of high-fidelity training courses / mission scenarios with representative operational set-up.

Since 2008 ESA studied the cave environment as a potential platform to create space exploration analogue missions. This resulted in the creation of "CAVES" (Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills), a training course specifically designed to prepare astronauts for long duration space missions. In this article we describe the main analogies developed in the training, course philosophy and structure, as well as the overall feedback of astronauts participating to the activity and the potential future evolution of the training platform.

2. Environmental and expeditionary analogies having an impact on stress and team behaviour in caves and in space

The cave environment naturally shares several of the stressors that are usually found in human spaceflights (Morphew, 2011). From a physiological point of view the absence of natural zeitgebers (environmental time cues) can cause alteration of the circadian rhythms (Shulz and Steimer 2009) and the related physiological stress can be avoided only through earth-like work/rest schedules, similar to those developed for the ISS. In the dark environment of a cave there is a decrease in sunlight exposure requiring consequent adaptation to artificial light, similar to conditions on the ISS, due to confinement and the sixteen day/night cycle / day, and for future interplanetary travel, due to dimming of light, as well as the need to live in artificial habitats. The three-dimensionality of cave passages, the lack of common references, and the presence of shadows and darkness is confusing the orientation capabilities causing a hostile perception of the environment, similar to that experienced during Extravehicular Activities (EVA).

Also from a psychological and psychosocial point of view many of the spaceflight stressors are present in cave exploration. When inside a cave, possibly days of progression far from the entrance, the isolation is complete and sometimes limited in confined environments where the mobility is constrained for safety reasons. The possibility to communicate with the surface is extremely limited and relies only on technologies that are not always trustworthy. This sense of deep isolation is directly correlated with the distance from the entrance, given the perception that every hour of progression would most probably require one full day for a rescue team to get back to the surface an injured person lying on a stretcher.

Other stress elements are related to human factors and logistics, some of which can be forcefully induced by planning the expeditions such as to maximise the impact of those factors and the actual operational analogies. There are minimal or no exchanges of communication between the cave team and the surface, imposing a high level of autonomy in the decision-making process to the exploration team, that needs a clear definition of task, roles, leadership and responsibility. The alternation of high and low levels of workload and their fair distribution within the team is another issue that must be efficiently managed for efficiency and for safety reasons. A typical daily exploration activity lasting 8-10 hours is very comparable with current ISS Extra Vehiclura Activity (EVA) sorties, and with typical planetary surface EVAs. Equipment, food, and other supplies are limited and have to be well managed to avoid mission abortion and falling into unexpected emergencies. For that the maintenance of a high level of team situational awareness is required to avoid that a mistake or a wrong evaluation from one single team member can cause safety issues to the whole crew.

Some stress elements are directly related to the rough nature of the cave environment and to the difficulty of creating comfortable habitability settings in the campsite. That is found in the lack of privacy, uncomfortable sleeping, lack of hygiene, suffering of cold and humidity, contamination with dust and mud, etc. All these stressors, if not managed, in the long term can bring easily to personal irritation, social and decision-making conflicts within the team, or even to physical health issues.

Different cultural approaches to leadership, information sharing, decision making and teamwork are employed during current ISS missions, all while respecting established hierarchies, rules and procedures. Whilst not all cave expeditions have a structured approach to team processes, the CAVES programme build upon the situational analogies, while imposing a very dynamic and flexible, yet structured approach to the development of the team, strongly emphasising the growth of the team via thorough analysis of its own activities. Behavioural issues for isolated, confined teams in future planetary missions are one of the least known factors with a very high potential impact on the mission success.

3. ESA CAVES training: history and location

The idea of using caves as a platform for astronaut trainings appeared in ESA in 2005, after the realization of survival training in the mountains of Supramonte in Sardinia, one of the most important cave areas of Italy. This area hosts some large, mainly horizontal cave systems, with a comfortable temperature range, a rather stable seismic environment, drinkable water and suitable chambers to host campsites for a large group of individuals, with additional suitable features to host an expedition and train for it. It became clear from the beginning that the environmental challenges and the complex technical operations and safety rules required to progress in caves were promising for a new spaceflight analogue. However it was also clear that the cave was just a "container", while it was necessary to insert team processes and embed them into speleological exploration and scientific activities, as well as to integrate into space-like mission operations to create experiences which would be fully creating analogies to space flight. Therefore the development that followed was to directly involve in the training experienced speleologists and cave scientists to recreate a realistic speleological expedition, and to offer real objectives to the expeditions, creating and maintaining a high motivational and engagement level both in the astronauts participating and in the scientists and speleologists involved. This approach has added relevant realistic elements to the training, including the astronauts performing a real exploration and documentation process, and scientific experiments. The other aspect was to adapt the actual progression techniques and tools to make them the most EVA-like possible. Strongly included into the basic speleological framework, ESA training experts have constructed an expedition based on structured team processes. The final step was the creation of an operationally relevant mission concept, with typical spaceflight operational elements, procedures, activity timelines, safety rules and emergency protocols, stowage notes and other space-like configurations.

In 2011, the first edition of the training course was implemented with a crew of 5 astronauts from ESA, NASA, ROSCOSMOS and JAXA. In 2012, 2013 and 2014 the courses also

Table 1. The table shows all the astronauts from different space agencies that participated to the five editions of CAVES. Pre-CAVES and Post-CAVES training spaceflights are listed for each crewmember. It can be seen that each crew was composed of experienced flown astronauts together with new astronauts without previous spaceflight experience. It is also worth to mention that some members of the same CAVES crew are planned to be part of the same crew to actual or future ISS missions.

caves	CAVES	PRE-CAVES SPACEFLIGHTS	POST-CAVES SPACEFLIGHTS
Timothy Peake	CAVES 2011		ISS46 ISS47
Thomas Pesquet	CAVES 2011		ISS50 ISS51
Randy Breznik	CAVES 2011	STS 129	ISS52 ISS53
Sergey Rizkhov	CAVES 2011		ISS49 ISS50
Norishige Kanai	CAVES 2011		ISS54 ISS55
Andreas Mogensen	CAVES 2012		TMA 18M
Michale Fincke	CAVES 2012	ISS9; ISS18; STS 134	
Drew Feustel	CAVES 2012	STS 125; STS 134	ISS57 ISS58
Nikolai Tikhonov	CAVES 2012		
Soichi Noguchi	CAVES 2012		
David Saint-Jacques	CAVES 2012		ISS58 ISS59
Paolo Nespoli	CAVES 2013	STS 120; ISS26 ISS27	ISS52 ISS53
Michael Barratt	CAVES 2013	STS 133	
Jack Fisher	CAVES 2013		ISS51 ISS52
Alexey Ovchinin	CAVES 2013		ISS47 ISS48
Satoshi Fukurawa	CAVES 2013	ISS28 ISS29	
Jeremy Hansen	CAVES 2013		
Luca Parmitano	CAVES 2014	ISS36 ISS37	
Matthias Maurer	CAVES 2014		
Scott Tingle	CAVES 2014		ISS54 ISS55
Alexander Misurkin	CAVES 2014	ISS35 ISS36	ISS53 ISS54
Sergey Kud-Sverchkov	CAVES 2014		
Pedro Duque	CAVES 2016		
Richard Arnold	CAVES 2016	STS 119	
Jessica Meir	CAVES 2016		
Sergei Korsakov	CAVES 2016		
Akihiko Hoshide	CAVES 2016	STS 124; ISS32 ISS33	
Ye Guangfu	CAVES 2016		

Figure 1. Different activities performed during the preliminary training, extended exploration and post-mission phase: A) Training for biological research in Tiscali Cave; B) NASA astronaut Jessica Meir train for chemical analysis during the preliminary training phase; C) CNSA taikonaut Ye Guangfu and NASA astronaut Jessica Meir download survey data at the campsite; D) JAXA astronaut Akihiko Hoshide perform survey of a new explored branch; E) The crew test the food and decide quantities for the extended exploration; F) ESA astronaut Pedro Duque during microbiological sampling; G) the 2016 crew while documenting with photogrammetry a speleothem in Su Bentu cave; H) Briefing are crucial moments to define the day activities and strategies; I) the 2016 crew at the exit of the cave after the 6 days of the extended exploration mission. All photos are ESA/Sirio Sechi/Vittorio Crobu.

involved CSA astronauts and the last course in 2016 included also a Chinese astronaut from CNSA in the team. In total 28 astronauts have been trained in CAVES over the past 5 years (Table. 1). While the general structure of the course has remained the same as in the first course, scientific objectives and technology testing have evolved during the years. Also the application of space-like procedures and timelines has been implemented at different levels thanks also to the feedback of the astronaut crews.

All the courses took place in the Valley of Lanaittu in the Supramonte massif area of Sardinia (Italy). The main caves used for the extended exploration mission were Su Bentu, a huge underground system where the explorations are still ongoing, and the smaller Tiscali, Sos Jocos and Sa Oche caves used for the preliminary training phase of the course offering different environments and complexity levels. All classroom lessons and preparatory activities have been carried out in local mountain refuges, re-arranged as training facilities (Budorrai, PICAVE).

4. CAVES concept and training structure

CAVES training is structured as a full exploration mission divided in three main phases, similar to those of typical space missions, all integrated into a single event lasting overall twelve days (Fig. 1): 1) a pre-mission training and preparation phase, 2) the "extended cave exploration" mission, 3) a post-mission phase where the data and results are collected in reports and discussed with the science team and the mission support team.

4.1. Pre-mission: training phase

The pre-expedition phase (7-8 days) is fundamental to enable the crew to conduct a safe and effective mission. Training activities include classroom lessons about mission objectives and operations, safety, science and documentation operations, as well as an overview about the results obtained by previous crews in order to be aware of the current state of exploration. In this phase team processes are embedded seamlessly into topical training, which is constructed to enforce team cohesion and cooperation, justified by the technical and scientific requirements. The crew, with the support of each topic scientist and mission support engineer practices science experiments and technological tests, handling exactly the same kits and procedures that will be used during the extended exploration in the cave. Documentation tasks like photography and mapping are explained and demonstrated in the classroom and later performed in a real cave, to ensure the complexities of the real environment are faced and resolved during the preparatory phase. The sequence and objectives covered in the training have been created following the structured approach to training (Instructional System Design) applied by ESA to all its training curricula.

Aside from the training on specific activities, the pre-mission phase is also dedicated to familiarization with the cave environment through a visit to three caves with increasing complexity and difficulties. Astronauts are trained on rope progression techniques and clear operational safety rules. This technical training resembles skills and protocols that are required to move and operate in EVA, with reduced field of view, shadows, three-dimensional progression through viable paths, confused perception of obstacles and distances, keep-out and no-touch zones. The technical instructors evaluate the astronauts' performance in progression techniques to finally check if the acquired skills fully satisfy safety protocols.

In addition, the astronauts are involved in the logistic preparation of the mission, choosing food types and quantities, organizing the resupply of equipment, and preparing their personal and team kits for transportation inside the cave. The latter activities require a high level of team coordination and decision making, and have been specifically constructed to allow observation of team processes by the instructors, and forming of the team, offering the first opportunity to the participating crew to exercise the roles they will carry into the mission, and tune their communication, leadership and followership styles to the team and situation.

4.2. Mission phase: the extended cave exploration

Once the pre-mission training is finalized the crew is ready to enter the main cave system for the mission phase that consists of a six days underground expedition. The mission is also divided in three main stages: 1) the approach from the entrance to the campsite, 2) the exploration, documentation and science phase from the campsite to the exploration objectives, 3) the way back from the campsite to the exit.

Phase 1 and 2 are the most delicate in terms of safety of the crew, and in terms of stressors can be used as an analogue to the launch and entry phases of ISS missions, and to EVA activities. The way from the cave entrance to the campsite is the most demanding in terms of technical passages, with a 700 meters long *via ferrata* over a fifty meters deep canyon. In this phase the crew moves autonomously, using the technical skills acquired during the training, but for safety reasons they are still supervised by technical instructors with a ratio 1 to 1.

When the crew arrives at the campsite the exploration mission starts after a leadership handover between the instructor team and the crew. From this point on, for four days, the crew has the responsibility to follow an activity list partially timelined and fulfil their mission objectives, communicating to a "ground" team outside the cave, representing only in part space mission control, their plans through a wired telephone line. The instructor team will ensure safety and manage the situation in case of real emergencies, but in general will try to interfere as little as possible with the crew. The only exception being the mission director and team facilitator, whose role is to foster the team processes and growth in the rather novel environment, by supporting with relevant mission operations knowledge provisioned through the leader, and by supervising key decision making and debriefing activities throughout the expedition.

The crew has to inform the ground team about the status of the crew and the planned activities each day at fixed times in the morning and in the evening, replicating in part the typical ISS Daily Planning Conferences (DPC), which in the cave are held only with the crew commander and the mission director, to enforce leadership, otherwise limited by the duration of the expedition and the unfamiliarity of the commander with the environment, within the team. During the day the communication with the outside from the exploration branches is limited to tests of wireless communication devices whose functionality cannot be assured (TEDRA, XFERRA). To ensure safety, in case the daily DPC through the wire telephone is missed both by the crew and the support team to the ground team, or from the ground team at the surface to the underground teams, the emergency procedures start because of lack of communication.

Responsibilities are distributed within the crew, with assigned roles: Crew Commander, Campsite Manager, one or two Science Engineers with different operational tasks, Survey Engineer, and Photography Engineer. This role assignment is an important element of the mission: the crew shall take a decision on which role to take. Roles and their associated responsibilities have to be carried out throughout the mission, with the exception of the Commander and Campsite Manager, who shall exchange roles half through the mission.

A role that carries the overall responsibility of data collection and the accomplishment of the field-specific objectives remains their responsibility, but specific tasks can be delegated within the team, allowing all crewmember to experience the completion of all tasks if they so choose. The self-assignment of roles fulfils an important objective of forming the team, by forcing an important communication and decision making process early in the preparatory phase. It is to be noted that all roles carry an important component of leadership, each one exercised at various moments during the expedition, therefore requiring a continuous switch between leadership and followership behaviours for each member of the crew.

A typical exploration day starts with a crew briefing about the activities planned in the timeline and agreed with the ground team during the morning DPC. Then the crew has to prepare all the science and documentation equipment for the day and then don their individual technical gear. The progression from the campsite to the exploration area can take hours and during this transfer the crew shall carry out scientific experiments or sampling in specific spots as indicated in their activity list and on the map, where available. The organization of the activities is subject to flexible execution due to unexpected terrain difficulties, the physical state of the crew, or safety issues, but also because of specifically pre-planned impossible objectives, which fulfil the underlying most important goal of the CAVES activity, which is improving team processes while facing unknown complex situations in an unknown and alien environment. When the crew reaches an unknown area that is not reported on the map of the previous crew, it is mandatory that they survey and document the new cave branches. At all time, safety remains a priority over the activities and the crew needs to return to the campsite in time for the evening DPC and to organize the data collected during the day. A typical daily exploration activity shall last around 8 hours. It is responsibility of the crew commander to ensure, for crew safety and comfort, that this rule is respected, despite demanding and conflicting objectives, and the strong push and enthusiasm to continue the exploration. Depending on the distance from the campsite and the exploration area, these travel periods can be strenuous, and in the last two periods of the training it has been necessary to install an advanced bivouac where the crew can rest one night in the furthest cave regions in order to advance more and save the time of transfer from the campsite. However, in order to use the advance bivouac, the crew is required to check some constraints, like a successful communication with wireless cave radio (XFerra, TEDRA) with the ground team.

After four days of exploration and activities the leadership is handed over to the technical instructor team again, and the crew faces the long way back from the campsite to the entrance. This is a critical phase due to the tiredness of the crew after such a long period in the cave. Finally the mission ends with the exit of the entire crew and support staff from the cave. It is interesting to note that the visual and olfactory sensations associated with the re-surfacing has been compared by experienced spacefarers as very similar to the exit from a spacecraft after landing.

4.3. Post-mission: reporting phase

In the post-mission phase each member of the crew organizes the data collected during the mission in order to provide to the scientist and support engineers an exhaustive report about each experiment and test, as well as about survey and photography and the characteristics of the newly explored area of the cave. These data, organized in a final document, forms the starting documentation for the next crew activities and the last point mapped by the crew will become in the following edition the starting point for future expeditions. In this phase the crew also provides feedback about the course, which is incorporated in future editions, to always improve the space analogy, as well as the overall relevance of the course to prepare astronauts for their future flights.

5. CAVES scientific and technological program

As for space missions, in CAVES astronauts are trained not only for exploration but also to carry out a scientific program, according to a flexible operational timeline and space-like procedures. The scientific tasks the astronauts are asked to carry out are numerous: microbiological sampling of air, water, and solid material, monitoring of cave air temperature, relative humidity, CO_2 concentration, and wind speed and direction, sampling of waters and minerals for successive laboratory analyses, and monitoring (and, in some cases, sampling) of cave dwelling fauna (mainly troglobites). During the pre-expedition training, crew members test the different experiment procedures and methodologies assisted by topical scientists, in order also to achieve a full understanding of the scientific objectives. All astronauts are trained in the execution of all scientific tasks, even if during the extended exploration only two team members will be in charge of most of the scientific tasks.

The scientific programme not only offers a set of realistic tasks and objectives, but it also provides really interesting scientific results. Multidisciplinary research allow a continuative and detailed study on the caves visited during the course. The environmental monitoring and the geological and geochemical studies are giving important information about the cave environment in this karst area of Sardinia. Moreover systematic microbiological and biological research have provided new information on these peculiar ecosystems, even discovering previously unknown species. All these important scientific goals were achieved thanks to the astronauts' careful performance of strict scientific protocols and delicate procedures.

Aside of scientific experiments and research the mission is also the ground for technological testing of new innovative equipment that has the overall goal to improve operations in the cave environment, but also with potential applications in space. In the last three editions much of the efforts have been dedicated to the evaluation of two wireless cave radio systems, called TEDRA and XFERRA. Both of them have provided interesting results allowing to the crew the set up of an advanced bivouac, ensuring the communication with the ground team, required for safety reasons. The tests are used to improve the instruments and their user procedures for the next editions, but also these systems could provide a base from which to develop reliable communication systems from lunar lava tube missions in the future. Other technologies tested are those related to survey and documentation, like new laser measurement tools (Cavesniper, Megaplot SJ), or for equipment and clothing (new concept of cave shoes for slippery surfaces, CUPRON fibre socks and others).

6. Discussion: a real exploration mission analogue

In the five courses astronauts have increased their knowledge of this cave system from the initial 1.1 to 4.9 km. The scientific experiments, being realistic and proposed by real cave scientists, have brought new data and fascinating discoveries, like a new species of crustacean in the cave waters, and have provided material for scientific publications.

The fact that the combination of environment, activities and objectives is real and not simulated makes this overall training highly credible. The astronauts are directly involved in one of the last human frontiers of exploration on Earth: the underground world.

Despite various important differences with space stations, that host current space missions, caves are complex alien environments, offering several of the same situations and associated spaceflight stressors and team processes, as well as science opportunities, making this training platform a valuable tool to enforce team processes and skills, as well as offering complex scientific and technological operations in an unusual and dangerous environment.

Differently to other similar analogue environments, communication inside a cave is rather unreliable, forcing the development of very autonomous mission operations, with reduced reliance on the control and directions of the ground team. This offers a rather interesting testbed for future planetary exploration scenarios, which will include delayed communication or complete autonomy.

Progression tools, safety and emergency procedures that are used in the CAVES training could be in the future used to develop concepts for moonwalks and surface traverse activities on planetary bodies like asteroids and comets, or even for lunar or martian lava tube exploration.

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(Abstract) A Theoretical Approach to Energy and Materials Flow and Consequent Biodiversity: Predictions for Caves on Earth and Other Planetary Bodies

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Abstract

The thin living skin known as Earth's Critical Zone is comprised of the rock, fluid, and atmosphere compartments of the planet which interact to provide an environment that supports life. Extending as far as 5 to perhaps 10 km below the surface of both the landmasses and ocean floors, up through the troposphere and lower parts of the stratosphere, the material and energy exchange governs how life on our planet lives and dies. We have previously argued that caves, which are located in the near to mid-depth subsurface, are one of the best places on the planet to study the interactions of rock, water, air, and life that make up the Critical Zone. They can be studied as systems that are closed or partially closed over relatively short timescales, and which can transfer materials and energy on geologically significant timescales. The inter-relationship of the various temporal and spatial interactions and the effect on gene flow, partitioned environments, and evolutionary consequences may control much of the deeply converged biodiversity of the subsurface. We predict the presence of biodiversity hotspots based on the ecotonal intersection of energy sources from external (e.g. solar), and internal sources (e.g. chemically reduced crust and mantle gases). Such an exercise can be extended to other planetary bodies which could conceivably harbor life in their subsurfaces. Such theoretical habitability zones are predicted for three test cases: Mars, the interior of a liquid-filled icy moon, and a super Earth. All three types of planets could produce cave habitats.

What if the “Seven Sisters” are not volcanic? A look at deep hypogene sinkholes in Arabia

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This paper is gratefully dedicated to Dr. Herbert W. Franke, cave explorer, innovative scientist and creative author of caving and science fiction books on occasion of his 90th birthday, May 14th, 2017.

Abstract

With much hype the international press has hailed the discovery of “caves” on Mars. Speculation crystalized around the “Seven Sisters” at the flanks of Arsia Mons, the southern of the three Tharsis volcanoes. These are circular holes of 100 to 250 m in diameter with their bottoms in shadow. The situation on a volcano seems to suggest pukas (Hawai‘ian for ceiling collapses) over pyroducts (lava tubes) or, alternatively, pit craters, collapsed over empty magma chambers. Comparison with Hawai‘ian occurrences of these features clearly exclude the possibilities that the Seven Sisters are pukas. The flanks of Arisa Mons do not show the morphology of lava flows of a shield volcano and pyroducts are not voluminous enough (even considering lower gravity) to allow deep-seated collapses to propagate to the surface. As for pit craters, the situation is somewhat different, but again, inspection of the flanks of the volcano show that the volcano is dotted with many depressions that converge and show internal avalanches. High resolution pictures (accessible by Google “Mars”) show that the stratigraphy is dominated by layers of soft material with only a few harder, rocky strata. Pit craters on Hawai‘i puncture stacks of surface lava flows. They occur during the activity of the volcano and are quickly filled by later eruptions. Arsia depressions, however, seem to have occurred after the formation of the volcano and do not show signs of refilling.

This is suspicious and a geological different, non-volcanic process seems to be at work. In the center of the Arabian Plate dissolution at the lower interface of the over 100 m-thick Ain Heeth anhydrite Formation has produced series of sinkholes, some as long as a kilometer but some much deeper than wide with their bottoms in shadow of the overhanging walls. The walls of these sinkholes are composed of non-consolidated lake-chalk prone to constant collapse. If one replaces the anhydrite by frozen H2O or CO2 then one can envisage that the Arsia holes are collapse features that propagate upward over melting or evaporating ice or dry ice in the substructure of the volcano. Arsia is one of the “pedestal” volcanoes, i.e. it erupted, like Olympus Mons, on top of a kilometer-thick layer of dust and ice. Such a model seems to be geologically more likely for the origin of the Seven Sisters.

Keywords:

1. Introduction

Caves are generally of high public interest because they are metaphors of the unknown, of adventure and our animalistic fear of the darkness. The discovery of dark holes on Mars (Table 1) by the Mars Odyssey’s Thermal Emission Imaging System (THEMIS) (Fig. 1) were therefore of high interest world-wide. It fostered fantasies of vast underground caves that not only can be used to house future Mars explorers but also promised to be sites of subterraneous Martian microbes (i.e., http://www.space.com/7440-mars-caves-protect-microbes-astronauts.html; accessed 12/2016). Reactions included: “… is most likely a skylight onto a subterranean cavern“ (http://www.bibliotecapleyades.net/marte/esp_marte_40.htm; Accessed 12/2016), “ are potential entrances, the so-called “skylights” (http://blogs.esa.int/caves/2015/05/06/caves-the-hidden-side-of-planets; accessed 12/2016).

The holes were spotted on the northern premises (Fig. 2) of the southern of the three Tharsis Volcanoes, Arsia Mons, just south of the Martian equator. The Tharsis Volcanoes are, after Olympus Mons to their NE, the largest volcanoes on Mars (Fig. 3). The diameter of the openings range from 250 to 100 m. “Dena” is estimated to be ca. 130 m deep. More recent high resolution pictures for “Jeanne” and “Annie” can be spotted on the images available on Google Mars (Figs. 4 and 5). “Annie” was photographed at a high sun angle showing much of its rock-strewn bottom and walls comprising two firmer layers.

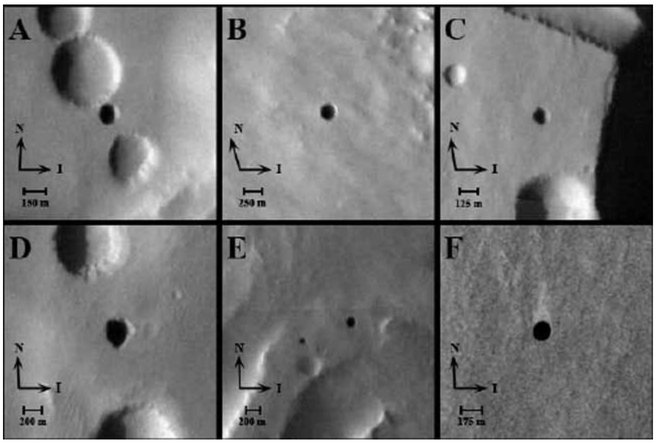

Figure 1. THEMIS VIS pictures of sinkholes on Mars, nicknamed “Seven Sisters”. Clockwise from upper-left: Dena (A), Chloë (B), Wendy (C), Annie (D), Abbey (E), Nikki (E) and Jeanne (F) (named by the researchers who spotted them). North (N), direction of illumination (I) and scalebar are indicated. Image IDs: 1853001, 13448001, 17716001, 1834001, 14334002 & 18315002. Credit: G.E. Cushing, T.N. Titus, J.J. Wynne, USGS, USGS, Northern Arizona University, and P.R. Christensen of Arizona State University (after Cushing et al. 2007).

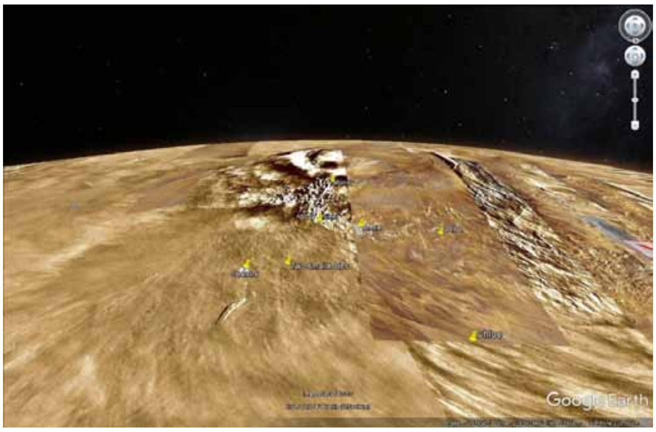

Figure 2. Position of the "Seven Sisters" on the northern flank of Arsia Mons looking south (Google Mars).

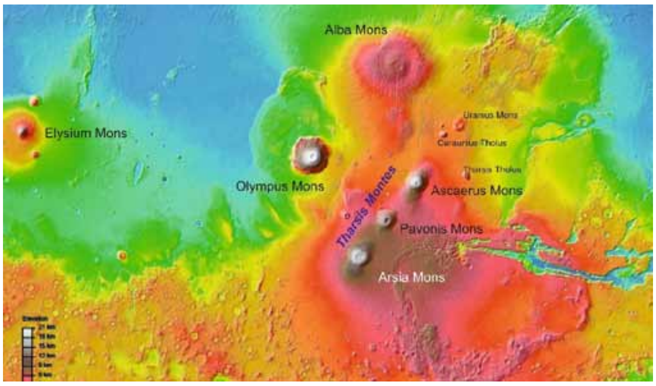

Figure 3. Fig. 3: Major volcanic edifices on Mars (altered after Google Mars).

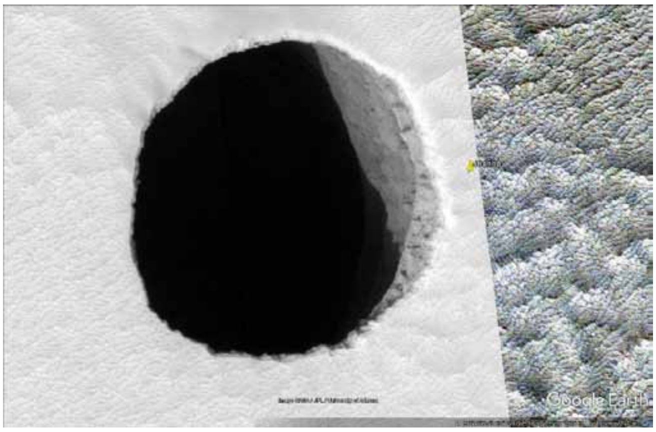

Figure 4. The "dark hole" nicknamed "Jeanne" at the NE of Arsia Mons at high resolution, the bottom is still clouded by shadows (Google Mars).

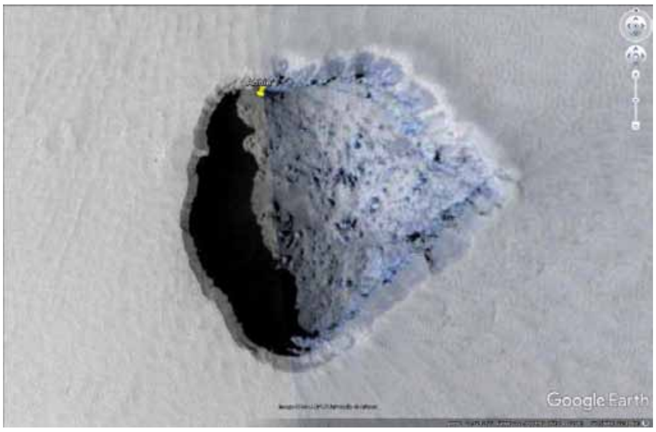

Figure 5. The "dark hole" named "Annie" at the NE of Arsia Mons at high resolution, showing most of its bottom blanketed with slumps and large blocks. This hole obviously does not lead into open cave. The strata exposed are obviously composed of fine-grained, rather loose material interrupted by only two solid strata (lava sheets?) (Google Mars).

Figure 6. The area W of "Annie" showing rows of depressions in an area of about 49 by 28 km on the northern flank of Arsia Mons (Google Mars).

By now several other holes were spotted by the high-resolution camera of the Mars Odyssey Orbiter (see e.g., position of "two small holes" on Figure 2)

Figure 6 shows that "Annie" is only one (and most likely the youngest) of many depressions forming rows striking both downslope as well as across slope. Given time, these rows seem to coalesce into longitudinal, kilometer-wide closed depressions. Some of the depressions seem to arise from crossovers of two directions, causing depressions with acute angles. All these depressions are not impact craters since they

Table 1. Parameters of the original "Seven Sisters" sorted by latitude (altered after Cushing et al. 2007).

Name	Position	Diameter	Min. depth	Elevation	Themis Vid ID
Chloe	-120.78/-4.29	250 m	-	5.7 km	V13448001
Jeane	-118.62/-5.57	165 m	75 m	9.97 km	V18315002
Dena	-120.98/-6.31	162 m	80 m	9.1 km	V18053001
Annie	-119.97/-6.52	225 m	100 m	11.005 km	V18340001
Nikki	-119.45/-6.708	180 m	-	11.15 km	V14334002
Abby	-119.46/-6.708	100 m	-	11.15 km	V14334002
Wendy	-119.68/-7.84	125 m	68 m	15.5 km	V17716001

Figure 7. Lava flows at the E-flank of Ascraeus Mons punctured by post-eruptional sinkholes striking along slope. Note meanderings row of pits at lower left that could fit the concept of collapsed pyroducts. Scale bar 2 km (Google Mars).

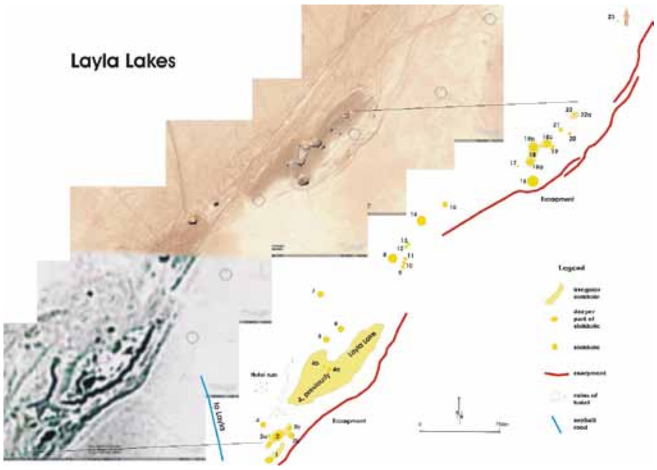

Figure 8. The sinkhole series of the former Layla Lakes, Saudi Arabia. Note the co-occurrence of both large, open depressions and younger, recently collapsed, round, "dark holes" (Google Earth; Kempe and Dirks 2008).

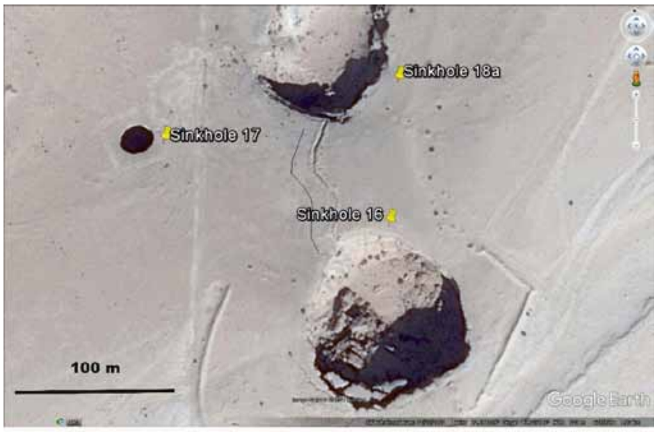

Figure 9. Sinkholes 16 to 18a of the Layla Lakes series. Note number 17, a "dark hole" of unknown depth with overhanging walls. Note also sinkhole number 16, showing ongoing collapse along its southern rim (Google Earth).

do not have raised walls (compare the large impact crater in the lower left corner on Fig. 6) and they are not volcanic vents since no material was ejected from them. They are sinkholes. Their sizes suggest enormous mass loss from the substructure of the underground of Arsia Mons.

2. Discussion

The fact that all the holes discovered occur on volcanoes has led to the suggestion that they are also volcanic in origin (e.g., Cushing, 2007; Cushing et al. 2007). Two hypotheses are advanced: the holes are either "skylights" over "lava tubes" (more correctly termed "pyroducts"; Kempe 2002; Lockwood and Hazlett 2010) or that they are "pit craters". In Hawai'i, "skylights" (a misleading term since pyroduct roof collapses can only be seen as such when looking from within) are termed "pukas" and are the most frequent entrances to pyroducts. Since pydroducts are underground conduits of lava flowing down-hill by gravity (e.g., Kempe, 2012), pukas can only form rows downslope. Even though the lava flowing in these conduits can erode substantially into older, underlying strata forming caves much more voluminous than the actual cross-section of the lava flow within them, pukas cannot be much deeper than the thickness of the lava flow containing them. Figure 7 shows lava flows on the flanks of Arsia Mons, the depression seen are several times deeper than the thickness of the lava sheets and they strike along slope. A row of meandering depressions seen in the lower right is more of the size expected from collapsed pyroducts. None of these small, meandering rows has however yet yielded a "dark hole".

Pit craters on the other hand are sinkholes with vertical walls cutting through stacks of lava produced by collapse of empty subsurface voids within the volcanic edifice. On Earth pit craters occur only on a few volcanoes, examples are known from Hawai'i and Galapagos. Okubo and Martel (1998) point out that the Kilauea pit craters seem to be located in between slip faults, suggesting that their collapse is tectonic in origin. Other researches think that empty magma chambers or magma conduits cause the collapse. There are only a limited number of pit craters on Hawai'i (e.g., Halliday et al. 2012) clearly different from volcanic vents or collapses along dilatational faults (Halliday et al. 2009, 2010). The reason for the low number of pit craters on terrestrial volcanoes is quite simple: they collapse during the activity of a volcano and are subsequently filled by lava of later eruptions, thus disappearing from the surface. Those on Mars are much more numerous and none show signs that any of the most recent flows have entered them. This suggests that they are much younger than the volcanic activity and not connected to subsurface magma movement.

2.1. Other options of sinkhole formation: Example Layla Lakes Saudi Arabia

If a volcanic genesis of the "Seven Sisters" and related sinkholes is to be ruled out, then other processes must be responsible for their collapse. The large sizes of these sinkholes can only be explained by finding layers in the substructure of the volcano that are thick enough and that are subject to consecutive removal.

On Earth, likely layers are salt or anhydrite/gypsum deposits. In Saudi Arabia, as an example, the Jurassic Anhydrite Ain Heeth Formation dips eastward underneath Cretaceous limestones, it is composed of four layers, the lower three amounting to 123 m in thickness and the upper measuring 90 m in thickness. Along the outcrop, many sinkholes have

Figure 10. Entrance into Ain Heeth, a cave 120 m deep in 2008 before the water table rose again into the daylight zone.

formed due to the dissolution of the anhydrite from below in way of hypogene karstification. The former Layla Lakes (now drained because of groundwater harvesting) represent the most impressive sinkhole chain (Kempe and Dirks 2008; Kempe et al. 2009; Schleusener et al. 2012) (Fig. 8). Among these are a series of young sinkholes deep enough to appear as "dark holes" (Fig. 9): Nobody has yet descended them because they occur within the Layla Formation, composed of former lake deposits of unconsolidated chalk that is extremely prone to collapse.

At the type location of the Formation, at Ain Heeth, south of Riyadh, a large vault looms (Fig. 10), giving entrance to the only accessible cave within the Formation. It originally harbored a famous spring. In 2008, the water table was lowered so far, that the cave could be explored down to 120 m depth (Kempe and Dirks 2008). Since then, the water table rose again due to the infiltration of waste water from a nearby sewage plant (Michelsen et al. 2016). In spite of its large entrance, this cave cannot be detected visually from space, since it opens at the foot of a steep cliff.

These examples show that large sinkholes can also form by dissolution of rock at greater depth. In case of the Mars volcanoes the necessary layers must be several hundred meters, if not kilometers thick. This can only be permafrost layers that pre-existed at the places where the volcanoes erupted. Loss of these layers around the volcanoes causes them to stand on "pedestals", best seen at Olympus Mons, the classical "pedestal volcano". Thus, the collapses may be only incidentally appear to be "volcanic" because the volcanoes protected the underlying permafrost layers from being quickly evaporated. Over billions of years the melting and/or evaporation along dilatational fractures removes the ice (and/or dry ice) allowing the sinkholes to form until today.

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(Abstract) **Digital Terrain Model (DTM) morphometry of sinuous pit chains and atypical pit craters related to colossal inflated lava tubes on Mars**

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Abstract

In the last twenty years pit craters, skylights, rills, and outflow channels on Martian volcanoes have been commonly related to lava tubes, although a clear understanding of their size, depth and formation processes remains elusive. Thanks to the images provided by CTX and HiRISE cameras on the Mars Reconnaissance Orbiter, sinuous pit chains on Olympus and Arsia Mons have been documented in high detail allowing the elaboration of DTMs from paired stereo images and an accurate morphometric comparison with similar terrestrial landforms. The genetic mechanisms of lava tubes on Earth are related mainly to the processes of over-crusting of lava channels and/or shallow inflation underneath previous flow sheets. In this study we define the main tube characteristics that allow to distinguish between these two main genetic processes by just observing the morphometry, linear self-arrangement and topographic expressions of lava tube-related skylights, pit chains and collapses. These criteria are based on a detailed analogue comparison with over 350 morphometric measurements of terrestrial lava tube collapses and related underground conduits, both over-crusted and inflated, collected from satellite images and speleological surveys in the most representative lava tube areas explored on Earth.

The results of our morphological and morphometric analysis suggest that both over-crusted and inflated tubes exist on Martian volcanic slopes. In particular, the inflated tubes present peculiar characteristics compared with the terrestrial ones, such as a higher depth of emplacement (over 80 meters), high ellipticity of the conduit (asymmetry ratios ranging from 3 to 7), and huge overall dimensions (conduits up to 1000 meter wide).

The recognition of deep inflation lava tubes on Mars opens new hypotheses on the emplacement of lava flows and formation of deep valley networks in the Tharsis region.

Geomicrobiology of Cave and Karst Environments

Next-Generation Sequencing For Microbial Characterization Of Biovermiculations From A Sulfuric Acid Cave In Apulia (Italy)

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Abstract

Sulfuric acid cave systems host abundant microbial communities that can colonize several environments displaying a variety of morphologies, *i.e.* white filamentous mats floating on the water surface, white creamy moonmilk deposits on the walls, and biovermiculations. Up to date, only few reports have described the microbiological aspects behind biovermiculation geomicrobiology of Italian sulfuric acid caves despite their overall abundance.

Here, we present the first characterization of biovermiculation microbial populations from the Santa Cesarea Terme (Apulia, Italy) using next-generation sequencing and field emission scanning electron microscopy (FESEM) approaches. We focused our analysis on biovermiculations from Fetida Cave located along the Adriatic Sea coastline. This cave is at sea level, and moving from the entrance to its inner part, it is possible to observe a decrease of marine influence accompanied by a corresponding increase in the acidic effect of the upwelling waters. Biovermiculations are copiously observed covering the ceiling and walls mainly in the inner and middle environments of the cave, while they are absent near the entrance. Biovermiculations have a widespread range of colors going from grey to dark brown with an overall slimy appearance; dendritic morphologies alternate to very dense wall-covering sheets. Total DNA was extracted from each sample and 16S rDNA sequences were analyzed through Ilumina MiSeq platform. The main lineages found in all the samples included *Gammaproteobacteria, Betaproteobacteria, Alphaproteobacteria, Bacteroidetes, Planctomycetes*, *Actinobacteria* and *Acidobacteria*. In particular, the samples from the inner part of the cave had the highest abundance of *Acidobacteria* and showed the presence of *Epsilonproteobacteria* that can be related to bacterial sulfur-oxidizing activity. FESEM images revealed microbial mats composed of filamentous cells including *Actinobacteria* and reticulated filaments of unknown origin, as well as prosthecate bacteria.

This study shows that the biovermiculation microbial communities from Fetida cave is in accordance with previous data reported in acidic caves from Italy and support the role of *Epsilonproteobacteria* typically occurring in sulfidic environments.

Keywords: geomicrobiology, Santa Cesarea Terme, hypogenic cave, FESEM, 16S rDNA

1. Introduction

In the last decade microbiological studies of hypogean environments have improved the overall knowledge on the presence of extremophile microorganisms able to live in extreme conditions such as: absence of light, low organic compounds, high humidity, possible high gases concentration in cave atmosphere, extreme variability in pH and temperature (Tomczyk-Żak and Zielenkiewicz 2015). Hypogean systems are also getting attention as Mars analogues, and cave biosignature suites have been used for astrobiological studies (Boston et al. 2004). In these environments, the microbial organization in collective structures supports the cooperation into mutualistic relationships favoring the bacterial survival and resulting in the formation of features that can be observed within a cave (Grotenhuis et al., 1991). Indeed, microbial activities are associated with the formation of different speleothems and biomineralization processes (Tisato et al. 2015; Bontognali et al. 2016). Bacteria can colonize different types of subterranean environments from the normal epigenic caves to the thermal acidic ones, to lava tubes and any other underground systems.

In this work we describe biovermiculation microbial communities from an active sulfuric acid cave, called Fetida, which is located in the southeastern area of the Apulian foreland, in Santa Cesarea Terme (Italy). The microbiology of biovermiculations was previously described by Jones et al. (2008) who reported details on these formations from the Frasassi cave system (Italy). Sulfuric acid cave systems are hypogean environments (Klimchouk 2009), characterized by high H2S concentration that, under oxidizing conditions, tends to become H2SO4 (Egemeier 1981). The interaction of H2SO4 with the host rocks (mainly carbonates) tends to form gypsum replacements and carbonic acid. This oxidizing environment provides an important source of energy for extremophile microbes (Jones et al. 2008), which can colonize the sulfuric acid environments by creating different types of microbial mats such as white soft filaments well visible in sulfidic water (Engel et al. 2004), moonmilk deposits (Cañaveras et al. 2001) and biovermiculations on walls and ceilings

Figure 1. Location of Santa Cesarea Terme (Apulian Foreland, Italy)

(Hose and Pisarowicz, 1999). In Fetida Cave, the walls and ceilings from the inner and middle halls are copiously covered by slimy microbial materials showing a wide range of colors going from grey to brown- reddish and dark-brown tones, characterized by dendritic morphologies alternating to dense wall-covering sheets. In this study, next generation sequencing and FESEM analyses have been conducted to characterize the biovermiculation microbiological diversity in three samples collected from different sampling areas inside Fetida Cave (Santa Cesarea Terme).

2. Geological setting

Santa Cesarea Terme (Lecce, Italy) is located along the Adriatic coastline (Fig.1), where four active sulfuric acid caves are developed in Cretaceous carbonate rocks (limestones and dolostones) called "Calcari di Altamura" (Azzaroli 1967). Santa Cesarea Terme represents a commercially exploited spa.

The caves open at the sea level and are influenced by marine and upwelling sulfidic waters that meet creating an aggressive mixed solution. They represent very peculiar environments where it is possible to observe marine (mainly close to the entrance) and hypogenic evidences (in the inner and middle zones). These caves host a variety of sulfuric acid speleogenetic (SAS) minerals, in particular sulfur (that covers walls and ceiling), gypsum and jarosite deposits. Microbiological materials are abundant; it is possible to see white soft filaments in the acidic waters, white moonmilk deposits and slimy biovermiculations (Fig.2).

Geochemical analyses of waters have been conducted: they can be classified as Na-Cl-SO4 waters, with a temperature ranging between 25 and 29°C, and pH of 6.7 - 7.2.

Biovermiculation pH measured with litmus papers ranges between 5 and 5.5.

3. Results

Three samples were collected from the inner-middle part of Fetida Cave (Fig.2). Sample BV1 was obtained from the middle zone of the cave on a wall diffusely covered by red-brownish biovermiculations. CV1 was sampled on the ceiling of the inner room and is characterized by brownish biovermiculations, while CV2 was collected from a wall in the inner room covered by greyish biovermiculations. In these galleries it is possible to see upwelling sulfidic acidic water occurring in

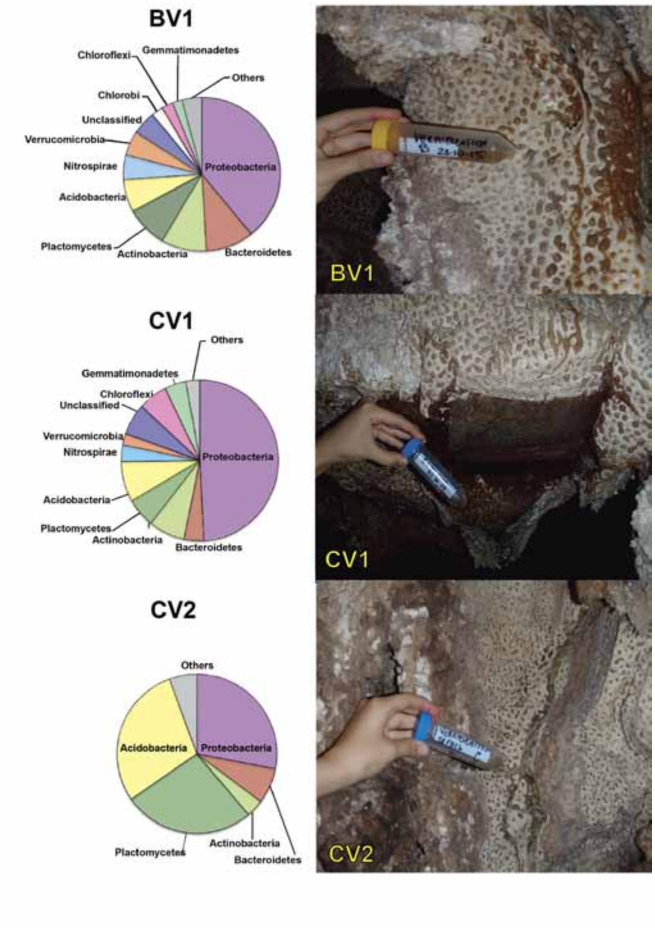

Figure 2. Samples BV1, CV1 and CV2 were collected in the inner-middle part of the cave, where sulfidic rising waters reach the surface, meet sea water and degas producing an atmosphere rich in H2S. The relative abundance different phyla detected through Illumina MiSeq platform sequencing is shown as a pie chart. The group "Others" includes the phyla < 2% of the total community.

the seawater, and degassing in the atmosphere. Oxygen presence in this type of environment is reduced.

Using the Illumina MiSeq next generation sequencing approach we assessed the microbial diversity in the three samples. The produced data were analyzed using publicly available algorithms and analysis pipeline, Mothur, following the MiSeq standard operating procedure (SOP) (Schloss et al., 2009, SOP accessed 23.5.2016). In short, the paired end reads were joined together, and the produced sequences were quality checked. Chimeric sequences were identified and removed, and the sequences were clustered into OTUs using average neighbour algorithm. Taxonomic assignment was performed by querying the sequence reads against a silva SSU 123 reference database (Quast et al., 2013) and various diversity indices and richness estimates were calculated.

The highest number of OTUs was observed for BV1, CV2, followed by CV1. We identified 10 and 9 abundant phyla (represented by more than 2% total bacterial sequences) in BV1 and CV1 samples, respectively (Fig. 2). Both samples were dominated by Proteobacteria; the phylum Chlorobi was solely detected in BV1 sample. Other commonly abundant phyla in BV1 and CV1 were Acidobacteria, Actinobacteria, Planctomycetes, Bacteroidetes and Nitrospirae. In contrast, only five abundant phyla were detected for sample CV2, with Pro-

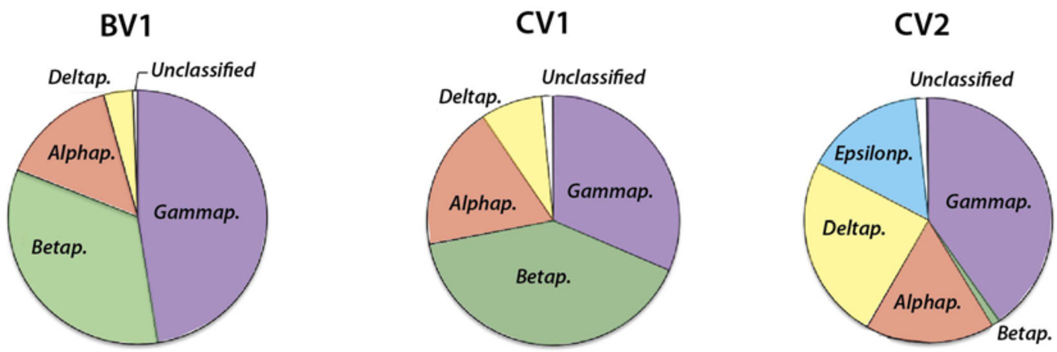

Figure 3. Relative class abundance of Proteobacteria classes in the three samples (BV1, CV1, CV2). Epsilonproteobacteria were only detected in sample CV2.

teobacteria, Acidobacteria and Actinobacteria representing almost 80% of the total microbial population. These results were in line with previous studies reporting Proteobacteria as one of the main bacterial phyla present in caves (Tomczyk-Żak and Zielenkiewicz 2015) along with Actinobacteria (Groth et al. 1999). Acidobacteria can be further associated with the acidophilic conditions due to the production of sulfuric acid.

Considering Proteobacteria phylum, the relative abundance of the respective classes is different in the three samples (Fig 3); Gammaproteobacteria and Betaproteobacteria were dominant in CV1 and BV1 samples, while in CV2 sample Gammaproteobacteria was followed by Deltaproteobacteria and Alphaproteobacteria. Interestingly, the Epsilonproteobacteria class was retrieved in CV2 sample, but absent in the other two samples. The great abundance of Acidobacteria in CV2 and the presence of Epsilonproteobacteria can be related to sulfur-oxidizing activity.

FESEM images revealed dense microbial mats in all the studied samples, mainly composed of filamentous bacteria (Fig. 4A). In addition, the abundance of prosthecate bacteria was noteworthy, particularly in the grey biovermiculations. Figure 4B depicts a bacterial cell with numerous prosthecae extending in all directions, resembling Ancalomicrobium (Alphaproteobacteria). A prosthecate cell with long appendages was also observed (Fig. 4C); this is probably related to the genus Prosthecomicrobium (Alphaproteobacteria) (Oertli et al. 2006). FESEM examinations also revealed intriguing reticulated filaments with honey-comb sheaths (Fig. 4D). These filaments have been previously reported by several authors in limestone, granite and lava caves (Melim et al. 2008, Miller et al. 2012), but their taxonomy is still unknown and represents a challenge for the ingenuity of microbiologists.

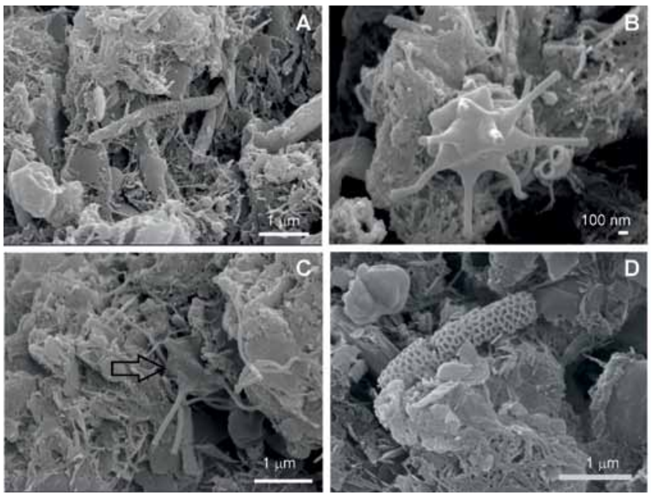

Figure 4. FESEM images of grey biovermiculations collected in Fetida Cave.
A) General view of microbial mats mainly composed of filamentous structures.
B) Prosthecate bacterium, resembling Ancalomicrobium.
C) Prosthecate bacterium with long appendages probably related to the genus Prosthecomicrobium (arrow).
D)Reticulated filament of unknown bacterial affiliation.

4. Concluding remarks

Sulfuric acid (SAS) cave systems host a wide variety of microbial mats with different morphologies, colors, and microbial diversity. Analyzing biovermiculations from Fetida Cave, we found diversified bacterial communities dominated by Proteobacteria and Acidobacteria. As suggested by Tomczyk-Żak and Zielenkiewicz (2015), the Proteobacteria lineage generally, represents the prevalent group in cave environments, from the sulfuric acid to the normal epigenic ones. The relative abundance of Betaproteobacteria (some microorganisms from this lineage are sulfur-oxidizing bacteria), Deltaproteobacteria (anaerobic sulfate-reducing bacteria), and in particular of Epsilonproteobacteria (several bacteria from this lineage are thermophiles and can tolerate high sulfur concentration), together with Acidobacteria (typical of sulfur dominated environments), can be considered endemic of SAS environments. In Fetida Cave, we observed that biovermiculations develop only on walls and ceiling close to sulfuric acid springs. This work shows that the microbial communities in biovermiculations from Fetida Cave are in accordance with previous data reported for acidic caves from Italy (Jones et al. 2008) and support the role of Epsilonproteobacteria (Engel et al., 2004) typically occurring in sulfidic-rich environments.

Acknowledgements

Many thanks Santa Cesarea Terme spa, for the availability to visit caves and sample geochemical and microbiological materials. Thanks to Lee Florea that helped us in monitoring geochemical parameters and in samples collection. Financial support from the Spanish project CGL2016-75590-P is acknowledged.

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What's Up With Antibiotics In Caves?

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Abstract

The discovery of antibiotics was one of the greatest breakthroughs in modern medicine; however, not long after their discovery, bacteria were found that demonstrated resistance to these same antibiotics. For a long time it had be assumed that the prescription and overuse of antibiotics had led to the emergence and spread of resistance, primarily because it was almost impossible to find natural habitats that had not been heavily impacted by anthropogenic sources. Nonetheless, geologically isolated caves, such as Lechuguilla Cave, which have not been impacted by man-made antibiotics, have allowed us to examine the presence of antibiotic resistance in natural habitats. These data suggest that antibiotic resistance may be pervasive and widespread in these habitats. This would therefore suggest that antibiotic production would similarly be prevalent. To determine if this theory is correct, we identified novel antibiotics within these environments. Such data may also indicate that in geologically isolated and nutrient-limited environments, such as caves, microbial resource competition may drive the production of novel antibiotics.

Keywords:

1. Background

When Paul Erlich developed the theory of select agents, which could kill a bacterial pathogen, he used the term 'magic bullet.' This idea of a battle, between the human host and an invading organism, became the metaphor for our interactions with pathogens (Martínez 2008). It is therefore not surprising that the discovery of antibiotics considered them to be 'chemical weapons', developed by microorganisms to defeat competitors in a battle for environmental resources. This assumption on the role of antibiotics is supported by Darwinian principles, allowing antibiotics to play an important role in natural selection: providing an advantage over competitors, antibiotics could increase fitness in the ecosystem (Mlot, 2009).

In the past decade there have been increasing experiments that call into doubt this long-held theory. These experiments indicate that low levels of antibiotics have a stimulatory, rather than inhibitory effect. Such effects are wide-ranging; from cell signaling and electron transfer to biofilm formation (Martínez 2008, Price-Whelan et al 2008, Kohanski et al 2010, Hoffman et al 2005, Yim et al 2007, Goh et al 2002, Linares et al 2006). This biphasic (hormesis) effect for antibiotics is further supported by the inability to detect antibiotics at bacteriocidal levels in natural systems (Allen et al 2010), although local accumulation and cell-to-cell contact could lead to bacteriocidal levels of antibiotic that would be undetectable using current instrumentation.

2. Current Work

Lechuguilla Cave was formed through ascending, sulfuric-acid rich groundwater, which created a very large (>200 Km) and deep (~500 m) cave over the last 7 million years (Barton 2013, Polyak et al 1998). The overlaying Yates sandstone and single entrance limits the input of surface water bringing organic carbon. As a result, chemolithotrophic primary productivity appears to dominate in the deeper regions of the cave and remains extremely nutrient limited with respect to nitrogen (Johnston 2013, Northup et al 2003). Such nutrient-limited conditions would suggest that competition for resources likely plays an important role in microbial community structure.

To provide a simple screen to determine if antibiotics played a role in community structure, we examined the antibiotic resistance profiles of 93 random bacterial strains (33% Gram positive and 66% Gram negative) isolated from deep within Lechuguilla Cave. These strains were screened against 26 different antibiotics and demonstrated resistance to most of the major drug classes, except synthetic and semi-synthetic derivatives. The lack of resistance to synthetic derivatives supports the notion that these organisms have only been exposed to naturally derived antibiotics due to their geologic isolation. Importantly, more than 70% of the tested strains demonstrated resistance to more than three antibiotic classes, including drugs of last resort, such as daptomycin. This level of resistance is much higher than has been observed for bacterial isolates in other natural systems (Bhullar et al 2012)

To examine the structure of such antimicrobial resistance, we sequenced the genome of *Paenibacillus* str. LC231, which demonstrated resistance to numerous antibiotic classes in our initial antibiotic screen (Bhullar et al 2012). Sequencing analysis of this isolate identified 18 different encoded resistance elements, which conferred resistance to 26 antibiotics that demonstrate activity against Gram-positive bacteria (Pawlsowski 2016). This remarkable expression of resistance included five novel resistance pathways, yet shared genetic similarity with resistance cassettes found in surface *Paenibacilli.* This suggests that strong selection pressure exists for the maintenance of these resistance pathways, even within the isolated cave environment (Pawlsowski 2016).

The diverse antibiotic resistance demonstrated by bacteria within Lechuguilla Cave suggests that they must be naturally exposed to antibiotics, which is in support of numerous studies that have demonstrated that cave bacteria produce antimicrobial agents and antibiotics (Cheeptham 2012, Maciejewska et al 2016, Ghosh et al 2016). Our early isolations of bacterial strains from nearby Carlsbad Caverns demonstrated that many species in hypogenic caves are similarly able to produce antibiotics, with one strain of *Polaromonas* producing so much of the antibiotic iodinine that it spontaneously crystallized within the media (Figure 1). Screening of the original 93 Lechuguilla Cave isolates using liquid-chromatography (LC) fractionation of culture supernatants revealed that

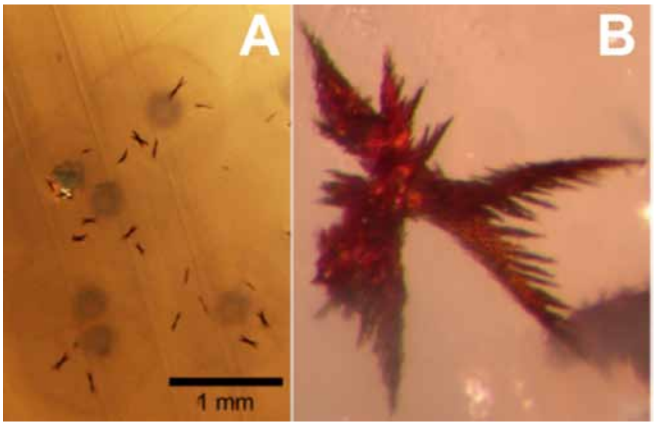

Figure 1. A strain of Polaromonas isolated from Carlsbad Caverns, NM, USA. A) Colonies of Polaromonas spp. in nutrient-limited culture media showing the precipitation of crystals. B) A close up of the precipitated crystals. X-ray powder diffraction analysis revealed that these crystals were iodinine, which has antimicrobial properties.

strains, such as a novel *Streptomyces* str. LC31, produced over 38 compounds demonstrating antimicrobial activity. Using a combination of LC-mass spectroscopy (LC-MS) and ion-mobility mass spectroscopy (IM-MS) we were able to show that this arsenal include three novel antibiotics (B. Bachmann, personal communication 2016). These data support the idea that microorganisms in these extremely nutrient-limited cave environments are producing and being exposed to naturally occurring antibiotics.

3. Conclusion

The dramatic increase in the emergence and spread of antibiotic resistance genes in human pathogens is leading to a modern-day healthcare crisis: the US Centers for Disease Control recently estimated that per year, >23,000 people die from infections that are untreatable, directly as a result of acquired antibiotic resistance (US)CfDCaP 2013). It had been thought that such resistance emerged directly as a result of the human production and use of antibiotics, both in clinical settings and agriculture (Allen et al 2016). Yet there is increasing evidence that antibiotic resistance genes share an ancient evolutionary history, emerging well before the therapeutic use of antibiotics (and even the emergence of humans as a species) (Allen et al 2016).

Within extreme environments, antibiotic resistance may provide significant advantages beyond simple resistance to an overt chemical attack. If low-doses of antibiotic cause changes in gene expression or motility, then the ability to resist such behavior modifying activities could provide an advantage over species otherwise compelled to synthesize unnecessary structural components (Linares et al 2002). Other research has demonstrated that antibiotic resistance can improve species fitness under multi-stress conditions, such as the high levels of calcium and osmotic stress that are seen in Lechuguilla Cave (Chait et al 2016), while Leisner *et al.,* (2015) have argued that antibiotic resistance provides a bystander effect. This theory suggests that expression of resistance does not require as much metabolic capital as antibiotic production, but still allows the organism to take advantage of the nutrients released as a result of antibiotic-mediated cell killing.

Whatever the selection pressures are for establishment of antimicrobial resistance, research to determine the origin and potential spread of resistance is complicated by the difficulty in finding natural systems that have not been impacted by industrially derived antibiotics. The microbial ecosystems in deep, isolated caves allow us to study antimicrobial resistance in the absence of such anthropogenic impact. As such, caves may provide critical environments in which to study the evolutionary drivers that have led to the rapid and pervasive spread of antimicrobial resistance in human pathogens.

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(Abstract) Microbial role in speleogenesis in a sulfidic aquifer

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Abstract

The Frasassi Cave system (Italy) is intersected by a sulfidic aquifer that mixes with oxygenated meteoric water in the upper 1-10 meters. The aquifer chemistry makes it an ideal setting to study dark sulfur cycling under oxygen-limiting conditions. White microbial mats colonize cave streams and pools within the oxic-anoxic mixing zone of the aquifer. Zero-valent sulfur concentrations in the microbial mats are 20 to 45% S(0) by dry weight, while underlying anoxic sediments contain less than 5% S(0). We analyzed paired mat and sediment samples using Illumina high-throughput sequencing with universal (bacteria and archaea) 16S rRNA primers and found that the mat communities are dominated by Gamma-, Beta-, Epsilon-, and Deltaproteobacteria. Underlying sediment microbial communities are nearly identical except for the much lower abundance of Gammaproteobacteria related to Beggiatoa. Deltaproteobacteria populations in both mats and sediments are dominated by diverse strains of Desulfocapsa thiozymogenes, which carries out sulfur disproportionation. Our data are consistent with Beggiatoa-dominated microbial mats in which cells are oriented at the sediment water (oxic-anoxic) interface and only oxidize sulfide incompletely to S(0). Our data also suggest that sulfur disproportionation by Desulfocapsa populations is the primary sink for the abundant S(0) generated in the aquifer mixing zone. Based on current and prior work at Frasassi, we suggest a new conceptual model for the microbial role in speleogenesis in sulfidic caves.

Exploring the microbial diversity featuring the geochemical complexity of the quartz-sandstone cave Imawarì Yeuta, Auyan Tepui, Venezuela

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Abstract

In the last three years, one of the longest quartz-sandstone caves, Imawarì Yeuta, has been explored in the Precambrian rocks of the Auyan Tepui massif in Venezuela. The uniqueness of this quartz-sandstone cave resides in its great age (estimated over 30 Ma) and its complete isolation from anthropogenic activities. Therefore, subsurface ecosystems might have been preserved from contamination and possible subsequent alteration. The cave contains a high level of microbial activity as demonstrated by the presence of silica stromatolite-like speleothems, biologically mediated sulphate-phosphate deposits and lakes covered by patinas of violaceous or other colourful biofilms. The high diversity of the environments, in terms of mineralogical substrate and geochemistry of the waters, suggests that niche-differentiation of the microbial communities could be mainly controlled by the specific chemical characteristics of each site rather than by light attenuation, i.e., the distance from the entrances of the cave toward the dark zones. To investigate this possibility, we characterised the microbial community composition in 17 samples collected during the expeditions of 2014 and 2016 to the cave system. In particular, the next-generation sequencing (NGS) approach was performed by using Illumina MiSeq technology targeting the 16S rRNA gene. The acquired data have then been correlated with geochemical (water pH, EC, major and minor elements) and mineralogical (predominant and secondary minerals) information from each sampling site. The results showed that the cave hosts three main types of microbial communities, each of these characteristic of a specific environment dominated by silica (crystalline or amorphous), iron hydroxides or hydrated sulphate-phosphates.

This work presents a first set of results on the microbial characterisation of each sampling site and proposes a preliminary hypothesis on the functional biological factors supporting the biodiversity distribution in relation with the different geochemical environments described in this exceptional cave.

Keywords: *microbial diversity; silica; sulphates; biospeleothems; tepui.*

1. Introduction

Deep subsurface and deep-sea environments are the two last largely unexplored habitats on earth. Since caves are natural openings into the deep surface they offer the unique possibility to explore and investigate this important ecosystem. Globally only 10% of all caves have been discovered and only a small fraction of these has been biologically explored (Eavis 2010; Engel, 2010, 2011). Up to now only ~60 caves have been investigated using molecular biological methods. So far results showed that subsurface microbes might be unique and genetically divergent from surface organisms, with only about half of bacterial and archaeal phyla somehow identifiable (Lee *et al.* 2012).

The identification of cave specific species and ecology opens interesting questions related to their interaction with the mineral substratum and with peculiar weathering and minerogenetic processes. Also the evolutionary mechanisms, which allowed microbes to proliferate in the extreme environment of deep surface where usually nutrients are low, are still largely unknown. Recently it was hypothesised that older caves might function as long-term reservoirs of largely non described microorganisms, similar to deep-sea hydrothermal vents that are used as model systems to better understand the origin and evolution of life on Earth or on other planets (Northup and Lavoie 2001; Engel and Northup 2008; Engel 2010; Lee *et al.* 2012).

Most previous research on this topic dealt with classic carbonate caves while very little attention has been given to peculiar environments like quartz-sandstone and quartzite caves, where silica is by far the dominant element. About twenty years ago cavers and karst scientists believed that speleogenesis of caves in quartz-sandstones was related to exceptional conditions and only of local importance. On the contrary, since 2000, several huge horizontal cave systems have been explored in the tepui massifs of Venezuela. There is still an ongoing debate in the scientific community concerning the processes responsible for the formation of such extensive caves in this extremely hard and barely soluble lithology. The

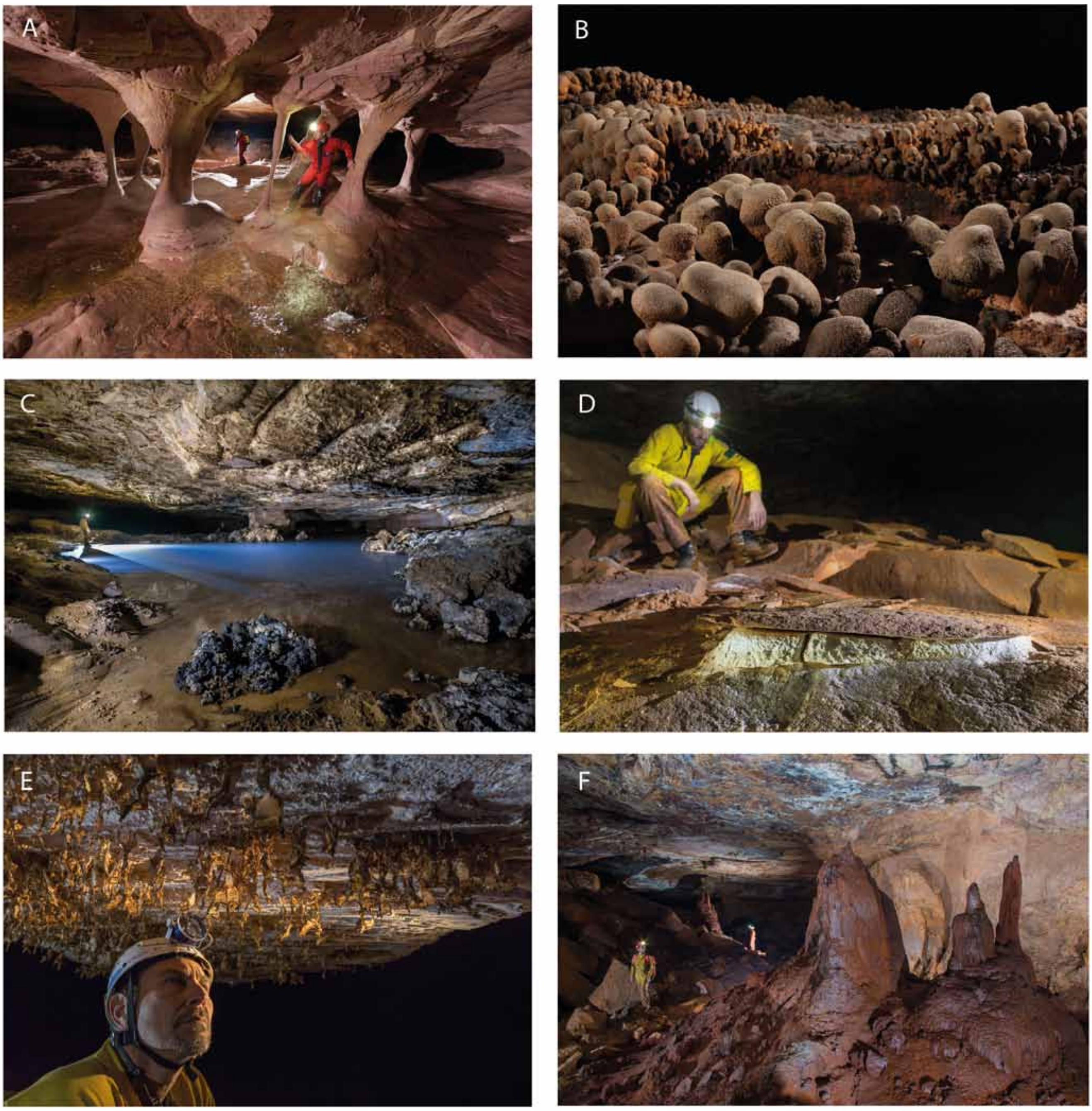

Figure 1. Different geochemical environments in Imawarì Yeuta: A) Eroded and polished quartzite walls along a stream active area (HSOR); B) Stromatolite-like speleothems made of amorphous silica (HSOR); C) A lake satured in SiO2 and covered by a violet patina (HSOW); D) A sulphate-phosphate deposit is accumulated below a quartzite boulder (SP); E) Mould speleothems made by philaments encrusted by amorphous silica (MS); F) A deposit of iron-hydroxides (HI). (Photos by R. Shone, R. De Luca, A. Romeo, V. Crobu – La Venta).

formation of caves and karst features in quartz-rich rocks was considered exceptional given the low solubility and dissolution rates of quartz (Wray 1997). Based on the slow dissolution rate of SiO_2, on geochemical analysis of dissolved silica in cave water and on the geomorphic history of the region, many authors agree that the formation of these caves could be reasonably dated back at least to ~20-30 Ma (Piccini and Mecchia 2009). In addition, all these caves present several types of silica speleothems (opal and amorphous silica) that have been proposed as biologically mediated or even as true silica stromatolites (Aubrecht et al. 2011). The discovery of new (Galli et al. 2014) or extremely rare sulphates and sulphate-phosphate minerals (Sauro et al. 2014) in these underground environments, with clear presence of EPS (extracellular polymeric substances) has also opened a debate on whether or not microbes are involved in their genesis. The uniqueness of the tepui caves resides in their great age and isolation from anthropogenic activities. Therefore subsurface ecosystems might have been preserved from contamination and possible subsequent alteration in these caves.

In 2013 a new giant cave, named Imawarì Yeuta, was discovered by a joint Italian-Venezuelan expedition on the Auyan Tepui in the Canaima National Park (Venezuela). Besides its dimensions (this is the longest quartzite cave in the world), the scientific interest of this karst system is very high ranging from the processes of weathering that lead to the cave formation, to the exceptional secondary minerals and speleothems

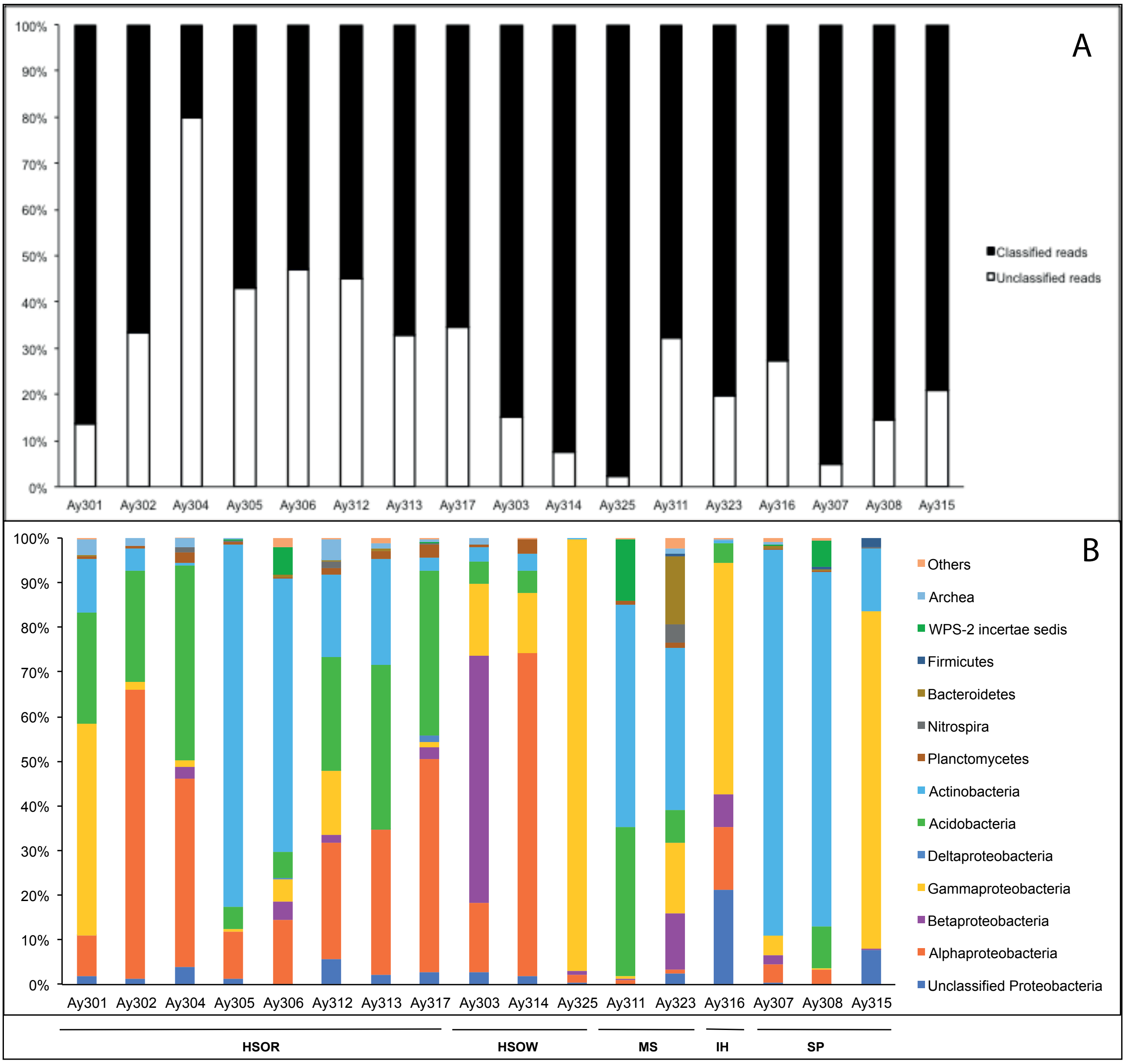

Figure 2. Taxonomy classification of sequences (reads adjusted for the copy number) for the samples under analysis. Panel A) shows the percentage of taxonomically classified (black) and unclassified (white) sequences found in each sample. Panel B) displays the relative abundance of the bacterial phyla and archea found in the classified fraction of sequences in each sample. "Others" comprises all the classified bacterial phyla present <2% in all samples. The corresponding sample group names defining the geological settings reported in Table 1 are reported below the histograms

(Sauro 2014). A set of 17 samples has been collected from this cave in order to start a research project on the microbial diversity and on the functional role of microorganisms in the speleogenesis and minerogenesis in silica environment. In this abstract we describe the first results of the microbial diversity next-generation sequencing analysis (NGS) and their relation with different geochemical environments (high silica, high sulphates, high iron) within the cave system.

2. Geochemical environments and samples

Imawarì Yeuta is actually one of the most developed cave systems in quartzite environment of the world. The rock hosting the cave is 85 to 95 % quartz, with small amounts of phyllosilicates (kaolinite and pyrophyllite) and iron hydroxides. Quartz has an extremely low solubility at the local T (15° C) and pH (3.4 to 5), thus stream waters crossing the cave are usually undersaturated and with extremely low EC values, almost approximating to that of distilled water. Nonetheless in the cave there are locally peculiar biogeochemical niches, like sulphate substrata, iron hydroxide deposits and rare opal and amorphous silica biostromatolites (Fig. 1). In general there is a clear transition between hydrologically active zones, where the quartzite rock is polished by water erosion and secondary mineral deposits are absent, to hydrologically inactive fossil zones where amorphous silica crusts, silica speleothems, and secondary minerals are abundant. In these areas the quartzite rock is more weathered and weaker and there is frequently the evidence of biological activity in the form of biofilms. Also here cave waters in still-standing pools have different chemical characteristics, with higher levels of pH (6) and significant levels of dissolved SiO_2 (most of them saturated at 8.5 mg L^{-1}). Fossil areas are environments with extremely low nutrient sources, where the only exchange with the surface is through air currents.

Most of the samples come from these fossil areas of the cave, being the most isolated spots where the biological activity has lasted for longer times in more or less stable environmental conditions, possibly for millions of years. The main group of samples is related to environments with high silica (HSOR) either on rocky substratum or in waters. In this group, samples have been collected on clean quartzite walls (Ay317), amorphous silica speleothems (Ay302-306), silica coralloids (Ay313), and quartz sands (Ay312). A peculiar subset of samples also related to unusual high silica content is that of silica-saturated waters and violet blue lakes in fossil areas (HSOW). Sulphate and phosphate-sulphate substrata represent another geochemically peculiar set of samples collected mainly in one chamber, where minerals like sanjuanite, rossiantonite, gypsum and alunite have been found in form of mounds (SP). One other set, with only one sample, is from giant iron hydroxide deposits forming flowstones and stalagmites (IH), where iron is surely the dominant element. Finally another set (MS) comes from a peculiar mould biospeleothem made of a mixture of amorphous silica, manganese and iron hydroxides, representing one of the most enigmatic features of this cave covering the cave roofs for hundreds of square metres.

3. Methods

Samples have been taken with a sterilized spoon directly from the rocky substratum, water ponds, or mineral aggregates and stored in sterilized 4 ml eppendorf tubes filled with a solution of LifeGuard RNA. The transport from the site to the lab was carried out in a portable fridge and then samples were stored at -90° C.

Genomic DNA was extracted from each sample using the UltraClean Soil DNA Isolation Kit (MoBio, Carlsbad, CA, USA) with slight modifications to the manufacturer's protocol (Cappelletti *et al.* 2016).

To provide amplicon for Illumina MiSeq analysis, the total DNA was amplified for V4-V5 region of 16S rRNA gene with universal forward 515F (5'-Illumina overhang-GTGY-CAGCMGCCGCGGTA-3') and reverse 907R (5'- Illumina overhang-CCCCGYCAATTCMTTTRAGT-3') primers. One µL of total DNA was added to a 50 µL (final volume) PCR reaction mixture containing 25 µL of Premix F (Epicentre Biotechnologies, WI, USA), 200 mM (each) forward and reverse primers, and 0.5 U of Ex *Taq* DNA polymerase (Takara Bio, Japan). Amplification reactions were carried out under the following thermocycling conditions: 95°C for 3 min, 30 cycles of 95°C for 30 s, 55°C for 30 s, 72°C for 30 s, with a final extension at 72°C for 5 min.

PCR amplicons were confirmed by electrophoresis with a 1% (w/v) agarose gel and then purified by AMPure XP beads (Beckman Coulter) prior to the index PCR. Nextera XT Index was incorporated into each of the individual samples during PCR. The thermal cycling program included a first denaturation step at 95°C for 3 min, followed by 8 cycles of denaturation at 95°C for 30 s, annealing at 55°C for 30 s, elongation at 72°C for 30 s, with a final extension at 72°C for 5 min. Purified amplicons were submitted to KAUST Genomic Core Lab for unidirectional sequencing reads on an Illumina MiSeq platform. Chimeric sequences were detected using UCHIME[37] and deleted.

To annotate the 16S rRNA gene sequences obtained from high-throughput sequencing, the Ribosomal Database Project (RDP) Classifier was used for taxonomical assignments at a 95% confidence level. After annotation, the relative abundance of each bacterial genus was calculated, collated and the normalized data were square-root transformed (Ansari *et al.* 2015). The transformed dataset was then computed for their Bray-Curtis similarities and represented graphically for spatial distribution in a non-metric threshold multidimensional scaling (nMDS) plot using Primer E version 7.

4. Results and Discussion

The analysis of Illumina MiSeq sequencing revealed a total number of 56,622 sequences (reads corrected for the taxon copy number) of which around 40% were not taxonomically defined by the RDP program (Fig. 2A). This high number of unclassified reads is probably related to the lack of previous microbiological studies in these pristine environments showing the interesting potential of this cave for biodiversity studies, particularly in the search of novel bacteria and novel metabolic activities (e.g. production of antibiotics, secondary metabolites generation). The classified sequences were mainly defined as *Eubacteria* and, in 12 out of 17 samples, sequences belonging to *Archaea* were also present within an abundance range of 0.1-5% (Fig. 2B).

The multi-dimensional scaling (MDS) plot in Fig. 3 compares the 17 samples on the basis of the relative abundance of classified and unclassified bacteria and archaea revealed by next-generation sequencing. In the MDS, the samples belonging to the geochemical groups (HS-R and HS-W) featured by the presence of high concentration of silica generally clustered together. On the other hand, the samples characterised by sulphate and phosphate presence tended to co-localize in the MDS plot and clustered apart from the HS-W sample group. Thus, differences in the geochemical settings seem to reflect the microbial community structure diversification.

In all the samples, the classified bacterial sequences belonged to the 8 most abundant phyla (representing >2% in at least one sample) i.e., *Proteobacteria, Acidobacteria, Actinobacteria, Nitrospirae, Bacteroidetes, Firmicutes, Planctomycetes,* and the taxonomically undefined lineage WPS-2 (Fig. 2B). *Proteobacteria, Acidobacteria* and *Actinobacteria* were dominant, comprising 75–100% of the classified bacterial sequences in all the samples. *Nitrospirae*, *Bacteroidetes* and *Firmicutes* generally represented less abundant phyla; only in Ay323 of the mold-like speleothem (MS-R) sample group, *Bacteroidetes* and *Nitrospirae* amounted for 16% and 4%, respectively, while they were <2% in the other samples. *Firmicutes* was >2% only in Ay315 of the SP-R sample group. The *Planctomycetes* community was identified in almost all samples with an occurrence lower than 3%.

Alphaproteobacteria and *Gammaproteobacteria* were the dominant classes within *Proteobacteria*. Interestingly, in one of the samples (Ay303) collected from a pond with saturated content of silica and an unusual sulphate concentration (HSOW group), *Betaproteobacteria* dominated over *Alpha-* and *Gammaproteobacteria* being mainly composed by *Janthinobacterium* genus. These bacteria have been previously isolated from cave samples for their Mn(II)-oxidizing abilities and violacein-producing capacity (Rodrigues *et al.* 2012; Carmichael *et al.* 2013). This last feature might be related to the violet-like appearance of the water pond where Ay303

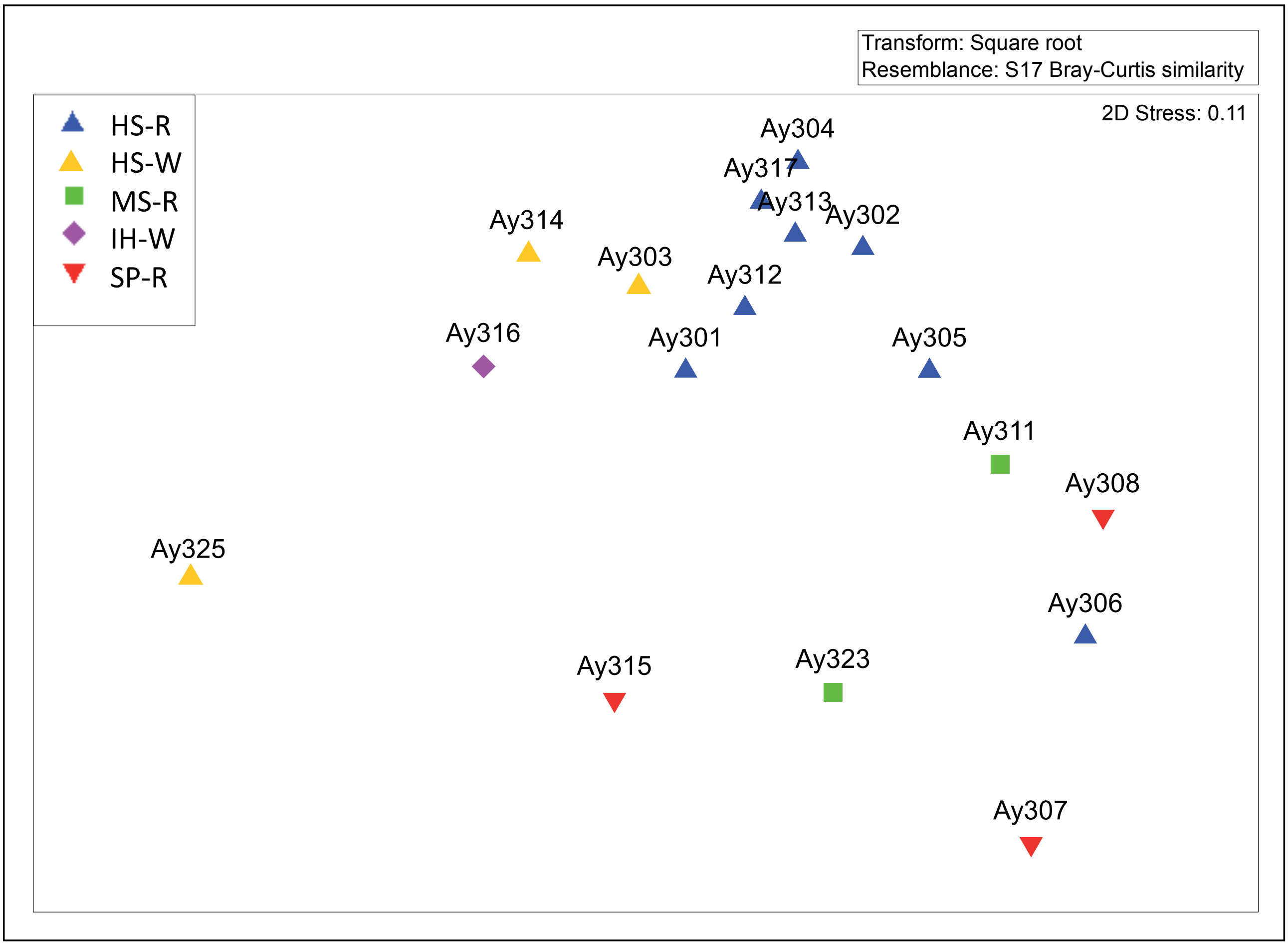

Figure 3. Multi-dimensional scaling (MDS) plot for the microbial community in tepui samples described in Table 1. The MDS plot displays the community structure distribution of the 17 samples under analysis on the basis of the relative abundance of classified and unclassified bacterial and archeal sequences detected in each sample through Illumina Miseq analysis. Symbols with the same shape and colour represent samples of the same geochemistry-based grouping (Table 1). The acronyms shown in the legend are explained in Table 1.

was collected. *Alphaproteobacteria* and *Rhizobiales* covered more than 50% of the *Proteobacteria* found in the microbial community in some HS-R samples (quartzite rock) and one HS-W sample (violet slime on water pond). A number of novel *Rhizobiales* species have been described from caves and they are well represented in subterranean environments. They are known to fix nitrogen and to play key roles in biodeterioration processes (Diaz-Herraiz *et al.* 2014). Among *Gammaproteobacteria*, *Pseudomonadales*, *Xanthomonadales*, *Alteromonadales* and *Enterobacterales* represented the most abundant orders in different sample groups being associated with various natural and cave fauna (e.g. bats or oil birds) carbon organic sources. A representative group of *Deltaproteobacteria* in the HS-R samples was the *Myxococcales* order whose abundance was higher in sample Ay317 collected from pure quartzite rock walls. Previously, *Myxobacteria* have been found within caves in areas apparently untouched by man before (Menne and Rückert 1988). Some *Myxobacteria* species are known to induce bioprecipitation of calcium carbonate and to tolerate high concentrations of heavy metals (Tisato *et al.* 2015).

The *Actinobacteria* represents the second most abundant phylum after *Proteobacteria* found in this study. More than half of the samples tested showed *Actinobacteria* abundance >20% of the classified bacterial community. In particular, the sample groups collected from water environments showed lower percentage (<4%) of this phylum. *Actinobacteria* have been described as one of the prevalent lineages in freshwater, but are also a small component in saltwater (Jensen and Lauro 2008).

Acidobacteria represent the third most abundant phylum found in our tepui samples. Their distribution is variable among samples, with the highest abundance being detected in the HS-R group. *Acidobacteria* are ubiquitous in different types of subterranean environments; in particular, *Acidobacteria* subgroups 1, 3, 4, and 6 are prevalent in terrestrial environments, including some cave samples (Sáiz-Jiménez 2015). In HS-R samples subgroups 1, 2, 3 and 13 were the most abundant, while in MS-R samples only *Acidobacteria* subgroup 1 was detected. Metabolic associations have been described between the different *Acidobacteria* subgroups and other bacteria-like methanotrophs, phototrophs, *Gamma-* and *Epsilonproteobacteria* (Sáiz-Jiménez, 2015).

In all the samples, considering only the classified sequences, the maximum *Archaea* representation was 5% (Ay312). *Thaumarchaeota* comprised a significant portion of the classified archaeal community detected in this study. The second most abundant phylum was *Crenarchaeota*, while *Euryarchaeota* phylum was identified exclusively in sample Ay307 (SP-R), where *Crenarchaeota* and *Thaumarchaeota* were absent. Previously, the presence of *Thaumarchaeota* and *Euryarchaeota* in caves has been related to oxygen concentration and to nitrogen source production for microbial community development.

In general these first data show that the biodiversity of each is group of samples seems to be controlled by the specific geochemical and environmental characteristics, with some variations in between group samples depending also on the substratum (rock or water). Further genomic studies will probably enable identification of functional metabolic associations that might induce silica bioweathering or have a control on the genesis of certain minerals, thus revealing the mutual influence between microbial communities and geochemical processes.

Acknowledgements

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Table 1. Description of the geological settings and chemical parameters featuring the tepui samples analysed in this study.

Sample	**Description**	**Type of substratum**	**pH**	**EC**	**Si**	**SO4 (mg/L)**	**PO4**	**FeOH (μg/L)**	**Al (μg/L)**	**T (°C)**	**Water activity**
High Silica on Rocks (HS-R)											
Ay301	Whitish dots of amorphous silica	Quartzite floor	/	/	High	No	No	No	Low	15,2	Wet, close to small stream
Ay302	White paste of amorphous silica	Quartzite floor	/	/	High	No	No	No	Low	15,2	Wet, close to small stream
Ay304	White spots resembling lichens	Quartzite floor	/	/	High	No	No	No	Low	15,2	Wet, along small stream
Ay305	White shiny on the floor	Quartzite floor	/	/	High	No	No	No	Low	15,2	Wet, along small stream
Ay306	Black amorphous silica coralllloid	Quartzite floor	/	/	High	No	No	No	Low	15,2	Wet, along small stream
Ay312	Yellow dots and agglomerates	Quartz sand	/	/	High	No	No	No	Low	15,2	Wet satured
Ay313	Black encrustation of amorphous Si	Quartz sand	/	/	High	No	No	No	Low	15,2	Wet, not satured
Ay317	Quartz sandstone walls	Quartzite rock wall	/	/	High	No	No	No	Low	15,2	Wet, close to small stream
High Silica on Waterpond (HS-W)											
Ay303	Brown slime with yellow dots	Water	5,1	6,9	8,87*	0,66	No	19,7	No	14,7	Stagnant waters
Ay314	Violet slime on water pond	Water	5,1	6,9	8,87*	0,66	No	19,7	No	14,7	Stagnant waters
Ay325	Irridescent patina on water	Water	6,1	11	8,6*	0,63	No	No	No	14,8	Stagnant waters
Mold-Like Speleothem (MS-R)											
Ay311	Violet patina on the roof	Quartzite floor	/	/	High	No	No	Low	No	15-17	Dry and windy
Ay323	Mold on silica coraloids on roof	Amorphous silica	/	/	High	No	No	Low	No	15-17	Dry and windy
Iron Hydroxides (IH-W)											
Ay316	Black gours of Goethite	Water	5	9,8	6,3	0,59	Low	10,1	57,0	14,4	Percolating water
Sulphates And Phosphates (SP-R)											
Ay307	Soft deposit of sulphates in the floor	Sulphates	/	/	Low	High	High	Low	Low	15,2	Dry on floor
Ay308	Powder of sulphates and amorphous silica	Sulphates and silica	/	/	Med	High	High	Low	High	15,2	Dry on floor
Ay315	Sanjuanite and Gypsum deposit	Sulphate powder	/	/	Low	High	High	Low	High	15,2	Dry

* = saturate

(Abstract) **Biosignature potential in sulfur isotopes of cave gypsum**

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Abstract

Cave minerals can potentially be utilized as biosignatures with applications to the search for subsurface life on Mars and other habitable worlds. We studied the crystal morphology and sulfur isotopic composition of gypsum ($CaSO_4.2H_2O$) formed in the presence of sulfur-oxidizing microbes in the sulfidic Frasassi cave system, Italy. Sulfur isotopic compositions ($\delta^{34}S_{V\text{-}CDT}$) of gypsum from cave rooms with sulfidic air varied from -11 to -24‰. Over centimeter length scales, the $\delta^{34}S$ values of gypsum varied by up to 8‰, reflecting the isotopic effects of local variations in microbial sulfide oxidation ($\Delta^{34}S_{SO4\text{-}H2S}$ = 0 to -8‰). This range is similar to that expected for abiotic sulfide oxidation with O_2 ($\Delta^{34}S_{SO4\text{-}H2S}$ mean of -5‰), apparently complicating the use of sulfur isotopes as a biosignature. However, at meter length scales, the ~13‰ variability in gypsum $\delta^{34}S$ reflects isotopic distillation of circulating H_2S gas due to microbial sulfide oxidation occurring at the cave walls. We interpret systematic variations of gypsum $\delta^{34}S$ along gas flow paths as a biosignature given that much slower, abiotic oxidation cannot produce the same distillation effect. We also show how variations in the relative rates of cave air circulation and microbial sulfide oxidation may affect the intensity of the sulfur isotope biosignature. Since physical and chemical diagenetic processes can lead to dissolution and recrystallization of cave gypsum, information about crystal morphology is critical to interpreting the role of microbial activity in sulfur isotopic patterns.

(Abstract) **Rock-powered life in the vadose zone at Wishing Well Cave, VA (USA)**

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Abstract

Wishing Well Cave near Burnsville, VA (USA) is developed in the Ordovician Licking Creek limestone and hosts a conspicuous biofilm thriving in pools fed by vadose drips. Based on repeated expeditions to the cave, the biofilm is a perennial feature and regrows after a disturbance such as sampling. Water surrounding the biofilm is cold (8 to 13°C), unmineralized (sp. conductivity ~200 µS/cm), neutral (pH 7.2 to 7.7), and oxic (~ 95% saturation). The biofilm contains abundant orange iron-rich particles < 0.2 µm in diameter, and small but significant amounts of dissolved sulfate (10-62 µM), phosphate (5-44 µM), Fe^{2+} (0.2-5 µM) and NH^{4+} (5-19 µM). Dissolved methane, sulfide, nitrate and nitrate were below detection limits. DNA sequencing of the biofilm samples revealed a N, S, Fe and CH_4 cycling microbial community, likely fed by low concentrations of dissolved chemicals originating in the overlying hydrocarbon-rich Oriskany sandstone.

Preliminary Observations on Tropical Bat Caves as Biogeochemical Nitrogen Sinks

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Abstract

A previously unrecognized aspect of nitrogen biogeochemistry in tropical moist forests (TMF) relates to the spatial biogeochemistry of these systems. In general, high levels of herbivory in TMF's transfer large amounts of fixed nitrogen and other nutrients into the insect community, which itself is harvested by aerial insectivorous vertebrates (bats and birds), or moves directly into the non-volant vertebrate community through leaf eating mammals and frugivorous mammals and birds. In non-karstic TMF's bats and birds can be expected to redistribute this fixed nitrogen through defecation and urination throughout the TMF, contributing to the efficient recycling of this potentially limiting nutrient. However, in karst environments, TMF's may support very large (10^5 – 10^6 individuals) populations of bats and in Southeast Asia, birds (cave dwelling swiftlets), that occupy very spatially localized roosts. A single large cave may support a bat or swiftlet population in the hundreds of thousands of individuals that forages for insects over thousands of square kilometers of TMF, but then deposits a substantial fraction of its total excretory nitrogen within that single cave. A large but undetermined fraction of this nitrogen input is retained within the cave, or lost as diatomic nitrogen gas following biological denitrification. Such a cave then functions as a point-source sink for TMF fixed nitrogen. Recent work in Deer Cave, Mulu National Park, Sarawak (Malaysia) has mapped the ammonia plume emanating from a large bat guano accumulation. Relating this plume to airflow, first order estimates of ammonia production are ~ 9 g NH_3/m^2/day below the main *Chaerephon plicata* roost. An additional 4 g N/m^2, or 45% of the total nitrogen budget, are retained in the guano and eventually lost to the external environment.

Keywords:

1. Introduction

Tropical (and in North America, warm temperate) environments may support very large colonies of certain hyper-colonial cave roosting bat species. Caves that host colonies of hundreds of thousands of insectivorous bats are repositories for very large quantities of bat guano. Insectivorous bat guano consists primarily of undigested insect chitin – an N-acetyl-glucosamine polysaccharide that is highly resistant to degradation, together with normal vertebrate fecal products and urine. The fate of these cave guano accumulations is largely determined by moisture content. In dry conditions, insectivorous bat guano may be preserved essentially intact for thousands of years, where it has been shown to be an important archive of palaeoenvironmental data (e.g., Wurster et al., 2008). Under moist conditions, decomposition by chitinase-producing microorganisms can proceed much more rapidly, although very little work has been published on measured rates.

Fresh bat guano contains some 12% nitrogen by weight in the chitin component, together with a significant contribution from bat urine. McFarlane et al. (1995) postulated that the urea component is rapidly metabolized by ammonifying bacteria and volatized as ammonia gas, which can reach concentrations >1000 ppm in some caves, but is more commonly exported from the cave by air flow. Chitin-derived nitrogen is metabolized much more slowly to nitric acid, and either denitrified, or under appropriate conditions of moisture saturation and wicking, combines with calcium, sodium or potassium ions to form one of a family of nitrate minerals (Hill, 1981) that may appear as a solid efflorescence in low humidity environments, or carried away in solution in saturated deposits.

The world's tropical forests are the Earth's major repository of biodiversity and play important roles in global climate regulation and biogeochemical cycling (e.g., Maldhi and Phillips, 2004). Previous studies of nitrogen fixation rates in tropical forest ecosystems have provided widely disparate results; Reed et al. (2008) report published TMF canopy fixation estimates that span four orders of magnitude. Furthermore, Feeley and Terborgh (2005) demonstrate that mammalian herbivore density on land-bridge islands isolated in Lago Guri, Venezuela, is strongly correlated with reduced nitrogen content (increased C:N ratio) in TMF soils. Nitrogen fixation in TMF's has also been shown to be limited by phosphorus availability (Townsend *et al*., 2007). In general, high levels of herbivory in TMF's transfer large amounts of fixed nitrogen and other nutrients into the insect community, which itself is harvested by aerial insectivorous vertebrates (bats and birds) and the non-volant vertebrate community of leaf eating and frugivorous mammals and birds. In non-karstic TMF's bats and birds can be expected to redistribute this fixed nitrogen through defecation and urination throughout the TMF, contributing to the efficient recycling of this potentially limiting nutrient. However, in karst environments, TMF's may support very large (105 – 106 individuals) populations of bats and, in Southeast Asia, birds (cave-dwelling swiftlets), that occupy very spatially-localized roosts. A single large cave may support a bat or swiftlet population in the hundreds of thousands of individuals that forages for insects over thousands of square kilometers of TMF, but then deposits a substantial fraction of its total excretory nitrogen within that single cave. The magnitude of the flux and ultimate fate of nitrogen passing through tropical bat caves has not previously been investigated; here, we argue that this represents an unrecognized but important component of tropical moist forest biogeochemistry in karst regions. In order to test this hypothesis, we constructed a simple input-output budget by measuring nitrogen sequestration in cave guano, guano decomposition rates, and

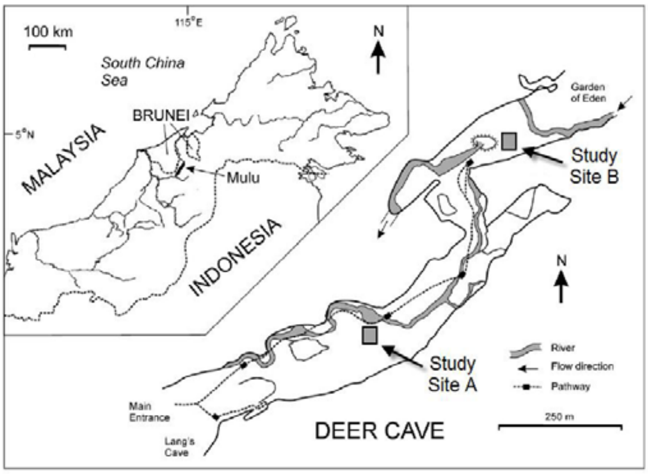

Figure 1. Deer Cave, Gunung Mulu National Park, showing guano study sites. (Cave plan modified from Brook and Waltham, 1978).

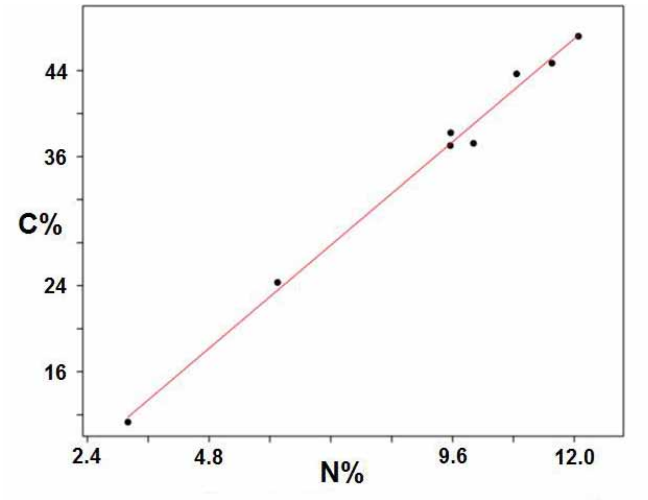

Figure 3. Relationship between chitin-bound carbon and nitrogen in Deer Cave guano.

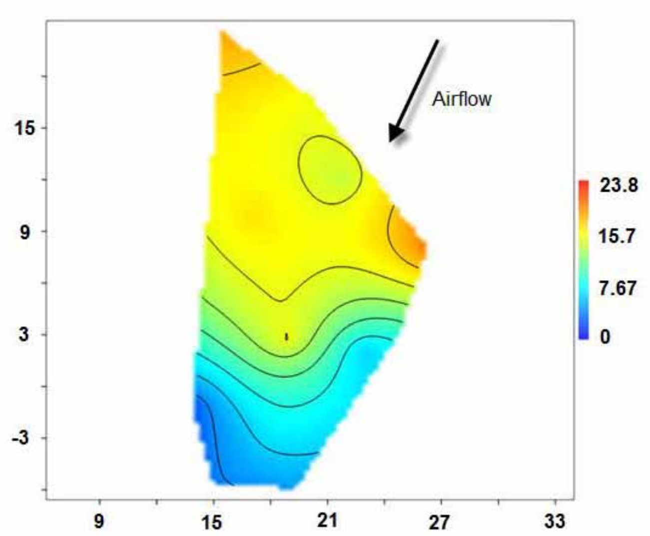

Figure 2. Ammonia plume, Site A, Deer Cave. Concentrations in ppm, X-Y scale in meters.

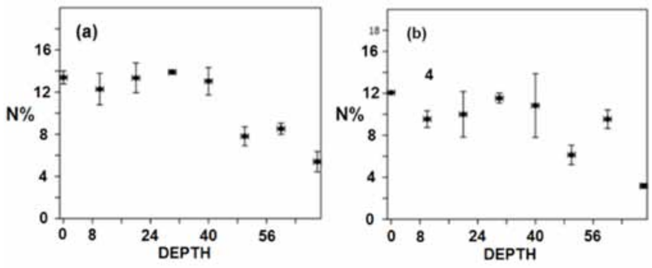

Figure 4. Relationship between chitin-bound nitrogen (a) and unbound nitrogen (b) and depth in the guano deposit.

nitrogen loss to the atmosphere by release of ammonia gas from the guano.

2. Location and Methods

Fieldwork was conducted in Deer Cave, Gunung Mulu National Park, Sarawak, Malaysia (Borneo) in April 2016. Two study sites were chosen: Site A beneath the main (south western) bat roost, and Site B, adjacent to the north eastern bat roost (Figure 1). Guano deposition was measured using a grid of plastic, 510 cm^2 collecting plates mounted on 50 cm dowel rods coated with a ring of petroleum jelly to prevent access by guanophagic invertebrates. Collecting stations were surveyed in to the base map using standard cave survey techniques, to a demonstrated precision of ± 10 cm (x, y) and ± 15 cm (z). Guano pellets accumulating on the plates over a 24 hour period were collected, dried, and weighed, yielding average and peak guano accumulation rates for the site. Atmospheric ammonia concentration was measured at each station over 24 hours employing ammonia diffusion cartridges (Radiello corporation) mounted beneath inverted plastic cups at ~ 35 cm above the guano surface. These cartridges absorb ammonia at a calibrated rate of 235 mL/minute (25 ^{0}C and 1013 kPa). After return to the laboratory, absorbed ammonium ions were quantified by reaction with phenol and sodium hypochlorite, with pentacyanonitrosylferrate catalysis, to form indophenol. The intense blue reaction product was measured by visible absorbance spectrometry at 635 nm. The final spatial data matrix was contoured in PAST software (Hammer et al., 2001).

Guano samples were also collected from a 70 cm-deep excavated profile at Site B and were dried and analyzed for chitin-bound and free (soluble) nitrogen, together with carbon, on an Elementar VarioCube C:N analyzer.

3. Results

The nitrogen content of Deer Cave guano is 0.076 g N/g dry wt. The nitrogen mobilization (as soluble nitrate and nitrite) at 40 cm depth is 36.2%. The highest observed guano deposition rate (site A) was 30.2 ± 3.4 g/m^2/day. Atmospheric ammonia reached 23.7 ppm (integrated over 24 hours) at Site A, generating an ammonia plume (Fig 2.) as the gas is washed from the cave by strong katabatic air flow of ~ 0.6 km/hr (cross sectional area at site A, 12700 m^2) during the study period.

Analysis of the carbon:nitrogen fraction of the washed samples from the guano profile demonstrate an almost perfect linear relationship (Fig 3), consistent with the assumption that this component of the nitrogen budget nitrogen is present as part of the chitin molecule, and only released by the slow depolymerization of the polysaccharide by chitinase-activity.

Comparison of the soluble and insoluble (chitin-bound) nitrogen content down the guano profile (Fig 4) shows little difference, further confirming the rapid loss of urea and fecal nitrogen in the most superficial layer of the profile.

4. Discussion

Guano diagenesis rate and long-term nitrate storage is closely tied to moisture content of the guano. In very dry conditions, such as those pertaining in caves of the arid southwestern United States, guano chitin fragments can retain their original structure over timescales of ~ 10 ka (McFarlane, personal observation, and Wurster et al., 2008). Significantly faster decomposition of guano chitin is observed in moist tropical caves, but the precise relationship between moisture content of the deposit and decomposition rate has yet to be determined. At Deer Cave, where the guano deposit contains >50% water, the decomposition and loss of a large fraction of the guano over ~ 70 cm depth, in circumstances of rapid continuous accumulation of fresh guano (~ mm increments per day) implies decomposition rates measured in years, not thousands of years. Work to date suggests that the urea component of the urine is rapidly (hours) metabolized, and the nitrogen volatized as ammonia. Microbial taxa associated with ammonification in soil include: *Bacillus*, *Clostridium*, *Proteus*, *Pseudomonas*, and *Streptomyces* (Wang *et al.*, 2015). This process is aerobic, and in this context must occur on the surface and immediate subsurface of the guano accumulation. At Deer cave, a mean airflow of 0.6 km/hr across the Site A study area results in the export of the ammonia from the cave. Our modelling of the ammonia plume yields first order estimates of ammonia production of ~ 9 g NH_3/m^2/day below the main Chaerephon plicata roost (site A).

Ammonification of chitin-associated nitrogen is much slower, and occurs deeper in the guano deposit. The three stages are: (1) decomposition of organic nitrogen to ammonia, presumably associated with chitinase-producing bacteria such as Aeromonads (facultatively anaerobic), Bacillus, and Vibrio (aerobic). (2) The oxidation of ammonia ions to nitrite, brought about by ammonia-oxidizing bacteria; e.g., *Nitrosomonas europaea, Nitrosococcus nitrosus, Nitrosospira briensis, Nitrosovibrio* and *Nitrocystis*. The process is aerobic and perhaps limited by the depth of invertebrate bioturbation. (3) Nitrite oxidation (aerobic) to nitrate by nitrite-oxidizing bacteria such as *Nitrobacter winogradsky, Nitrospira gracilis, Nirosococcus mobilis* etc., and several fungi *(eg., Penicillium, Aspergillus) and* actinomycetes *(eg., Streptomyces, Nocardia: Wang et al., 2015).* Under appropriate evaporative conditions, this nitrate may be deposited as the mineral niter (KNO_3), the only nitrate salt which can crystallize under tropical cave conditions of > 80% humidity and > 20 °C (Hill, 1981). The reverse process, in which nitrates are converted to nitrites and ammonia, occurs under anaerobic conditions (usually confined to the deeper, water-saturated layers of guano no longer subject to bioturbation). The most important denitrifying bacteria are *Thiobacillus denitrificans, Micrococcus denitrificans,* and species of *Pseudomonas, Bacillus, Achromobacter, and Serratia*.

At Deer cave, 9 g NH_3/m^2/day is lost from the guano. A further ~ 4 g/N/day/m², or 45% of the total nitrogen budget, is initially retained in the guano, gradually released by microbial decomposition of the chitin and eventually either exported in guano drainage waters, or in drier, evaporative environments, crystallized as niter. With a conservatively-estimated population of ~250,000 individuals, the *C. plicata* population in Deer Cave harvests an estimated 450 kg of nitrogen per day as insect prey. A similarly conservative foraging radius of 30 km incorporates 2800 km² of tropical moist forest, and amounts to a nitrogen "harvest" of ~0.5 kg N/day/ha, or some 48% of the typical TMF nitrogen budget. The cave is thus shown to act as a point-source sink for fixed nitrogen in the form of preserved guano or as crystallized niter; the nitrogen that is released to the atmosphere as ammonia gas is lost to the ecosystem; the nitrogen that is exported from the cave in the form of guano drainage waters is not distributed geographically and thus not available to most of the ecosystem. We conclude that the spatial bio-geochemistry of nitrogen is significantly modified in karst systems versus non-karst systems. Long-term sequestration of nitrogen in guano may be of the order of tens of thousands of years.

Acknowledgements

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(Abstract) Cryptic Microbes In Cave Minerals

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Abstract

A variety of secondary mineral deposits in caves harbor extensive communities of microorganisms and biofilm, but the mineral's appearance does not readily suggest the presence of microorganisms. Lava caves contain a great range of cryptic microbial-mineral communities that include organic ooze deposits, copper silicate coatings and stalactites, iron oxide speleothems including hexagons and mud-like deposits, biovermiculations, moonmilk-like puffballs, gold-colored mineral coatings, and vanadium oxides. These deposits were sampled aseptically in lava caves in the Azores, Iceland, New Mexico (USA), and Hawai`i (USA) for scanning electron microscopy (SEM) and next generation sequencing. Temperature and relative humidity data were collected and cave morphologies and number of entrances were characterized. SEM of these deposits revealed several common morphologies, which include filaments, both smooth and reticulated, rods embedded in biofilm, and beads-on-a-string shapes. Energy-dispersive X-ray spectroscopy (EDX) of these deposits has suggested the presence of amorphic copper silicates, hematite and other iron oxides, sulfur containing minerals, calcite, gypsum, and vanadium oxides. Next generation sequencing of samples of these deposits suggest the presence of chemolithotrophic microorganisms that utilize reduced iron, manganese, and sulfur, and methane or nitrite, as well as chemoheterotrophic microorganisms. The majority of these microbial communities from secondary minerals examined contained few Actinobacteria, in contrast to the composition of most lava cave microbial mats. The study of cryptic microbial communities in minerals can enhance our ability to detect life on extraterrestrial bodies, such as Mars, which has been shown to have putative lava caves that could preserve biosignatures.

Can Fermenting Bacteria Drive Speleogenesis in Fe(III)-rich Rocks?

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Abstract

The majority of caves are known to form through the speleogenetic processes of dissolution and solute transport, and erosion (Palmer 2011). Nonetheless, due to the high erosion and weathering resistance of banded iron formations (BIFs), it is unlikely that the thousands (>3,000) of iron ore caves (IOCs) found in Brazil's BIF formed under standard speleogenetic processes (Figure 1) (Piló and Auler 2009). Brazilian BIFs are ancient (1.8 - 2.7 Gya) sedimentary rocks composed of alternating quartz and hematite layers, covered by a cap of Fe(III) (hydr)oxide, known as canga (Spier et al 2007). Many of the IOCs form at the contact between the BIF and canga formations. As iron-reducing microorganisms (FeRM) have the ability to reduce insoluble Fe(III) phases to soluble Fe(II) (Lovley 1991), combined with removal of Fe(II) by water flow, we hypothesized that FeRM-induced iron-solubilization could account for the formation of IOCs.

Figure 1.

To determine if FeRM play a role in the formation of IOCs, a variety of anaerobic iron cultures were established, with different BIF associated minerals supplied as the sole Fe(III) electron acceptor. We monitored iron-reduction in these cultures with ferrozine to determine the amount of Fe(II) produced. The cultures using canga, iron ore, BIF or amorphous hydrous ferric oxide supplied as the terminal electron acceptor, all generated Fe(II), while the uninoculated controls did not (Figure 2). Although canga, BIF and iron ore all contain abundant Fe(III) phases (all more difficult to reduce than amorphous hydrous ferric oxide), most cultures demonstrated varying capabilities of reducing these iron oxides. We noted that all of our enrichment cultures exhibited a lag between the time when enrichments were established and when iron-reduction was observed (Figure 2).

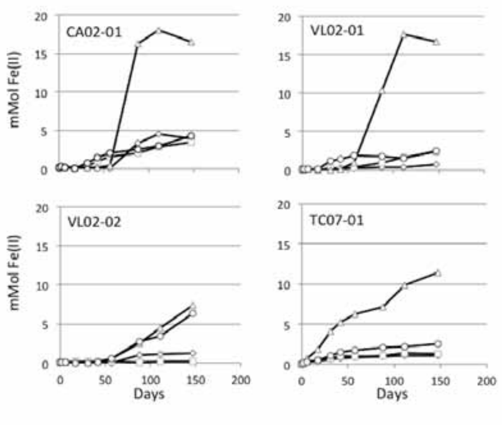

Figure 2.

To identify the microorganisms present in our iron-reducing cultures, we collected the cells and extracted total DNA followed by Polymerase Chain Reaction (PCR) amplification using the primers 8F (5'-AGAGTTTGATCCTGGCTCAG-3') and 1391R (5'-GACGGGCGGTGWGTRCA-3) for the bacterial 16S rRNA (small ribosomal RNA subunit) gene (Lane 1991). The resulting PCR products were ligated into TOPO TA vectors and then transformed into chemically competent *Escherichia coli* cells (Invitrogen, Carlsbad, CA), and inserts recovered from these clones were then sequenced via Sanger sequencing (AGTC, Lexington, KY). The sequences were then analyzed using molecular phylogenetic techniques, including sequence alignment in ARB (https://www.arb-silva.de/aligner/) followed by comparative analyses using the maximum likelihood method (via the program RAxML [http://www.phylo.org](Stamatakis, 2006; Miller et al., 2010)) to determine the phylogenetic relationship to known species. Despite the use of a variety of enrichment culture conditions, all iron-reducing cultures were dominated by members of the *Firmicutes* and the family *Enterobacteriaceae* (Figure 3). Unlike iron-respiring microorganisms that use Fe(III) as a terminal electron acceptor, members of the *Firmicutes* and *Enterobacteriaceae* aare fermentative, and use Fe(III) as a secondary electron sink; *Clostridia* produce H_2 during fermentation until its accumulation becomes thermodynamically unfavorable (Lovley 1991; Gapes, 2000). At this point, the *Clostridia* excrete reduced flavin molecules that transfer excess electrons to Fe(III) (Vecchia et al., 2014; Milliken & May, 2007). The lag period that we observed in our enrichment cultures could be explained as the time necessary for H_2 to accumulate in the headspace before the cells switch to Fe(III) as a secondary electron sink.

Our work demonstrates that fermentative FeRM are present in IOCs and that these FeRM could contribute to the formation of the IOCs, reducing the Fe(III) oxides of both BIF and canga. Although there are examples of speleogenesis driven microbial metabolism, such as sulfuric-acid hypogenic caves in carbonate rocks (Hill 1990), Brazilian IOCs are the first example of biospeleogenesis occurring in Fe-rich rock.

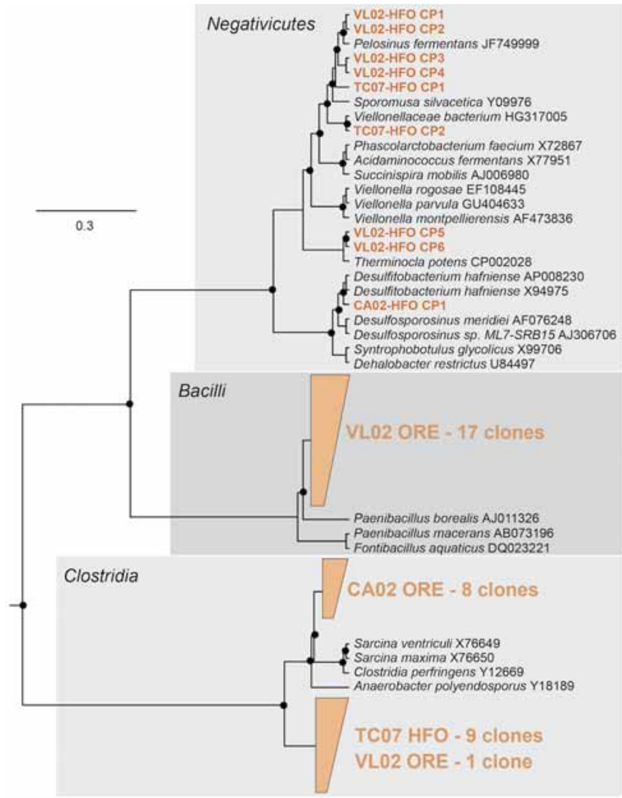

Figure 3.

Keywords: Keywords: Speleogenesis, Iron-reducing Microorganisms, Brazilian Iron Ore Caves, Fermenting Bacteria

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(Abstract) **Chemoautotrophic microbial mats rich in nanowires at a gas-gas redox interface in Smelly Cave (Romania)**

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Abstract

We describe microbial mats from Smelly Cave developed in andesitic rocks in a dormant volcanic area of Romania. The climate is temperate continental and the altitude is 1,100 m. Gases containing approximately 96% CO_2, 2.6% N_2, 1% CH_4 and 0.3% H_2S are emitted in this area, with 95% relative humidity and a temperature of 11°C. This gas mixture fills the Smelly Cave's deeper parts to an upper limit where a redox gas:gas interface is formed with O_2-containing atmospheric air on top. The wall surface pH is 0.5-1.0 due to sulfur oxidation or possibly pyrite oxidation to sulfuric acid. The dominant secondary mineral is orthorhombic sulfur. Possible energy sources for life are sulfur oxidation at the gas:gas interface, methane oxidation, and iron oxidation. The microbial community displays low diversity and (based on 16S rDNA sequencing) consists of Mycobacterium bacteria and Ferroplasmaceae archaea. Water vapor, presumably from the emitted gases and the moist ambient air, condenses on the cave walls. Microbial biofilms are very abundant at the gas:gas interface, with a thickness of up to 5 mm and a vertical span of approximately 5 cm. Microbial biofilms are not visible with the stereoscope microscope above and below the redox interface, but isolated cells were revealed by scanning electron microscopy (SEM) afar from the redox interface and were also detected in low abundance in DNA extracts. SEM images show abundant structures resembling nanowires between cells and sulfur crystals. Approximately 10 to 20 cm below the microbial mats, on the cave walls, massive soft deposits of elemental sulfur are up to 20 cm thick and consist of very dense bundles of sulfur fibers (approximately 1 μm in diameter) that are oriented perpendicularly to the cave wall. We discuss the potential significance of these findings as biosignatures at gas:gas interfaces in solfatara and similar cave environments associated with volcanic gas emission.

(Abstract) **Biogeography of microbes from caves in the Interior Low Plateau and Appalachians karst regions**

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Abstract

Most cave microbiology research focuses on the diversity of microbes in specific caves, such as Mammoth Cave in central Kentucky, or only from defined habitats like cave streams. To address questions about microbial biogeography and potential endemism in cave and karst systems, we analyzed the bacterial and archaeal 16S rRNA gene sequence diversity from cave-wall biofilms found in Tennessee and Kentucky caves, spanning the Interior Low Plateau and the Appalachians karst regions.

We selected cave-wall biofilms because they form distinctive, conspicuous, and often colorful features in all types of carbonate caves and basaltic lava tubes worldwide. We hypothesized that similar colony types (i.e., by color) would have more similar community compositions compared to other colony types, regardless of geography. Yellow, white, pink, and blue colonies, as well as nearby sediment, manganese-coatings, and bare rock were sampled by buccal swabbing. Next generation sequencing was conducted with bacterial- and archaeal-specific primers, and sequence reads from different samples were clustered into operational taxonomic units (OTUs) to compare community compositions.

White colonies had distinctly different bacterial community compositions, regardless of the cave. White and blue colonies were dominated by OTUs classified as either Pseudomonadales (Gammaproteobacteria: Proteobacteria) or Pseudonocardiaceae (Actinobacteria), and the dominant bacterial OTUs were occasionally shared among different colony types in the same cave. Rubrobacteraceae (Actinobacteria), Rhizobiales (Alphaproteobacteria), and unclassified Gammaproteobacteria were also present in white colonies, but in lower abundances. Most of the yellow colonies were dominated by Actinobacteria, as well as by Rhizobiales, Acidobacteria, and Nitrospirae. Among the archaea, white and yellow colonies were dominated by Euyarchaeota (Themoplasmata, Methanomicrobia), but blue colonies were dominated by Crenarchaeota (Thermoprotei and others).

Examination of shared OTU biogeography revealed potential endemism for some taxonomic groups, such as within the Proteobacteria, because different white colonies from different areas of a single cave did not share OTUs with white colonies from other caves even in the same region. But, the most prevalent Actinobacteria OTUs were shared in both regions, in all caves, and among all colony types. These results may indicate that the cave-wall habitat selects for specific groups of bacteria, and that these bacteria form a distinctive core microbiome for the subsurface.

Keywords: microbiology, karst, 16S rRNA, Tennessee, Kentucky, diversity

Fungal diversity in caves and on hibernating bats in North America

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The introduction to North America of the fungal pathogen *Pseudogymnoascus destructans*, causal agent of white-nose syndrome (WNS; Lorch et al. 2011), has stimulated research on the poorly known mycology of caves. In particular, fungal assemblages on the external surfaces of bats have attracted attention. WNS is estimated to have caused the deaths of >6.5 million bats in North America since it was first reported in 2006 (U.S. Fish and Wildlife Service, 2012). *Pseudogymnoascus destructans* has been documented on bats and in cave environments across North America, Europe, and some parts of Asia (Puechmaille *et al.* 2011; Heffernan 2016; Hoyt *et al.* 2016). Bat hibernacula are cool, humid, dark environments that seem to be conducive to the growth of a diverse assemblage of fungi. However, detailed studies of the mycology of cave environments are few. Most of the fungal taxa commonly reported from caves are widespread and cosmopolitan opportunistic saprotrophs associated with soils, plant material, or insects (Vanderwolf et al. 2013). Fungi found in cave environments may influence the fungal assemblage found on bats, and have the potential to interact with *P. destructans*.

We characterized patterns of fungal diversity found in eastern North American cave environments (e.g. soil, cave walls) compared to fungal assemblages on hibernating bats of multiple species (mainly Myotis sp.) using culture-dependent methods. Multiple media types were used and plates were incubated in the dark at 7 °C. Isolates were identified using a combination of morphology and molecular genetic techniques.

Environmental characteristics of individual caves, particularly sources of energy (organic matter), appear to influence the fungal assemblages cultured from hibernating bats and other substrates at specific hibernacula (Vanderwolf et al. 2016). The species composition of fungal assemblages cultured from cave soil, cave walls, and hibernating bats overlap, with *Pseudogymnoascus spp*. and *Penicillium* spp. commonly cultured from all three substrates in multiple hibernacula (Lorch et al. 2013; Vanderwolf et al. 2016). A core group of fungi appear to be widespread in North American cave environments and also on hibernating bats, accompanied by many rarely isolated fungal species. Common sources of energy in North American caves include mammal dung, arthropods, and plant debris, with the species composition of fungal assemblages reflecting this diversity of nutrients. Bats appear to acquire fungal spores from their immediate environment, and play a largely unrecognized role in fungal dispersal. Bats also contribute to the diversity of fungi in caves by transporting spores on their external surfaces, both from the aboveground and underground environments. Previous studies have shown bats can transport pollen, viruses, parasites, and the fungus *Histoplasma capsulatum* (Kunz and Parsons 2009), and it is believed that bats are responsible for much of the rapid spread of *P. destructans* across eastern North America.

Few fungi were previously known to grow on bat skin, but recent research efforts have documented novel fungal species that appear to be commensals (Lorch et al. 2015). It has been demonstrated that natural skin floras may protect animals from pathogenic microorganisms, a good example being amphibians infected with *chytrid* fungus (Becker and Harris 2010). While recent work demonstrates that Pd is not unique in its ability to grow on the skin of bats, there is a lack of information about how fungal skin floras vary between bat species. Such information, combined with experimental work, may provide insight into whether these floras play a role in protecting bats from WNS.

Acknowledgements:

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Cultivable Bacterial Diversity from Iron Curtain Cave in Canada

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Introduction

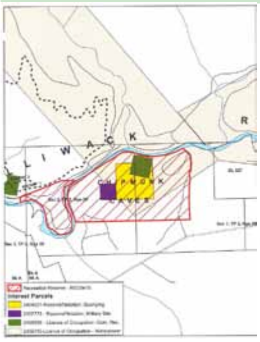

Figure 1. The area shaded with red lines shows the Chipmunk Ridge.

- The Iron Curtain Cave is located near Chilliwack, British Columbia on the back side of Chipmunk Ridge (Figure 1).
- It is a pristine carbonate cave and was discovered by Rob Wall in November, 1993.
- The cave's survey was performed and the map was chiefly drawn by Trevor Moelaert in April 1999 (Figure 2).
- In this study we have elucidated the cultivated bacterial diversities of the Iron Curtain Cave and further more evaluated their antimicrobial properties.

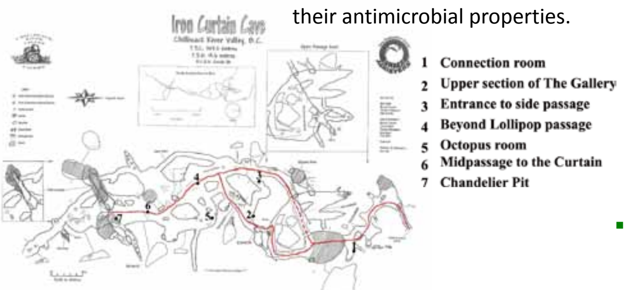

Figure 2. The Iron Curtain Cave map and the black dots exhibits the sampling points.

Materials and Methods

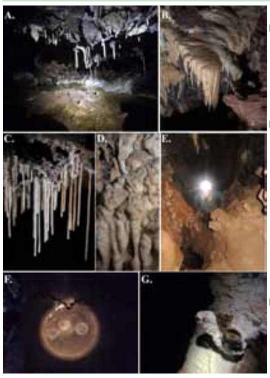

Figure 2 (A-E, G) Sample types collected from Iron Curtain Cave. **(2F)** R2A plates kept for incubation in the cave.

- Seven sampling points and incubation sites were chosen.
- R2A agar plates were inoculated with wall swabs and the plates were left exposed to the cave conditions for 9 months.
- The bacterial isolates were identified by 16S rRNA gene profiling and also assessed for their antimicrobial activities by implementing Seeded Agar Diffusion assay.

Results

- 65 bacterial isolates were cultivated and purified with majority identified as *Arthrobacter* (Figure 4).
- SeqICC1 and SeqICC4 exhibited antimicrobial activities against MDR strains of *E. coli* (15-318, 15-124, 15-102), *Pseudomonas* and non-resistant strain of *Staphyloccocus aureus* and *E. coli*.

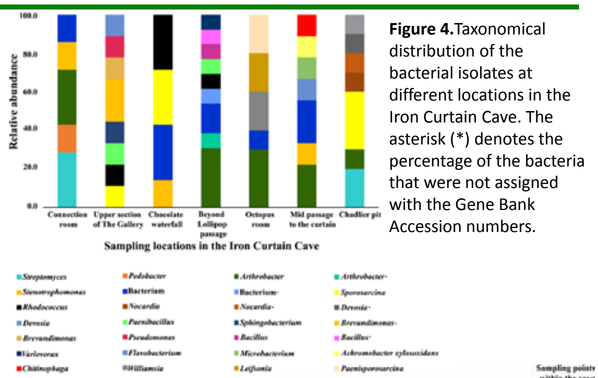

Figure 4. Taxonomical distribution of the bacterial isolates at different locations in the Iron Curtain Cave. The asterisk (*) denotes the percentage of the bacteria that were not assigned with the Gene Bank Accession numbers.

Percentage of isolates present in the cave

Arthrobacter	21.53%
Bacterium	12.30%
Stenotrophomonas, *Sporosarcina*	9.23%
Streptomyces	6.15%
Brevundimonas	4.61%
Rhodococcus, *Nocardia*, *Devosia*, *Paenisporosarcina*, *Flavobacterium*, *Paenibacillus*, *Bacillus*, *Williamsia*, *Leifsonia*	3.07%
Variovorax, *Chitinophaga*, *Pseudomonas*, *Sphingobacterium*, *Pedobacter*, *Microbacterium*, *Achromobacter xylosoxidans*	1.53%

- Molecular identification of SeqICC1 and SeqICC4 revealed as *Streptomyces* species (Figure 5).
- Scanning electron micrographs of both SeqICC1 and SeqICC4 exhibited *Actinobacteria* like structures (Figure 6A and B).

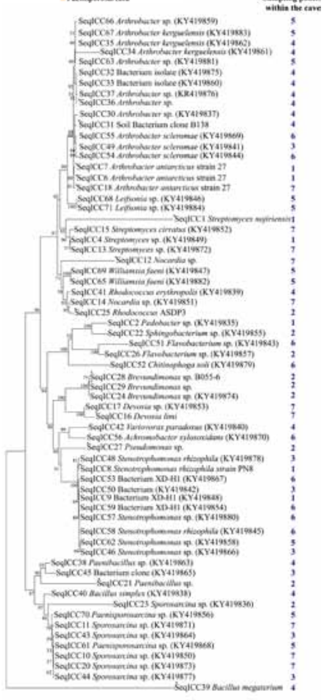

Figure 5. Phylogenetic dendogram of culturable bacterial 16S rRNA gene sequences. Numbers in parenthesis denotes the Gene Bank Accession numbers

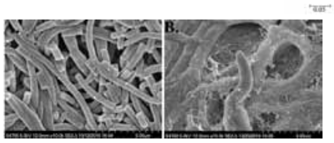

Figure 6. Scanning electron images of SeqICC1 and SeqICC4.

Conclusion

Future studies should embark on the metagenomic exploration to unravel the microbial interactions, population dynamics and also bioprospect other potential molecules such as enzymes, antibiotics of industrial relevance.

Acknowledgement

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Bacteria isolated from Bush Lake and Timber Lake, British Columbia, Canada exhibit antagonistic activities against *Pseudogymnoascus destructans* the causative agent of white-nose syndrome

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Introduction

- *Pseudogymnoascus destructans* (*Pd*), the fungus responsible for white-nose syndrome (WNS) in bats, has devastated North American bat populations over the last decade.
- There have been a limited number of studies reporting anti-*Pd* activities of bacterial and fungal strains (Ex. *Rhodococcus rhodochrous* strain DAP96253) till date.
- The present study, encompassed collection of mushrooms from the phylloplane, tree bark and several infected plant woods and leaves from Bush Lake and Timber Lake, BC, Canada (Figure 1A & B) and further isolate the fungal and bacterial communities through cultivation based approach.
- These cultivated microbes were screened against *Pd* and anti-*Pd* activities were recognized.
- To the best of our knowledge this is the first study of its kind conducted in these areas of Canada.

Figure1 (A and B) Google map images of Bush and timber lakes. The arrows indicating the sampling points.

Materials and Methods

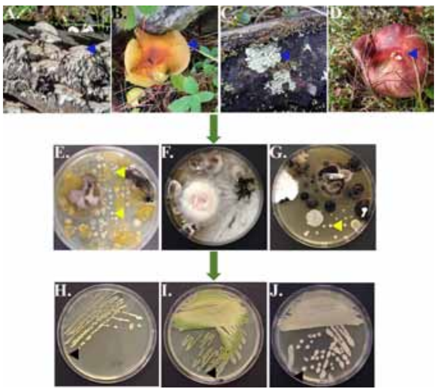

Figure 2. (A-D) Mushrooms growing on the bark, phylloplane. (E-G) Samples laid down on SDA plates. (H-J) Bacterial and fungal pure isolates .

- Mushroom samples from the indicated areas were collected (Figure 2A-D) and placed on the Sabouraud Dextrose Agar Plates (SDA) (65g/L) and incubated at 25°C (Figure 2 E-G).
- Morphologically distinct colonies were isolated for pure cultures (Figure 2H-J).
- These isolates were then tested for their inhibitory activity against *Pd in vitro*.
- Seeded agar technique was implemented where SDA medium was inoculated with a spore suspension (concentration 1.2x 10^6 spores/mL) of *Pd* strain M3906-2.
- The microbial isolates were then streaked on the seeded *Pd* agar plates, which were incubated for a period of 10 days at 15°C and observed for the anti-*Pd* activities .

Results

- 213 microorganisms (fungus and bacteria) were isolated and purified.
- 93 bacteria were screened against *Pd*.
- 30 bacterial isolates exhibited anti-*Pd* activities. (Figure 3A-D).

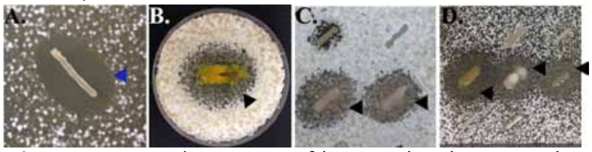

Figure 3. Anti-*Pd* activities of bacterial isolates. A. Blue arrow heads indicates complete zone of inhibitions while the black arrow heads (B-D) indicates the partial zone of inhibition.

- 16S amplicons (Figure 4) of the 30 bacterial positive candidates will be subjected to nucleotide sequencing.

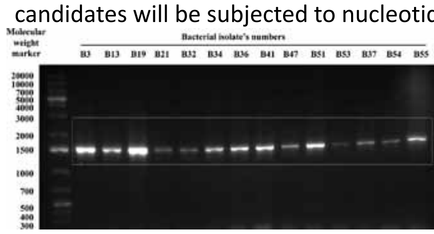

Figure 4. The rectangular box indicates the 16S amplicons of the positive candidates.

Conclusion

These positive anti-*Pd* bacterial isolates upon identification will be further examined for their whole genome sequence and annotations. Furthermore, the putative gene/s/gene clusters present on their genome will be identified and evaluated for anti-*Pd* activities.

Acknowledgement

We are thankful to USFWS (F16AP00028) for funding and Dr. J.P. Xu from McMaster University, Canada for donating the *Pd* strain. We are grateful to Jennifer Petersen, Jennifer Barden and Christine Petersen for helping us in collecting the samples.

History of Speleology and Karst Research

Honouring Personages: named caverns in Jubilee right-hand branch

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Abstract

In Jubilee Cave there are three enamelled tin signs bearing names of people who visited there in 1900. These are the only remaining examples from a number of signs that were placed within the caves. Members of the Jenolan Caves Historical and Preservation Society searched newspaper articles to identify these visitors and determine the reason for naming some of the most beautiful areas of Jubilee Cave after them. While researching these articles it was discovered that distinguished visitors liked to bestow names on features. It is important for historical purposes to record the origin of cave nomenclature and the reasons for and reactions to these names. Cave tours include these old references although little was known about obscure names such as Edies Bower and Ethels Grotto. While these visitors names are of little importance today, the research has provided a snap shot of cave politics from another century.

Keywords: Jenolan, Jubilee, Nomenclature,

1. Introduction

In 2015 members of the Jenolan Caves Historical & Preservation Society had the opportunity to take photographs in Jubilee Cave with the old protective wire netting removed. It was possible to view cave formations in the same way as early visitors first saw them. The cave was discovered in 1893 and visitor inspections were allowed by special permit. It was opened to the public by September 1898 and named in honour of the Diamond Jubilee of Queen Victoria. Bestowing royal names commenced earlier when during the 1895 visit of Prince Joseph of Battenberg a section of cave was called the Princes Chambers. Naming areas and formations after distinguished visitors had been accepted practice at Jenolan since their discovery.

Signs were placed within the caves displaying names of chambers and discovery dates. In 1882 there was a board in Katies Bower recording the names of twenty two ladies and gentlemen who had been the first to visit there. None of these early signs survive. An old photograph shows a decorative example.

Figure 1. Margareta Cave sign

Figure 2. Cooks Cavern sign named after Joseph Cook the local Member for Hartley and future Prime Minister

Figure 3. Edies Bower after the wife of the Minister for Mines John Fegan

2. Origin of tin signs in Jubilee Cave

Newspaper articles were a source of information about the naming of cave features. One particular visit to Jubilee Cave in 1900 by members of the NSW Parliament received much publicity. This provided a valuable record of the names that were apportioned to a number of chambers during this ministerial visit. All names were attributed to the members of the official party Contemporary newspaper articles expressed contempt for the practice describing the desecration of the caves as not being confined to the uneducated but receiving official sanction. One writer commented it would be prudent to keep politics out of the caves while another noted that the average Australian displayed a lack of originality when bestowing names on inanimate objects. Names were displayed on enamelled tin signs of which three are extant.

Figure 4. Sydney Smith Cave sign

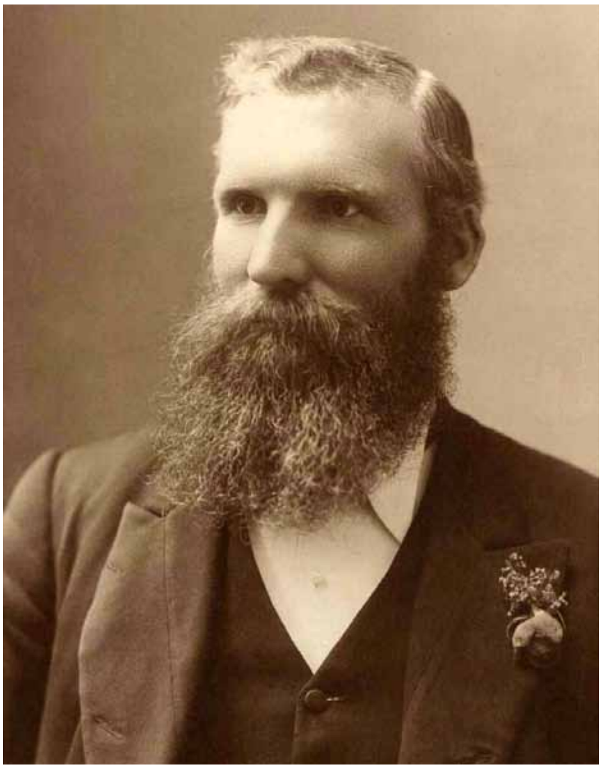

Figure 5. Sydney Smith the Secretary for Mines

Figure 6. Ethels Grotto after the daughter of the Under Secretary for Mines Duncan McLachlan

Figure 7. Matildas Retreat after the wife of Duncan McLachlan

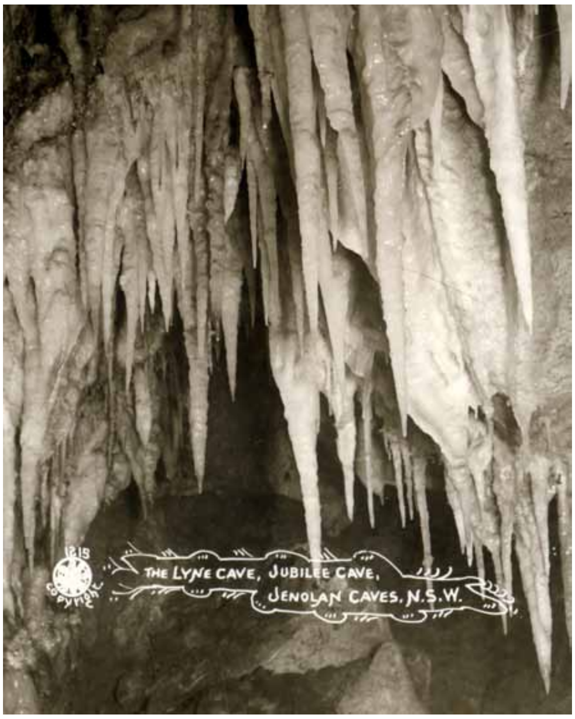

Figure 8. Lyne Cave

The signs for Ethels Grotto and Matildas Retreat no longer exist but the names are still in use on tours.

3. Politicians influence on cave names

Naming cave features after political personages is particularly evident at Jenolan. Two of the show caves had their original names changed to honour Member of Parliament John Lucas and Australian Prime Minister J B Chifley. Both men had special interest in Jenolan but some of the obscure figures named in Jubilee had little connection to the area. A newspaper article commented how ludicrous it was to name natural beauties after political nonentities and their female relatives and

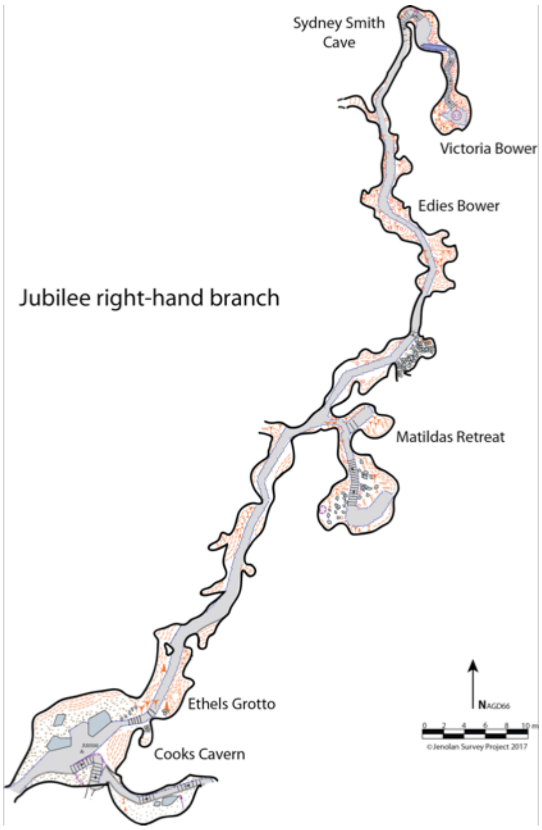

Figure 9. *Map of Jubilee Cave*

asked who was responsible for the nomenclature. An early photographer recorded cave decoration in a Jubilee cavern named for the Premier of New South Wales William Lyne. At the time a suggestion was made that the name should be a reversible one and that each Premier in turn should be thus honoured.

4. Conclusion

Victoria Bower is easily recognised as being in honour of the Queen. The ladies enshrined in Edies Bower, Matildas Retreat and Ethels Grotto now have identities. These visitors were referred to as tin pot personages on tin advertisements but the remaining signs present a snap shot of caving history. Fifteen years after the ministerial visit to Jubilee the sons of both Sydney Smith and John Fegan were killed on Gallipoli. Researching the history of the tin signs has revealed something about their namesakes and has given them a new significance. The practice was looked on as nepotism but it has provided a link to early visitors and their shared history. The signs are showing deterioration after one hundred years being on display in a cave environment but visitors still ask who were the tin pot personages.

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Jimmy Y.M.Lim for photographs in Jubilee Cave

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Jenolan Caves Historical & Preservation Society

Photographs

Figures 1,5,8,Jenolan Caves Historical & Preservation Society

Figures 2,3,4,6,7, Jimmy Y.M.Lim

Figure 9. Jenolan Caves Survey Project

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Cave Exploration During The Little Ice Age

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Abstract

The expression "little ice age" was coined by geologist Francois Matthes in 1939 with reference to glacial moraines in the Sierra Nevada Mountains of California, USA. He was referring not to the Pleistocene ice age but rather a more recent readvance of the glaciers. Later, the phrase was capitalized and became applied to the Alps in Europe and to events in non-mountainous, unglaciated areas, becoming more of a climatic than a glacial term. The British climatologist H.H. Lamb assigned a specific date range to the Little Ice Age, "about 1550 to 1800." A recent popular account brackets it more broadly by the years from 1300 to 1850. The centuries-long cold snap is usually attributed to solar variability or cooling due to volcanic eruptions. The Little Ice Age ended about 1850, when the present worldwide retreat of glaciers began, and this is often attributed, at least in part, to anthropogenic factors. There have been several book-length treatments of the Little Ice Age but perhaps the most popular is Brian Fagan's *The Little Ice Age: How Climate Made History 1300-1850,* published in 2000. Fagan quotes two examples of caves demonstrating climatic change. Poissonet's 1586 exploration of the Froidiere de Chaux in the Jura Mountains of France, the earliest account of an ice cave, reported much ice where none exists today. The Arveyron Cave at the source of the Arve River where it discharges from the Le Bois glacier, Chamonix, France, no longer exists, having melted away as the glacier retreated, but it was a tourist spectacle during the Little Ice Age, appearing in several paintings. These obscure narratives of cave exploration during the Little Ice Age have been resurrected and given new meaning in the context of the climate change discussion of our own times.

Keywords: cave exploration, Little Ice Age, ice caves, glaciers, climate change

The somewhat journalistic expression "little ice age" was originally coined by geologist Francois Matthes with reference to glacial moraines in the Sierra Nevada Mountains of California, USA (Matthes 1939; Porter and Denton 1967). He was referring not to the Pleistocene ice age but rather a more recent readvance of the glaciers. Later, the phrase was capitalized and became applied to the Alps in Europe and to events in non-mountainous, unglaciated areas, becoming more of a climatic than a glacial term (Ogilvie and Jonsson 2001; Matthews and Briffa 2005). The British climatologist H.H. Lamb assigned a specific date range to the Little Ice Age, "about 1550 to 1800" (Lamb 1977). A recent popular account brackets it more broadly by the years from 1300 to 1850 (Fagan 2000). The centuries-long cold snap is usually attributed to solar variability or cooling due to volcanic eruptions (Crowley et al. 2008). The Little Ice Age ended about 1850, when the present worldwide retreat of glaciers began, and this is often attributed, at least in part, to anthropogenic factors (Free and Robock 1999; Painter et al. 2013).

Once the Little Ice Age (LIA) concept had crystallized, cultural historians drew connections with everything from the medieval witch craze (Behringer 1999) to the excess cloudiness depicted by painters, especially the winter scenery of Pieter Brueghel the Elder (Neuberger 1970; Robinson 2005). The LIA coldness brought everything from mirth, like the frost fairs (winter carnivals) on the frozen Thames River in London (Snider 2008) to the extinction of the Norse colonies in Greenland (Grove 1988). The LIA has become a prolific source for teacher's lesson plans, involving as it does such multifarious historical events (Glenn 1996). All of these cultural proxy records are invoked to help estimate temperature before the thermometer itself had been invented. So does cave exploration during the Little Ice Age offer any insights?

There have been several excellent book-length treatments of the Little Ice Age (e.g., Grove 1988). But perhaps the most popular account is Brian Fagan's *The Little Ice Age: How Climate Made History 1300-1850* (Fagan 2000). Much of this ground was already covered by Emmanuel Le Roy Ladurie's earlier book, *Times of Feast, Times of Famine* (1971). Here is the chief cave-related extract from Fagan (2000: 88-89):

> *On June 24, 1584, another traveler, Benigne Poissonet, was drinking wine chilled with ice in Besançon in the Jura. He was told that the ice came from a natural refrigerator nearby, a cave called the* **Froidiere de Chaux**. *"Burning with desire to see this place filled with ice in the height of the summer," Poissonet was led through the forest along a narrow path to a huge, dark cave opening. He drew his sword and advanced into its depths, "as long and wide as a big room, all paved with ice, and with crystal-clear water…running in a number of small streams, and forming small clear fountains in which I washed and drank greedily." When he looked upward, he saw great ice stalactites hanging from the roof threatening to crush him at any moment. The cave was a busy place. Every night peasants arrived with carts to load with blocks of ice for Besançon's wine cellars. Another summer visitor, a century later, reported a row of mule carts waiting to take ice to neighboring towns. As late as the nineteenth century, Froidiere de Chaux was still being exploited industrially. As many as 192 tons of ice are said to have been removed from it in 1901. But after an extensive flood in 1910, the ice never reformed, as warmer conditions caused the glacier to retreat. No ice stalactites hang from the roof of the cavern today.*

Edwin Swift Balch's book *Glacieres or Freezing Caverns* (1900) devotes more space to this ice cave, the Froidiere de Chaux, than any of the other ice caves he describes worldwide (Fig. 1). He cites Poissonet's letter, published in 1586, as "the earliest notice of a glaciere which I have been able to find." But I did not detect in Balch's narratives any suggestion that ice caves generally were losing their ice with time due to climate change, which Fagan (2000), a century later, was able to argue.

Figure 1. Froidiere de Chaux, note figure sitting amidst the ice stalagmites for scale. From Balch (1900).

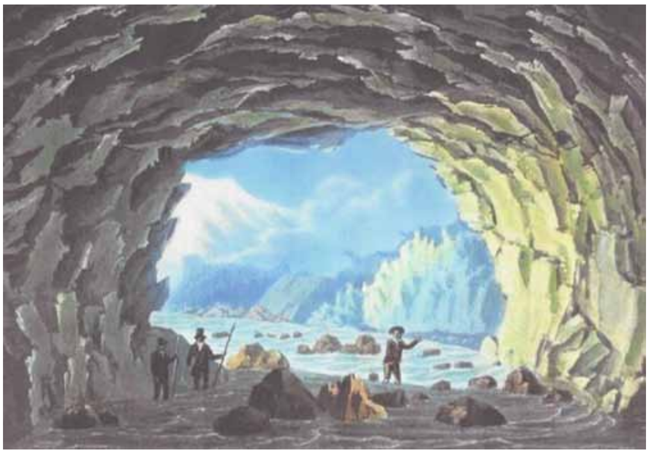

Figure 2. The Arveyron Cave at the source of the Arve River where it discharges from the Le Bois glacier, Chamonix, France, in an aquatint attributed to Samuel Grundmann (1826). This cave no longer exists, having melted away as the glacier retreated, but it was a tourist spectacle during the Little Ice Age.

Fagan (2000: 127) describes another cave in his book, but it is clear that this one is a subglacial cavity rather than a cave in rock (Fig. 2):

> *French traveler Pierre Martel climbed up to the source of the Arveyron stream at the foot of the Le Bois glacier [in 1742]. "It issues from beneath the ice through two icy caves, like the crystal grottoes where fairies are supposed to live.... The irregularities of the roof, over eighty feet high, make a marvelous sight.... You can walk underneath, but there is danger from the fragments of ice which sometimes fall off. The* **Arveyron cave** *became a popular tourist attraction, a cavern "carved by the hand of nature out of an enormous rock of ice." The changing sunlight made the ice change from white and opaque to transparent and "green as aquamarine." The retreat of the Le Bois glacier over the next century and a half caused the cave to vanish in about 1880.*

The Le Bois glacier is described as "the tongue of the Mer de Glace," a glacier in the Mont Blanc massif (Grove 1966). Those who have read Mary Shelley's *Frankenstein* may recall the scene where Frankenstein meets the monster on the Mer de Glace. This book is often said to have been a by-product of the Little Ice Age, in as much as the cold, gloomy weather of that time influenced the author (Nardin 1999; Fagan 2000; Le Roy Ladurie 1971). Among the movie versions of the story, the 1994 remake, *Mary Shelley's Frankenstein*, in which Robert De Niro plays the monster, shows the meeting taking place in a subglacial cavity.

Figure 3. Oil painting of Swiss engineer Ignace Venetz about 1815, showing the Gietroz glacier cave over his shoulder. He presided over one of the great dramas of the Little Ice Age.

An oil painting of Swiss engineer Ignace Venetz about 1815 shows the Gietroz glacier cave over his shoulder (Fig. 3). Venetz presided over one of the great dramas of the Little Ice Age, the fatal bursting of an ice-dammed lake in the Alps. If he had not tapped off about one third of the lake's volume beforehand the destruction would have been far worse. This work got him interested in glaciers and he published an early version of the ice age theory in 1821 that pre-dated Louis Agassiz's more widely known account (Asimov 1982; Grove 1988).

Glaciers were still advancing in 1840 when Louis Agassiz published his classic *Etudes sur les glaciers*, introducing the Pleistocene ice age, which ended thousands of years before the LIA readvance of historical times. Indeed, Agassiz measured this glacial advance by driving stakes into the ice. As a cave-related footnote, while studying the advancing Aar glacier near Neuchatel, Switzerland, Agassiz constructed a makeshift camp in a boulder cave atop the glacier, the so-called "Hotel des Neuchatelois" (Gos 1928; Walker and Waddington 1988). (Fig. 4)

Further physical evidence of changes in ice caves since the end of the LIA has been forthcoming, augmenting Fagan's examples. Baron Valvasor (1641-1693) published a famous work on the karst of what is now Slovenia in 1689. Kranjc (2004) mused whether the Slovenian ice caves of Valvasor's day (during the LIA) but now no longer ice caves, are indications of climate change. Subsequently, Luetscher et al. (2005)

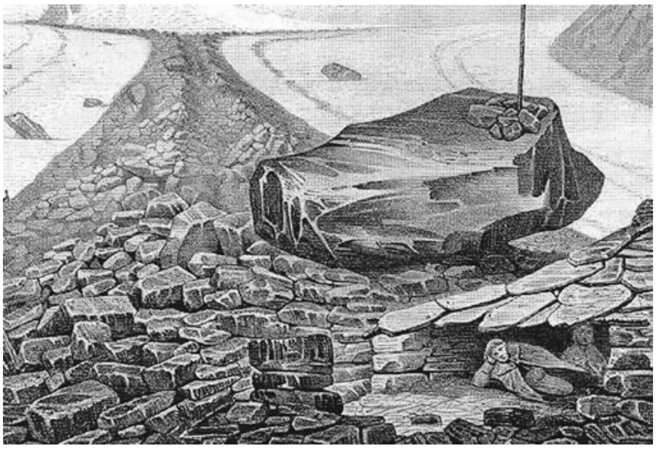

Figure 4. The famous boulder cave "hotel" on a medial moraine of the Aar Glacier.

documented how ice caves are indeed valid paleoclimatic indicators.

Overall, the obscure narratives of cave exploration during the Little Ice Age have been resurrected and given new meaning in the context of the climate change debate of our own times.

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The Prehistory Of Cave Fauna Paradigms

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Abstract

Humankind has observed cave animals since Paleolithic times. But few groups of organisms have been so persistently classified by their degree of association with a particular environment as cave fauna. Scientists such as Schiner (1854) and Racovitzka (1907) are among the founders of biospeleology. The Schiner-Racovitzka ecological classification of cavernicoles into trogloxenes, troglophiles, and troglobites, was early recognized as a possible evolutionary sequence. The chief paradigm of biospeleology had been established and is widely used today. But pioneers before this did not use an ecological classification. The German physician Theodor Tellkampf, for example, studying the fauna of Mammoth Cave, USA, described animals according to their degree of adaptation to caves, as bearing eyes, rudiments of eyes, or being eyeless (Tellkampf 1845). This is essentially what Christiansen (1962) revived with the concept of troglomorphy. Sket (2008) has given examples of the shortcomings of both paradigms.

Keywords: Schiner-Racovitzka ecological classification, troglobites, troglomorphy

Humankind has observed cave animals since Paleolithic times (Vandel, 1965). But an illusory fauna populated the mind of man until recent centuries. The cyclops of Antiquity, the dragons of Alpine caves in the Middle Ages, are good examples. Real cave fauna such as the Proteus, extinct cave bears, and Humboldt's guacharos were known by the late 18th century but it was not until the discovery of the first cave beetle (*Leptodirus hochenwartii*) in Postojna Jama in 1832 that caves were seriously considered as a habitat for animals (Polak 2005).

Few groups of organisms have been so persistently classified by their degree of association with a particular environment as cave fauna. The Danish zoologist Schiodte (1849) recognized shade animals, twilight animals, cave animals, and stalactite animals, distinctions that were observed by Charles Darwin and late 19th century American biospeleologists such as Packard and Putnam (1872). The Schiner (1854) and Racovitzka (1907) ecological classification of cavernicoles into trogloxenes, troglophiles, and troglobites, was early recognized as a possible evolutionary sequence. The chief paradigm of biospeleology had been established and is widely used today.

But pioneers before this did not use an ecological classification. The German physician Theodor Tellkampf, for example, studying the fauna of Mammoth Cave, USA, described the blind fishes according to their degree of adaptation to caves, as bearing eyes, rudiments of eyes, or being eyeless (Tellkampf 1845).

This is essentially what Christiansen (1962) revived with the concept of troglomorphy. Instead of their degree of association with caves, he emphasized troglomorphic characters. He divided troglobionts into epigeomorphes, ambimorphes, and troglomorphes.

Sket (2008) has critiqued both paradigms. Citing the species-rich amphipod genus *Niphargus*, he gave examples of where avowedly epigean species have apparently troglomorphic characters such as lack of pigmentation and longer legs, and vice versa. He proposed instead to recognize "the duality of the category troglophiles" by proposing a four-fold ecological classification: troglobiont, eutroglophile, subtroglophile, and trogloxene. Eutroglophiles are epigean species able to establish permanent subterranean populations, while subtroglophiles are epigeans in search of temporary shelter, yet dependent upon the richer food resources outside of caves. Trogloxenes are accidentals. He discouraged the stygo- and phreato- designations for distinguishing aquatic from terrestrial troglobionts.

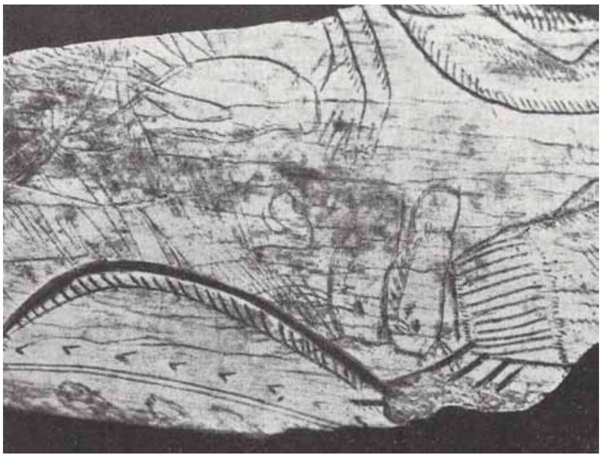

Figure 1. Paleolithic carving of cave cricket on bison bone. From Vandel (1965).

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Cyprus caving history

Bernard Chirol

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Abstract

Since the late Prehistoric period Cyprus has been inhabited by mankind. At that time, dwarf fauna was living on the island and Mediterranean caves were often filled with animal bones of which Homer wrote about in the Odyssey. During the Renaissance a few books were written about the caves. Since the 19th century and during the second half of the 20th century the island has been explored mostly by the English.

In 2003 in the northern part of the island, Turkish cavers from Ankara led a survey of 42 caves on or close to the Kyrenian Range. The Republic of Cyprus is currently concerned with the European project for Bat protection in caves near Akamas and the Cape Pyla regions. A French team recently conducted investigations on the whole of the island to determine the real karstic potential and an NGO was created in the north after that expedition in 2014. A European caving project is programmed to start in 2016.

Keywords: Cyprus, Caving, bats

Since the late Prehistoric period Cyprus has been inhabited by mankind (12 000 years ago). At that time, dwarf fauna (hippopotamus, elephants) was still living on the island and during the Pleistocene period Mediterranean caves were filled with animals bones of which Homer wrote about in the Odyssey when for example, based on elephant skull he imagined Cyclop. In 1160, Neophyte le Reclus could represent the patron saint for cavers. His monastery stands 8 km on the north of Paphos, where his underground grave can be visited (Fig. 1). During the Renaissance a few books were written about the caves of Cyprus (Chirol and Savoi, 2015). Leontios Machairas wrote about bones in caves in 1450 and Benedetto Bordone did the same in 1528. In 1698, Cornelius de Bruyn wrote again about bone-breaches in the Pentadactylos, the main limestone range in the North part of Cyprus island (Kyrenian Range; 1024 m ASL) (Fig. 2 & 3).

Excavations were conducted in Sicily, Baleares, Crete, Cyprus, Malta during the second half of the 19th century. Dorothea Bate (1878-1951) was a well-known palaeontologist to explore these islands. She did that as a pioneer, a sportswoman and scientist. Like for other female cavers or scientists, the recognition of their merit was a hard target to reach during the 20th century.

During the second half of the 20th century Cyprus has been explored since the 1950s mostly by the English cavers, very often soldiers. The political situation, with the conflict between the Greek and Turkish communities and terrorism against the English troops and police who occupied the area, resulted in Cyprus being very difficult to explore between 1960 and 2003. In 2003 in the northern part of the island, Turkish cavers from Ankara led a survey on 42 caves in or close to the Kyrenian Range (Nazik et al, 2004).

The Republic of Cyprus is currently concerned with the European project for Bat protection in caves near Akamas and the Cape Pyla regions (Fig.1). A French team recently conducted investigations on the whole of the island to determine the real karst potential and an NGO was created in the north after the first French expedition in 2014, followed by a second one in 2015. (Chirol & Savoi, 2015).

Figure 1. General map of our explored areas in Cyprus :
1 Kyrenian Range (Pentadactylos)
2 Fig Tree Cave (Incirli Cave) in the gypsum area of the Mesaoria
3 Cape Greko areas
4 Cape Pyla (two interesting fossil caves)
5 Akamas National Park
6 Sea caves place near Paphos

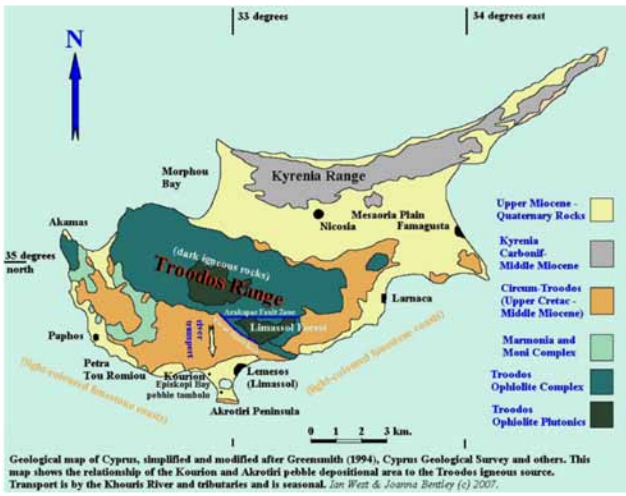

Figure 2. Geological map of Cyprus.

A European caving project is programmed to start as soon as possible while negotiations are being carried for reunification (January 2017). The UIS (Fadi Nader), FSE, European Union and Dr Salih Gücel with Laureen Satterfield (NSS) are the partners of the project with the authorities in the North part of the island since April 2015 (Action V Program for the Civil Society).

Cyprus is a place of endless discovery of many cultures, and its heritage has many magnificent remains. Currently there are very few karstological works dealing with the karst in Cyprus. Apart from Necdet (2003), we have recently found some old geomorphological works of de Vaumas, who studied the island karst between 1963 (with Birot) and 1972 (de Vaumas, 1967 & 1972). His papers were not reported in our published book in 2015.

Speleological review

The deepest pothole: -134 m in the Kyrenian Range (Pentadactylos Pothole).

The longest cave: 310 m in the Mesaoria (North part); Fig Tree Cave also called Incirli Cave and used as ashow-cave.

The number of caves: between 100 and 150 (mostly in the North) are known.

This includes Akamas Pothole (Cyprus Republic). Depth: -58 m Length: around 150 m and containing protected bats and Copper period remains (Fig. 4) revealed by Paragamian's team in 1995 (Hellenic Speleological Society of Crete).

The lack of explorable active systems is due to the structural conditions, to the aquifers, to the climate and to the long anthropic use of deep water.

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Photographs of Aphrodite's child team 2014 (FFS)

Figure 3. Exploring a pothole of the Kyrenian Range.

Figure 4. An ancient pottery in Akamas Pothole.

The oldest cave maps in the world

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Abstract

The first drawing of an artificial cave with orientation information is the plan of the Labyrinth of Gortyne (Crete) drawn in 1415 by Cristoforo Buondelmonti. Until now, it has been regarded that the map of the artificial cave "Stufe di Neron" situated at Pozzuoli near Naples and published by Georg Bauer (Agricola) in 1546 was the most ancient (Shaw, 1992). The Labyrinth drawing is a bird's eye view, with orientation. It was published in 1417 (Buondelmonti, 1417). This "map" was found on the Internet when doing a research about Anna Petrochilou who studied it in 1984-1985.

Le plus ancien dessin d'une cavité artificielle avec indication de l'orientation est la vue cavalière du Labyrinthe de Gortyne en Crète, dessinée en 1415 au cours d'un voyage par le Florentin Cristoforo Buondelmonti. Jusqu'à aujourd'hui, on considérait comme le plus vieux plan celui du « Stufe di Nerone », situé à Pozzuoli, près de Naples. Il a été publié par Georg Bauer (Agricola) en 1546 (T. Shaw, 1992). Le dessin du Labyrinthe a été publié en 1417 (C. Buondelmonti, *Descriptio insulae Cretae*). J'ai trouvé ce « plan » sur internet en effectuant une recherche sur Anna Petrochilou qui étudia le site en 1984-85 (topographie). Michel Fournier a mis en ligne de nombreux e-documents sur les mystères de ce site dont le Suisse Thomas M. Waldmann semble être le meilleur spécialiste. Mes collègues de la Commission Histoire de l'UIS confirment la nouveauté de ce constat. Le plus ancien plan de cavité naturelle reste celui de l'église souterraine de Santa Rosalia en Sicile, daté de 1627.

Keywords:

The first drawing of an artificial cave with orientation information is the plan of the Labyrinth of Gortyne (Crete) drawn in 1415 by Cristoforo Buondelmonti. Till today, we considered that the map of **the artificial cave "Stufe di Neron"** situated at Pozzuoli near Naples and published by Georg Bauer (Agricola) in 1546 was the most ancient (T. Shaw, 1992,). (Fig. 1.) The Labyrinth drawing is a bird's eye view, with orientation (almost a usual one). It was published in 1417 (C. Buondelmonti, 1417) (Fig. 2). I found this "map" on Internet when doing a research about Anna Petrochilou who studied the topography of the Labyrinth in 1984-1985. A number of plans of the Labyrinth have been published since 1415 up until modern times (Table 1). Many books speak about the life and works of Buondelmonti e.g. G. K. L. Sinner (1824), Legrand (1974), a synthetic view from M. A. Van Spitael (1981), and G. Ragone (2002). The National Library in Düsseldorf owns copies of two books by Buondelmonti.

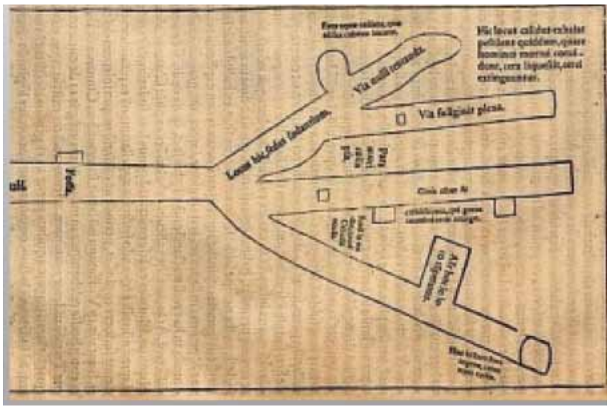

Figure 1. Artificial cave Stufe di Neron, Pozzuoli (Naples). Georg Bauer (Agricola) 1546. This map appears in the De ortu et causis subterraneorum libri V p 146 by Geogius Agricola (1494-1555) and published by Froben, Basel 1546.

The oldest map (plan and profile) of **a natural cave** is that of Santa Rosalia Cave (and Church) in Sicily). It is dated from 1627 (Fig. 3). The drawings were published in 1627 by Giordano Cascini (Mancini & Forti 2009)

There are others that are very interesting but it is possible to that older maps of articificial caves and/or older maps of natural caves.

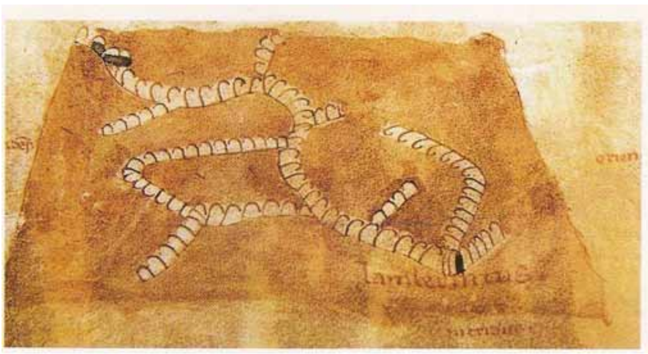

Figure 2. Map of the Labyrinth C. Buondelmonti, 1417

Among the old plans, one of Chiaciaina Moncodeno near Trente (Italy), was published by the father of Geology, Nils Stensen in 1671. It shows the profile of a pothole with ice speleothems (after Vlado Bozic).

One plan of Baumannshöhle, a German cave in Harz is dated from 1656, very close to the age of the Santa Rosalia maps (after Kempe and Knolle). Beautiful maps of the Demanova Ice Cave (Slovakia) by Georg Buchholtz appeared in 1719 and for the Glacière de la Grâce Dieu (Doubs, France) by De Cos-

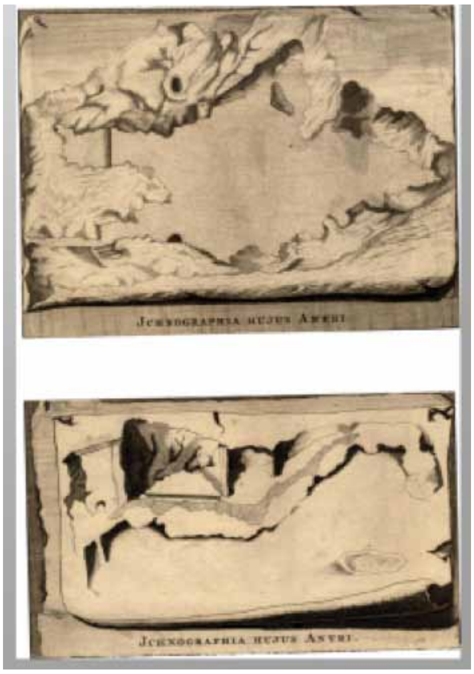

Figure 3. Map and profile Santa Rosalia Cave and church Sicily.

signy in 1743. These drawings are proof of the improvements in the study of geometry indicate that the spread of cave science in Europe: technical schools, technical progress, communication, travels of scientists, and publications becoming widespread.

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The Labyrinth of Crete by Dudley Moore (last updated in 2014)

The Cretan Labyrinth Cave by Thomas Waldmann (last updated in 2014)

Wikipedia gives a lot of information.

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Table 1. Plans and dates of the Labyrinth

Date	Author & comments
1415	Buondelmonti
1699	Tournefort, well known for his interpretation of speleothems.
1783	Dumas (published in 1839)
1788	C. Ernest Savary
1811	Cockerell (published in 1820)
1817	Sieber (published in 1823)
1821	Bertuch (copy of the1811map)
1825	Prokesch Von Osten (published in 1836)
1842	simple map by Sigalas
1845	Félix Victor Raulin
1854	E. Charton (Magasin Pittoresque)
1857	Ame (copy of the one of 1811)
1865	Spratt (copy of the one of 1817)
1982	Romanasetco
1882	Kern (copy of the 1811 map)
1985	Anna Petrocheilou and collegues.
1998-2010	Thomas M. Waldmann

(Abstract) **Women Underground — A world history of female contribution in speleology**

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Abstract

It seems that very few women in the world have chosen to become cavers. This work tries to show that women, since the prehistoric period, were in fact early and courageous cavers, and also have lead in scientific areas. Sociological obstacles are described.

A large survey on many countries shows that by overcoming sexism during the pioneering times, women cavers deserve a good place in our common history, even if their percentage remains very low in many countries. Now the differences are being swept away in many cases. The survey will continue over the next few years.

The Lost Pot of the Sinkhole of the River Rhône

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If you travelled in the past between Lyon and Geneva, it was possible to see a geomorphological phenomenon: the sinkhole of the Rhône near Bellegarde-sur-Valserine (Ain-France). Fig. 1.

This is where in winter at low flow, the Rhône River disappeared into a pothole (canyon) at a very famous tourist site. In summer, high water totally covered the hole (363 m^3/s) (Figs. 2 & 3).

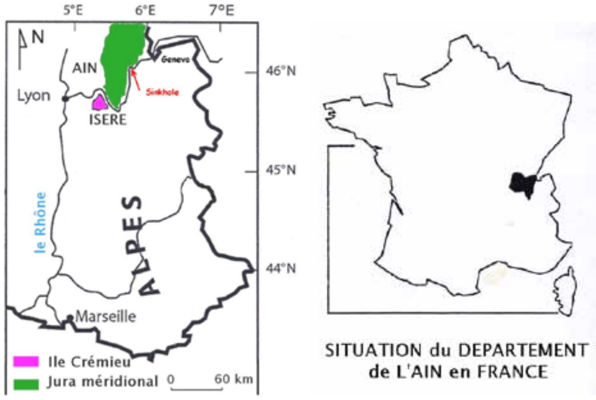

Figure 1. Situation of the site in the South-East of France

An old known place

This area was mentionned by Julius Caesar in "La guerre des Gaules", and Aristotle perhaps write about the sinkhole when he compared the Rhône with the River Pô in Italy However there are no references to it during the Middle-Ages nor the Renaissance, and not until the beginning of the 17th century are the first texts about this site found. Abraham Golnitz published his travel guide in Netherlands in 1631 (Golnitz, 1631), followed by a French author who mentioned several karst phenomena in this region of France (Guichenon, 1650). Both described the site.

These works, as thick historical volumes or lighter touring guides were very important for the Grand Tour (17th-18th C) and the development of European tourism (Verhoven, 2005). During the 18th century, when mountaineering appeared and mountains no longer remained a place of threats or misery, many travellers stopped their stage-coaches to admire the place where the rumbling waves of the Rhône sank underground. Engravings were drawn, and both the romantics and scientists were fascinated by this spectacular natural curiosity. When photographs of mountains appeared, the romantic conceptions changed around 1865.

Figure 2. The sinkhole of the Rhône in summer

A Geological approach

Jean-Etinne Guettard began to study the geology of the area in 1758 but according to the well informed General Bourdon (1894) he didn't see the sinkhole ! A good survey with beautiful geological colored maps were made by Eugène Renevier (1853). Many geologists studied the place because of the interest for mollassic phosphates and for the stratotypes from the Cretaceous period (Urgonian). The loss of the Rhône can be dated from the late Quaternary but It would be interesting investigate the origin and evolution of the Rhône since the Tertiary period.

Figure 3. The sinkhole of the Rhône in winter

An controversed identity for the sinkhole

Many authors including Martel, wrote that this phenomenon was a pseudo-sinkhole or an ancient one (Chirol, 1985). However, the two natural bridges that were there before 1709, were lost when developments to improve access started in 1709 and blasting occurred. At least 12 attempts of destruction were conducted on the canyon walls near the pothole between 1709 and 1948.

The exploration of the pothole

During a winter low level of the Rhône two ingeneers of the Royal Institution of the "Ponts et Chaussées" explored the caverns of the sinkhole. Thomas Riboud, a French Deputy reported that before the French Revolution they had entered the hole before he did. These engineers were Nicolas Céard and Léonard Racle, working in the future Ain county, close to Geneva. They suggested perched roads, channels, tunnels and dam in order to make an easyer passage in the gorge. Thomas Riboud wrote 52 pages to describe the outside and inside of the geomorphosite (Riboud, 1812).

Jean-Marie Gay goes down the pothole

The next known visit at the sinkhole was conducted in 1883. During the night of the 2 – 3 January 1883, a few kilometers upstream, a big landslide of between 250 000 and 400 000 m^3 of Quaternary deposits from the slope of the Jura Mountain occurred, due to very wet and frosty conditions. There is also a large fault and a spring (Bouna Spring). A tunnel and a 200 m long railway were destroyed. Two trains were stopped Fort l'Ecluse (Fig. 4). The course of the Rhône was blocked by the deposits and this natural dam allowed access to the pothole due to dry conditions. A blacksmith, Jean-Marie Gay took a hemp rope, a ladder and stayed an hour and a half underground observing big boulders and tree-trunks, but because of the dangers did not stay longer. The level of the Rhône was rising and the dam finally broke flooding the area again (Fig. 5). There was little damage downstream. The blacksmith became an unknown pioneer of caving. He died 7 years later at the age of 49 when digging a pit in a garden, when because of the bad weather he was burried under 15 m of soil. He survived from for 4 days, fed by a pipe. The newspapers of France spoke more about this accident than they about his previous feat. This exploration recently became known through a local newspaper (Ernst, 2015).

The disappearance of the sinkhole

The beginning of the 20th century was a good period for local tourism here. Many postcards were published showing the sinkhole, but in 1911 a struggle broke out between the Swiss geologist Maurice Lugeon, working for the authorities and the well known Edouard-Alfred Martel "working" for some companies and tourism and nature protection associations (Martel, 1914). The geologist led a project for building a big dam at Génissiat. Martel the speleologist, wanted to preserve the natural site. The fight was cruael, and Lugeon and the Compagnie du Rhône won as France needed much energy in this period of reconstruction. The dam was built and the canyon with its pothole were finally submerged in January 1948 (Fig. 6).

The hidden geomorphosite documented as Rhône-Alpes heritage site in the National Geological Inventory rests underwater (Cayla & al., 2012).

Special tribute to Marius Pinard (1903-1944)

I want to make a tribute to the memory of Marius Pinard. Teacher, anti-nazi and anti-Pétain, he was murdered by the militia at the end of the Second World War and thrown down

Figure 4. The landslide in 1883.

Figure 5. J.-M. Gay: the descent

Figure 6. Génissiat dam between Ain and Haute-Savoie counties (France).

the pothole of the Rhône on the 9th of April. His body was found on the 10th of May in the canyon.

(Saint-Pierre, 2013).

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Hermann Bock, A Forgotten Precursor Of Cave Meteorology

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Abstract

More than one century ago Hermann Bock published the first paper on cave meteorology with a mathematical treatment. It was written in German and unfortunately this paper was ignored. New scientific quantitative studies and research started a half-century later. He was an Austrian scientist born in Brünn on February 9, 1882 and died in Graz on January 2, 1968. During his life he published about 50 papers on different branches of speleology but, probably, the most interesting of his papers was a chapter entitled "Mathematical-Physical Investigation on Ice Caves and Wind Caves", included in a book on caves in Dachstein, Austria. This important contribution is described with a link to download the full original text.

Keywords: Hermann Bock, cave meteorology, physics-mathematics.

1. Introduction

Cave science has a very long history, perhaps sometime a little fantastic, and it has been detailed described by Trevor Shaw (1992). But this argument has been dealt with a qualitative approach until recently. Leonardo da Vinci (1540) in his "Treatise of painting" stated that: "There is no certainty in sciences where one of the mathematical sciences cannot be applied".

From this point of view only at the beginning of the last century, Hermann Bock provided this "certainty" thanks to a chapter in a book on caves of Dachstein, Austria (Bock, 1913). He was an Austrian scientist born in Brünn on February 9, 1882 and died in Graz on January 2, 1968. In his life he published about 50 papers on different branches of speleology but, probably, the most interesting of his papers was the chapter quoted above.

The circulation of air in caves was described also some centuries before, as for example, by Kirchner (1678), but from a qualitative point of view only. Bock was the first one to switch to a quantitative evaluation of the phenomenon. Nevertheless such a scientific approach was disregarded for nearly half a century, even if many books dealt with cave meteorology (such as Crestani & Anelli, 1939; Trombe, 1952; Myers 1953; Moore and Nicholas, 1964; Cigna 1961, 1962, 1967; Cigna & Forti 1986).

Often, a simple description of the air movements in different season and cave type was reported. Sometimes a quantitative evaluation of some quantities (mass, pressure, temperature, humidity) was also added. But only decades later, models of air circulation were firstly proposed (e.g. Cigna, 1961). Successively cave physics was developed with more details by taking into account different situations and factors (Badino, 1995; Lismonde, 2002).

2. Hermann Bock 's paper.

As reported above, this paper was somewhat ignored notwithstanding its new approach to the study of cave meteorology. Probably it was due to its inclusion as a chapter in a book dealing with caves of a single area (Simonys, 1913). At the time of the publication, German authors were much appreciated; nevertheless their language was not widely read outside of a relatively restricted elite. For this reason it seems convenient to report here at least the main issues of his paper. The following main cases are considered:

- Airflow in caves with a single entrance
- Airflow in caves with many entrances
- Influence of the airflow on the temperature of caves with a single entrance
- Temperature distribution in wind tubes
- Influence of evaporation on cave temperature

For each of them particular conditions are considered and some examples are also reported, as well as the case of ice caves. It would be too long reporting such specific conditions taken into account by H. Bock, and here the details of simple cases of airflow in caves are given as examples.

2.1. Airflow in caves with many entrances

Caves with more than one entrance are much more interesting from the point of view of the air currents. In fig 1 a scheme is reported, where *S* is the density, *H* the height, *L* the length of the cave, *U* is the perimeter of the middle cross section, *F* is the cross section, *T* is the air temperature, *P* is the pressure, T_m is mass air temperature, *P* is the pressure, *m* is mass of the average cross-sectional area, *v* the air speed and ρ is a factor depending on the roughness of the walls and the shape of the cave. The final equation is:

$$v = \mu \sqrt{\frac{2gH\left(T_1 - T_2\right)}{273 + T_1}}$$

where

$$\mu = \frac{1}{\sqrt{1 + \frac{2g\rho UL}{F}}}$$

2.2. Airflow in caves with a single entrance

In the paragraph on the influence of the airflow on the temperature of caves it is considered and the example of Beilstein Ice cave (Fig.2) is used for a detailed description referring

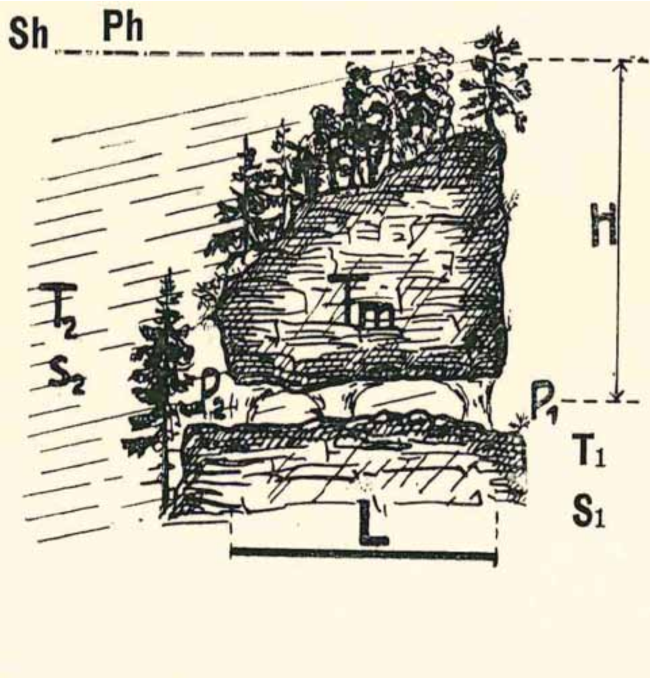


Figure 1. Example of a cave with two entrances

Figure 2. Beilstein ice cave, Steiremark, Austria

to different local possibilities.In Fig. 3 another example, the Kolowrat Cave, for horizontal caves is reported, while the example of the Katerloch cave (Fig. 4) is considered for the case vertical caves. Typical patterns are taken into account and treated in details.

In a single entrance cave, by substituting T_1-T_2 with y_1-y_3 and 273+T_1 with 273+T where T is the average temperature of the moving air flow above or below the ice, the following equation is obtained:

$$v = \mu \sqrt{2gH \frac{y_1 - y_3}{273 + T - y_2}}$$

where y_n are the average temperatures at S_n .

Frequently caves have more than a single entrance and therefore the distribution of temperature in the cave environment is not simple but, on the other hand, is very interesting. The case of canyons with many cave entrances is considered with

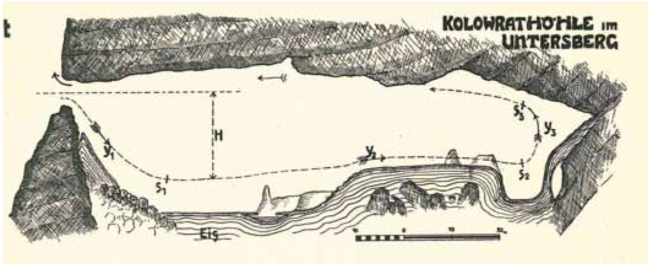


Figure 3. Kolowrat Cave Untersberg near Salzburg, Austria

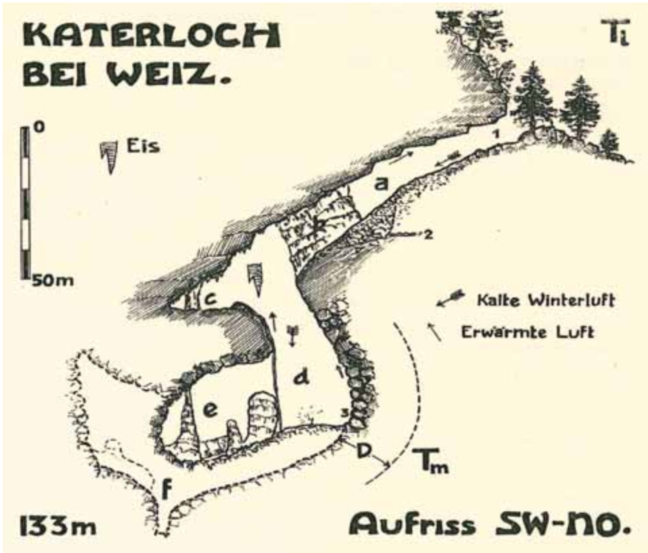
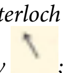


Figure 4. Katerloch cave (Austria); Legenda: winter airflow  *summer airflow*  *; 1-entrance; 2-source; 3-thermometer 50 m above the large hall; a-30m above the great hall; b-columns 10-20m high; c-top of the shaft; d-Hall Martel; e-standing and collapsed columns; f-top of the deep shaft.*

the example of the canyon of Baudiñard is reported as well another example, the Petrefaktenhöhle, as a wind tube.

The mathematical treatment of the different aspects of these caves is too long and complicated to be reported here. The relationships between temperature, airflow and cave geometrical features is taken into account resulting in different equations.

3. Conclusions

This paper by H. Bock is really a unique study much in advance for his time, because no one had the idea of a quantitative approach to cave meteorology. Qualitative aspects only were discussed by developing, in particular, a description of the airflow in winter and summer without any evaluation of its intensity. After some decades only, quantitative studies were developed.

Herman Bock was a real pioneer of this special branch of cave science and deserves a full merit for his skill. The original paper can be freely downloaded from:

(http://uis-speleo.org/index.php?option=com_content&view=article&id=87&Itemid=415)

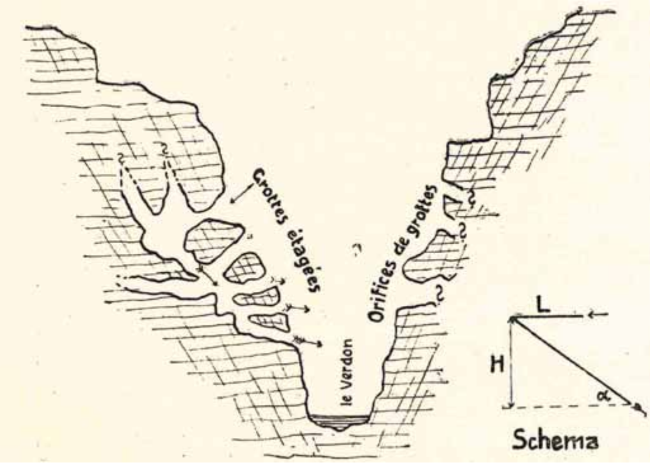


Figure 5. Cross section of the canyon of Baudiñard (France)

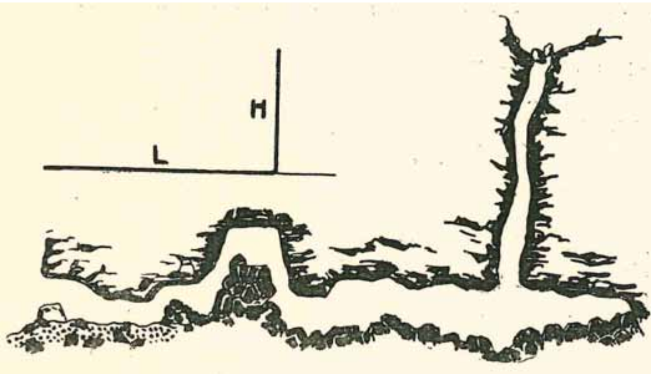


Figure 6. Section of the Petrefaktenhöhle (Austria).

Acknowledgements

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Investigating Mammoth Cave during the American Civil War

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Abstract

Beginning in January 2016, the author initiated a research project to investigate the history of the American Civil War in Mammoth Cave National Park, focusing on the interactions between soldiers in the Union and Confederate armies and the cave environment and karst landscape. This is part of a larger regional study of Kentucky caves and the Civil War begun in 2015. After presenting an overview of the project goals, methods, and strategies, and consulting with National Park Service cave resource specialists, a core research team was assembled to conduct archival and cave graffiti studies, consisting of the author, historian Marion O. Smith, caver Kristen Bobo, and Larry W. Johnson of the National Park Service. Field work began in February 2016 and for the year as a whole included seventeen research days in Mammoth Cave National Park dedicated to identifying historic graffiti from the Civil War era, and recording them in notes and images. We also recorded the presence of other significant cultural materials even if not Civil War related, including evidence for Native American usage, saltpeter and onyx mining, and historic graffiti from other chronological periods, such as Antebellum and Gilded Age. Utilizing an intuitive survey methodology, we took five separate trips into different parts of historic Mammoth Cave which we knew or suspected might have soldier graffiti: Gothic and Gratz Avenues, Pensacola Avenue, Cyclops Gateway, the Labyrinth and the Ramble, Marion Avenue, and the Maelstrom. Fifteen other Park caves were examined in the remaining dozen field trips. Two of these, Long Cave and Salts Cave required two trips each to document in an even cursory manner. Thirteen other researchers, including cavers, Park staff, and Park volunteers assisted the project in the field during 2016.

Keywords:

Discussion

Archival research has uncovered soldier references of visits to a dozen of the better known (or geographically more accessible) caves in the Mississippian Plateau of Western Kentucky. While soldiers sometimes turned to caves as dependable water sources in the karst landscape, like at Dripping Cave near Glasgow Junction (Park City), most soldier visits in Kentucky were recreational in nature, social in context, and motivated by the cultural conception of caves as sublime curiosities. For some military visitors the journey underground may have been one of their last pleasurable adventures; by 1862 the American Civil War was proving to be a horrendously bloody affair. Many of the Union soldiers at Shiloh in April 1862, or Stones River in January 1863, had travelled through the Mammoth Cave region of Kentucky before meeting their fates in these Tennessee battles. There is a poignant aspect to the research; as we find Civil War cave literature or extant graffiti in caves, and as we identify the solders, we always have to ask, did this person survive the war? And if so, was he injured or disabled? Isaac McCann, for example, of Company K, 34th Illinois Regiment, visited Mammoth Cave in February or early March 1862 as the Union Army was moving south, and he wrote about his experiences in a letter to his sister, stating that the cave stimulated one's imagination. He was mortally wounded in the Battle of Shiloh in early April; he died in a St. Louis hospital later that month.

Being the most famous cave in the United States and the subject of a large popular literature, including recent guidebooks by Professor Charles W. Wright in 1858 and 1860, Mammoth Cave was a particular magnet for soldiers. These soldiers could be travelling through the region or posted in garrison or anti-guerilla duty; Kentucky was strategic ground in the war. The main north/south transportation artery, the Louisville and Nashville Railroad, was located less than fifteen kilometers to the east of Mammoth Cave. In early 1862, tens of thousands of Union troops, including Isaac McCann, travelled down the railroad and parallel surface roads south through the Kentucky sinkhole plain, just a few kilometers from the uplands containing Mammoth Cave.

We recorded significant soldier graffiti, both Confederate and Union, in most of the Mammoth Cave passages we checked, with the exception of Marion Avenue, which seemingly was no longer on the standard long tour route during the 1860s. Some of the recently recorded graffiti have now been recognized as relevant and significant. For example, Captain Alexander Ahab Arnold wrote his name and unit, the 30th Wisconsin Volunteer Infantry, in the Labyrinth near the window into Gorin's Dome. Arnold survived the war and went on to distinguished career in Wisconsin politics, including election to the State Senate and as Speaker of the State Assembly. Beyond Mammoth Cave, one Union soldier (at least) visited Long Cave, J. A. Sprowl of the 58th Indiana Regiment, who wrote his name with paint on the cave wall on February 26th, 1862. Later a second lieutenant, Sprowl survived the war and returned to Indiana, where he became active in his Regimental Association and the Union veterans organization, the Grand Army of the Republic. Whether made by high status personages or ordinary soldiers, the Civil War graffiti in area caves collectively provide snapshots of men in a kaleidoscopic society during wartime.

Confederate soldiers primarily visited caves in the area during 1861 and early 1862, with Union soldiers predominating after the spring of 1862, as Confederate occupation of southern Kentucky ended, although guerillas and occasional raiders remained. Early in the war there had been skirmishing in the Mammoth Cave area and troops were deployed along the road to the cave. Somewhat later, in 1863, the cave itself was raided by troops under the command of Confederate General John Hunt Morgan, perhaps targeted because the Cave and Hotel proprietor, E. K. Owsley, was known as a strong Union man. One 1862 graffito in Mammoth Cave is by Thomas Quirk, a Kentucky native who joined the Confederate Army and served as a captain of scouts in Morgan's Squadron. The presence of Union soldier graffiti in the same area, including R. J. Parks of the 3rd Ohio Volunteer Cavalry from March 1862, underscores how caves were contested spaces during the conflict. Quirk also visited Diamond Cave, and left his name incised on the cave wall. A recently discovered and opened-to-the-public cave with outstanding speleothems, Diamond Cave was located directly on the road from Glasgow Junction to Mammoth Cave.

Civilians sometimes displayed their political sympathies on the cave walls as well, such as the anonymous visitor to Mammoth Cave who in June 1861 wrote "Hurrah for Jeff Davis" in Gratz Avenue. The impulse to mark cave walls with one's name was long established in the United States, but during the Civil War it became more than a statement of "I was here." For both Confederate and Union men, it was also a claim on the space itself. Partisan graffiti took on new meaning as participants in rival political systems, with similar cultural conceptions of caves, appropriated the underground spaces, especially the famous Mammoth Cave, for their own purposes.

So we know numerous officers and enlisted men visited Mammoth Cave throughout the war, along with civilians. Some wrote of their experiences in letters or journals, while others marked their names on the walls and ceilings of the cave. These graffiti show, among other things, how individual identities shifted in the war, as civilians became soldiers. In the graffiti, and also in the surviving Civil War era Mammoth Cave Hotel register, regiments now supplanted hometowns as identifiers, and formal rank was often indicated. These developments mark a clear break with most pre-war and post-war graffiti.

Although the content of Civil War Soldier graffiti in Mammoth Cave and neighboring caves is distinctive, there is no difference in how it was made or applied, or where in the underground space it was placed, when compared to other historic graffiti in the caves. In terms of media, the most common methods include incised or scratched marks, writing in pencil, and carbon smoke from candles or oil lamps. Some are on prepared surfaces, which take two forms. In the first, the wall or ceiling surface is deliberately darkened with carbon (and then scratched). In the second, the target area is mechanically smoothed (and then overwritten in pencil). Many marks are on unprepared surfaces, raw walls if you will. The orthography and iconography of soldier graffiti are also typical for the period. In terms of locations, most soldier markings are in galleries with other graffiti, or placed in visible locations along prominent ceilings and walls. Like almost all Euro-American cave graffiti, it was meant to be seen. Soldier graffiti in Kentucky cave are conventional in every technical aspect. Where they differ is in content and meaning.

Graffiti from other contexts during the Civil War era were also recorded in Long Cave, Salts Cave, Proctor Cave, and Jim Cave. Proctor Cave was first explored by Johnathan Smith in 1863; there is extant graffiti by Smith from that year and by Larkin J. Proctor in 1864. Jim Cave contains a graffiti panel made by two local men in March 1865, F. W. Woolsey and E. Boucher, who noted that they were cutting timber for the Louisville and Nashville (L&N) Railroad. This was shortly before the end of the conflict.

An examination of visitor trends in several Park caves, using recorded historic graffiti as a proxy for the number of visitors, supports the thesis that the Civil War saw a significant reduction in visits by inhabitants to many local caves. Thus at caves like Dennison Cave and Salts Cave, which were not on major transportation routes, and were generally known only to local inhabitants, the disruption of the Civil War extended deeply into the region's environmental and social history. Unlike for soldiers experiencing the Mammoth Cave region for the first time, or for that matter any karst topography, recreational and social visiting by neighborhood groups to local caves were a low priority for inhabitants during the war years. Proctor Cave was a significant exception, but it was likely explored with an eye towards post-war commercialization. It was opened to public view as a show cave in 1866. Still, its history shows that cave exploration did not totally cease during the war, despite the turmoil of the era. At Mammoth Cave, too, there were significant attempts to explore new passages, notably the efforts by Englishman F. J. Stevenson over ten days in August 1863. When he descended the Maelstrom Pit to check a possible side passage, among the twenty persons assisting him were a number of officers and soldiers staying at the Mammoth Cave Hotel. Unfortunately, Stevenson's results were meager.

Although the Mammoth Cave management at first tried to ignore the war, by 1862 Mammoth Cave saw a steep decline in the number of ordinary tourists, although this was mitigated by the large number of soldiers who came. The cave stayed open to tours throughout the Civil War. Summers remained the busy season, while visitor numbers dropped precipitously in winter, which replicated pre-war patterns. By the summer of 1864, Kentucky was no longer near the center of fighting and the threat of major raids subsided. The Mammoth Cave region began to slowly regain a sense of normalcy. Economic recovery in the cave industry, and re-establishment of more 'normal' patterns of cave use and social visiting, came only after the April 1865 conclusion to the war.

We have assembled a fair number of written soldier accounts, as well as Civil War references to area caves in regimental and local histories, some of which were previously unknown to Mammoth Cave scholars. The details in these accounts make fascinating reading. For example, Major William G. Dickson of the 1st Ohio Heavy Artillery Regiment wrote in August 1864 of his visit to the Mammoth Cave using vivid descriptions of the unpleasant late night stage coach ride to the hotel and his subsequent tours of the cave with a mixed party of eighteen men and women, with the men consisting mostly of Union officers. Dickson took the short tour the first day and the long tour the following. In a relatively short letter he manages to give his impressions of the cave, describe with admiration the bloomer costume worn by women, and notes that the party of eighteen brought a detail of twenty guards with them, fearing guerillas. It was, he said, "*a little frolic of three days*." There are numerous other examples of telling soldier accounts although not all are so descriptive.

Some soldier narratives are short but still informative. For example, Union soldier John Garrison's January 19, 1863 letter to his wife summarizes his visit to Mammoth Cave in one paragraph, but in it he explains how a cave feature, Elizabeth's Kettle, received its name. Garrison, of the 128th Regiment Illinois Volunteers, named it for his spouse, in a deal he made with proprietor E. K. Owsley, in exchange for a poem Garrison had written about the Mammoth Cave blind fish. At the other extreme, James Fowler Rusling, a former New Jersey lawyer who was rising up through the Union Army officer ranks, was so captivated by his tour of Mammoth Cave that in 1864 he wrote and self-published a book, forty pages in length, about his excursion, *A Trip to the Mammoth Cave, Ky*.

In addition to the soldiers who made it to the Mammoth Cave, other soldiers wrote wistfully of wanting to go to the famous site but not having the opportunity. It seems officers sometimes had a better chance to make it to the big cave, having the time, money, and perhaps a horse, to travel the fourteen kilometers along a poor road, and stay at the Mammoth Cave hotel, while taking one of the two standard tours. Enlisted men often had to settle for a trip to a cave closer to the railroad line, such as Horse, Hundred Dome, Indian, or Diamond Cave. There was also the delicate question of permission from one's superior officers. One local history tells the story of a naïve soldier, Frank Winthrop Draper of Wayland, Massachusetts, who, stopping at the Cave City Provost Marshall office to get directions to Mammoth Cave, was arrested for leaving the ranks without a written pass. By the time his commanding officer sent word that he was not shirking his duty, and he was released from custody, his opportunity to visit the cave was gone. He later wrote that on his return journey to Lexington he "entered the [rail] cars a wiser man than when I left them the day before" and that "[t]he moral of this romance is, that I travelled two hundred and ninety-six miles, saw much of Kentucky, but didn't see Mammoth Cave." Fortunately, other soldiers had better luck with caves in the Mammoth Cave region.

Acknowledgments

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(Abstract) Karst Studies in Australia – Jiří V. Daneš and his Australian travels

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Abstract

In 1916 Czech Professor Jiří Viktor Daneš published *"Karst Studies in Australia"*. A good translation of this valuable 76-page work only recently became available along with more information on his Australian journeys. A paper in Helictite is forthcoming.

Daneš (1880-1928) was an accomplished polymath: a determined, curious and extraordinarily hardy inveterate traveller with a distinguished academic and consular career. With botanist Karel Domin he travelled across northern Australia visiting Chillagoe and Olsens Caves (Rockhampton), contrasting them with the Gunung Sewu and Jamaican cockpit karsts (previously visited). Alone, he later visited the Barkly Karst. Returning from Brisbane to Sydney, he visited Jenolan Caves, discussed other caves with Oliver Trickett, and en route home diverted from Fremantle to visit Yallingup Caves.

In 1921 the 3-year old republic of Czechoslovakia appointed him Consul General to Australia. Arriving in Fremantle he crossed on the Trans-Australia line to Sydney, probably just to see the Nullarbor Plain, as a ship would be quicker. Most of his writings of the next 2½ years are about plebeian matters such as trade opportunities and the joys of travel but we know he travelled to AAAS in Melbourne, visited Buchan Caves, Kosciuszko, Tasmania and Papua. By nature he was an observant geographer of an old-school world, and a great traveller. But karst was a great obsession.

51 years ago J. N. Jennings described Daneš's work at Chillagoe (Helictite 4 (4)) but little has been written since about Daneš's karst interests in Australia. The Australian Dictionary of Biography recognises him in two paragraphs about karst, concluding that his penetrating writings on both physical and human geography have largely been ignored by scholars. His legacy is *"Karst Studies in Australia"*, published in German in 1916 and only recently completely translated. As a physiographer (these days called a geomorphologist) Daneš was our first professional karst scientist, albeit a visitor, and his writings rank with those of Sir Thomas Mitchell and Julian Tennison-Woods.

The Publications Exchange Working Group

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Abstract

Published speleological information has been partly disseminated through journals and books published by various organisations, some of whom have made private bilateral arrangements to exchange publications amongst themselves. Such documents are commonly housed in libraries of various sizes and physical accessibility. Three main issues now confront this beneficial exchange of information: the rising costs of postal delivery; the opportunities presented by electronic publication, electronic delivery, electronic storage and digital searching; and the intention of some Governments for all papers that report publicly-funded research to be freely available under an 'Open Access' policy. The Publications Exchange Working Group (PEWG) has been established to tackle the new challenges and opportunities for the exchange, accessing, organisation, safe storage and archiving of world-wide karst literature. The main aims of the PEWG are to: Promote the exchanges of previous and new paper journals and books; Publicise the extent of this international cooperation; and Examine the issues related to the use of electronic information. The vision is that the Working Group will assist in the networking of over 100 existing speleological libraries internationally that will each hold and catalogue a good selection of published cave and karst literature. This article describes the formation of the PEWG in 2013 and its progress to date.

Keywords:

1. Introduction

The Publications Exchange Working Group (PEWG) of the UIS Informatics Commission has been established to tackle the challenges and opportunities for the exchange, accessing, organisation, safe storage and archiving of world-wide published speleological and karstic information into the future; it is believed that this literature has enormous historical and research value. The information has been partly disseminated through journals and books published by international and national bodies and by local caving clubs. Since the 1950s, many of these organisations have made international bilateral arrangements to exchange new publications amongst themselves, usually by post, but in an *ad hoc* pattern that remained unknown internationally. The documents exchanged are commonly housed in speleological libraries of various sizes and physical accessibility. Many are thus stored in relative safety and are available for study, at least to local members. Three main issues now confront this beneficial exchange of information:

- the rising costs of postal delivery;
- the opportunities presented by electronic publication, electronic delivery, electronic storage and digital searching;
- the intention of some Governments for all papers that report publicly-funded research to be freely available under an 'Open Access' policy.

The main aims of this Working Group are to:

1. Promote the exchanges of previous and new paper journals and books that will be housed in physical libraries internationally;
2. Publicise the extent of this international cooperation to help safeguard the preservation of important speleological information into the distant future, as a widely distributed paper archive;
3. Examine the opportunities and problems related to the production, dissemination and long-term storage of information electronically, to improve its international, searchable, 'access' and to produce a distributed digital archive.

The vision is that the Working Group will assist in the networking of over 100 existing speleological libraries internationally that will each hold and catalogue a good selection of published cave and karst literature.

2. The formation of the Working Group

The PEWG was formally established within the UIS Informatics Commission, with close liaison with the UIS Bibliography Commission, at the 16th International Congress of Speleology (ICS) held in Brno, Czech Republic, from 21–28 July 2013. This action followed a meeting in Brno on 25 July about Journal Exchanges that was convened by the British Cave Research Association (BCRA) and attended by 19 Editors, Librarians and other interested people from 12 Countries. That meeting discussed the BCRA experience in re-creating a British Caving Library (BCL) and in re-establishing contact with over 45 overseas organisations with whom exchange agreements had lapsed. The 'Publications Exchange' name of this Working Group indicates that books and other material can also be exchanged between speleological organisations. The second meeting of the PEWG was held on 16 August 2016 in Yorkshire, UK, as part of the 2016 European Speleological Congress, to discuss the latest Terms of Reference and its associated Appendices. New meetings of the PEWG will be arranged at future international speleological meetings, such as the 17th ICS in Sydney, Australia, from 23–30 July 2017. These meetings enable discussions about progress, the dissemination of exchange information, and the actual exchange of back issues of speleological journals and books. All attendees at the various meetings of the PEWG, Editors and Librarians of other international speleological organisations, and other people who have expressed an interest, are regarded as part of this Working Group. The main method of direct communication is by email at present. The latest published version of the PEWG Terms of Reference and its attached Appendices are held on the UIS website at http://www.uisic.uis-speleo.org/publexch/. Versions that are still being developed are distributed to the Working Group as email attachments.

3. Achievements of the Working Group

The aims of the PEWG are achieved by the preparation and maintenance of its Terms of Reference (ToR, which reflect the issues and processes discussed above) and the various Recommendations and informational spreadsheets that are attached as Appendices to the ToR. Appendices currently identified are:

Appendix 1: Speleological libraries

This provides recommendations for the location and financing of libraries, their contents and catalogues, and the searchable digitization of each organisation's early journals and records. A scheme for such libraries to be registered as UIS Documentation Centres is also introduced.

Appendix 2: Paper publications and Digital Warnings

The case is made that to achieve a long term archive, organisations should consider publishing at least some journal copies on paper that will be stored in each organisation's library and those of its Exchange Partners. Warnings by the Vice President of Google and others about the folly of relying totally on digital storage are included.

Appendix 3: Postal exchanges

Recommendations about how each organisation should handle postal exchanges include: keeping in touch by email, cataloguing journals received, and seeking deliveries from Exchange Partners for journals and books that are missing.

Appendix 4: Scanning documents for digital archiving

Recommendations about how to scan printed documents to provide digital versions, and to upload to the Karst Information Portal, have been kindly provided by Bill Mixon (USA). It is planned to include advice from Bob McIntosh (UK) about Optical Character Recognition (OCR) in the near future.

Appendix 5: Guidelines for the creation, exchange and storage of digital publications

Comprehensive advice for editors and publishers about the standards to follow in producing new journals electronically, which can still be printed to paper by publishers and readers, has been kindly provided by Greg Middleton (Australia) and Bill Mixon. The recommendations include how digital versions can be exchanged between organisations and how they can be stored in the long term.

Appendix 6: Working Party Contacts spreadsheet.

This spreadsheet lists the contact names and email addresses of various Librarians, Editors and other PEWG members, but is not placed on the website, to avoid generating spam. Two lists are provided, both being organised into Continental areas: First, for National caving organisations and some large caving Clubs that have several international postal exchange agreements for journals that normally started before year 2000; and Second, for other organisations that have also entered into some international exchange agreements.

Appendix 7: Journal Titles Published spreadsheet.

This spreadsheet, also organised into Continental areas for First and Second lists, gives the titles of paper journals known to have been published by major international and national speleological organisations.

Appendix 8: Publications Exchanges Status spreadsheets.

Two spreadsheets, one for all sending organisations in Continents outside Europe, and the other for Europe, are being populated and will eventually summarise the paper journals held by the major international speleological organisations and some large caving Clubs that form the First list of Appendices 6 and 7. Source organisations are listed by column and all recipient organisations are listed by row in both spreadsheets. Each intersection on the spreadsheets will show the status of any exchange by a simple 1, 0 or blank entry, but without showing the holdings of individual journal titles. This will be the main method by which the extent of international cooperation on exchanging and holding speleological journals and books will be publicised. If organisations or their libraries cease to function in future, or items become lost, then this spreadsheet will provide guidance on where to seek access to secure and archived information. Although these two spreadsheets will not include information from the smaller local caving clubs in each Country, each national organisation or library could usefully construct similar spreadsheets for use at a national level.

Appendix 9: Action Review

This Appendix shows previous and outstanding actions for the Working Group.

It is hoped that most of the work of the PEWG, including the finalising of the recommendations and the populating of the spreadsheets, can be completed by the time of the UIS Congress in Australia in 2017. Thereafter, only a limited amount of maintenance should be necessary prior to each subsequent Congress.

Acknowledgements

Thanks are expressed to all those who have attended the two PEWG meetings and / or have contributed ideas and information for the Terms of Reference and the Appendices, including especially Bill Mixon, Greg Middleton and Bob McIntosh for their expert work on the digital opportunities. Peter Matthews, Chairman of the UIS Informatics Commission, is thanked for his help and guidance and for placing the PEWG information on the UIS website.

Cavers For Cavers – 50 Years Of Uis Cave Rescue Commission

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Abstract

Bernard Urbain (1952-2011) started to summarize the history of UIS Cave Rescue Commission (CRC). The target of this paper is to continue his job, to take it more complete, more detailed and updated. CRC is among the first commissions which is actively existing from the first steps of UIS. It was established by Alexis de Martinoff in 1965. Following presidents have continued his job to realize his dream in the field of cave rescue. The presidents promoted organizing regular meetings, congresses, or international conferences on the subject of the subterranean help. During the second international meeting held in Mozet/Belgium in 1971, it was decided to organize an international cave rescue conference every four years. The first meeting of cave doctors was held at Eisriesenwelt/Austria in 1975. Nowadays, CRC holds conferences in different countries every four years and holds commission meetings at the ICSes. These meetings deal with different rescue topics such as medical, technical, communication, responsibility, insurance policy, legal and aspects, sharing rescue information and experiences among UIS member countries. During international meetings the participants sometimes arrange demonstrations and training. During the 11th International Cave Rescue Conference (ICRS) held in Aggtelek-Josvafo/Hungary in 2007 the representatives of the 26 countries created the Aggtelek Agreement containing basic recommendations concerning cave rescue operations. This document may serve to support negotiations between rescue managers and administrations. Only 8 countries were represented at the first international meeting about cave rescue held at Brussels and Han-sur-Lesse/Belgium in1963, but there were representatives of 26 countries at Aggtelek-Josvafo/Hungary in 2007 and 110 participants from 14 countries at Vaumarcus/Switzerland where the 13th ICRS was held in 2015.

Keywords: rescue, training, demonstration, prevention, operation, equipment

1. Before UIS CRC

Caving as a sport started in the British Isles during the latter years of the nineteenth century but until after World War 1 it remained largely the preserve of a very few adventurers and scientists. During the 1920s and 1930s interest in caving grew, leading to the formation of the first caving clubs, initially in the Yorkshire Dales and in Somerset. Inevitably, the risks of cavers meeting accidents in places accessible only to fellow cavers increased. Although the new clubs had the means to cope with minor accidents, it became obvious that in the event of a serious incident a long way underground, the manpower and equipment available to any single club was totally inadequate. This concern led to a pooling of resources and the formation of the Cave Rescue Organisation in Yorkshire, reputably the first in the world, in 1935 and the Mendip Rescue Organisation in Somerset in 1936. (BCRC, 2017)

1963 – Bruxelles and Han-sur-Lesse/Belgium

This was the first international meeting about cave rescue. 8 countries participated: England, Belgium, France, Lebanon, Luxembourg, Italy, Romania, Switzerland, the topics were discussed were:

- necessity for caving leaders to be ready to carry out rescues themselves;
- involvement of the country where a rescue operation is being conducted;
- recognition of legal power;
- search for an adaptive stretcher;
- post-siphon rescue problems.

(Labegalini, 2015)

2. Establishment of the UIS CRC

The 4th International Congress of Speleology was held in Postojna/Yugoslavia in 1965. During the General Assembly 23 countries decided on the official establishment of the International Union of Speleology (UIS). One of the first three commissions was the Cave Rescue Commission. The proposal was made by Alexis de Martynoff and he was elected as the first president. The organization was headquartered in Belgium.

3. Key persons of UIS CRC

Alexis de Martynoff (1907-1985)

Alexis de Martinoff was born in Kharkow/USSR at 27 September 1907 and died in Bruxelles/Belgium at 25 April 1985. This good and generous man had a busy life. He was interested in everything related to nature and especially to the exploration of the underground world. In Belgium, during the creation of the Speleological Federation of Belgium, in 1952 he founded the organization of Belgian Cave Rescue, which rendered many services in the rescue of explorers in distress. His activity and the knowledge he gained in this field, earned him nomination as President of the UIS CRC. He filled that position for 16 years between 1965 and 1981. At the international level, he was one of the leaders not only of the techniques of rescue in caves, but also of the prevention by teaching and education cavers. (UIS Bulletin, 1985)

Mike Meredith

After 1981, when Martynoff resigned from his position, Mike was elected as president of UIS CRC. He held that position until 1987. Mike was turned–on to caving with Burnley Caving Club. He then joined the staff of Whernside Caving Centre as Chief Instructor for three years before departing for France. Living in Grenoble he became a leading light in the Furets Jaune de Seyssins caving club. Later he became resident in Salzburg and continuing his caving in Austria. He had the opportunity to study developments in caving techniques in three countries. (Meredith, 1979). After 1987 he went to Malaysia where he was mostly concerned with park management, management planning and training of park staff. He became Vice-Chair of Biodiversity Conservation Society Sarawak. (BCSS, 2017)

André Slagmolen

André Slagmolen (Belgium) was the secretary of the UIS CRC after the 6th International Cave Rescue Conference held in Aggtelek/Hungary in 1983. He became the third president in Cividake/Italy in1987. André was one of the founder of the Belgian Cave Rescue in 1952. He died in 22 April 2007, just one month before the 11th International Conference held in Aggtelek again. All his life he was devoted to cave rescue. (Speleo-Secours Info 2007; Urbain, 2011)

Christian Dodelin

André Slagmolen transfered his position to Christian Dodelin (France) in Athens/Kalamos (Greece) in 2005. Christian has been a caver since 1970, instructor at the French Caving School and he joined to French Cave Rescue (Spéléo Secours Français – SSF) in 1982. He has participated of more than fifty rescue operations and he was president of SSF from 1996 to 2004, and leader of international cave rescue training since 1997. He has participated in cave rescue training in other countries (Romania, Bulgaria, Greece, Belgium, Brasil, Argentina, Turkey, Mexico). (Urbain, 2011)

Gyorgy Denes (1923-2015)

Gyorgy Denes was father of Hungarian speleologists, prominent character of speleology in 20th century, honorary president of Hungarian Speleological Society, founder of the Hungarian Cave Rescue Service. Within the UIS CRC he was elected as secretary general in Zakopane/Poland in 1979, as vice president in Aggtelek/Hungary in 1983 and as honorary president in Aggtelek/Hungary 2007. Gyorgy Denes was born at 3 September, 1923. He graduated in law in Pecs University. He participated in reorganization of Hungarian Speleological Society in 1958, where he became secretary, secretary general and finally honorary president. He established the Hungarian Cave Rescue Service in 1961, which still exists. He was member of the presidency in Hungarian Geographical Society and in Hungarian Naturefriend Federation (HNF), president of Cave Commission of HNF. He was leader of uncountable cave research projects in different parts of Hungary, but his favourite area was the Aggtelek karst region. His scientific work was wide: from karsthydrology through history to linguistics. His scholarship gave him opportunities to deal with ancient diplomas and found new knowledge. He was great lecturer and was ready to share his knowledge at all times. He has more than 300 publications in Hungary and abroad in different languages. He enjoyed the appreciation of cavers during his life and additionally he received a lot of awards from state and governmental authorities in Hungary and foreign countries.

4. Events of UIS CRC

One of the main preoccupations of the various presidents was to promote information to the countries of the UIS. It has been decided to organize regular meetings, congresses or international conferences on the subject of the subterranean rescue.

Mozet/Belgium 1971

The second international meeting was held in Province de Namur, Belgium at 17-21 September, 1971. Participants had arrived from 16 countries (Germany, England, Belgium, Bulgaria, Congo, Denmark, Spain, France, Greece, Hungary, Italy, Lebanon, New Zealand, Poland, Switzerland, Yugoslavia). This meeting saw the evolution of concern about techniques involved in cave rescue, including the presentation of the first cave stretcher by Dr Castin (France), and a demonstration of cave radio communication. Various presentations by national cave rescue organizations and a demonstration of a diving rescue were also presented. Legal problems, responsibilities and insurance policies were also discussed. It was decided such an international meeting should be organized every four years, but not coinciding with UIS congresses. (Urbain 2011; Labegalini 2015)

Eisriesenwelt/Austria 1975

Representatives of 12 countries participated (Germany, England, Austria, Belgium, Spain, France, Greece, Hungary, Italy, Poland, Switzerland and Yugoslavia). At this third meeting, the Commission made plans to create another Sub-Commission to develop a catalogue of safety materials especially developed for use in caves and rescue work. Technical contributions at that meeting included a demonstration with more than 9 stretchers and others ways to move injured people, as well as the first demonstration of removing obstructions in caves. The medical program included first meeting of cave doctors, led by Dr. Castin. Medical discussions were around first aid, cave diet and speed of intervention. (Labegalini, 2015)

Sheffield/Great-Britain 1977

Next meeting of cave rescuers was held on the occasion of 7th ICS held in Sheffield/UK at 10-17 September, 1977. Many papers dealt with cave rescue and there were some practical demonstrations. Martynoff presented an overview of the past and current activity of CRC. At that time 17 countries informed him that they have or are in the process of creating cave rescue services. Some countries (e.g. UK, Hungary, USA, Poland etc.) presented their organizations, activities and development of cave rescue equipments and techniques. Using 10 years of experience the National Cave Rescue Commission (USA) together with UIS CRC developed a scoring system which would act as a measure of overall technical or the gross ability of a rescue service. The system counts emergency medical skills, training, team size, special skills, organization, mobilization and equipments as for communication and vertical caving, extraction and patient transportation tools. (Smith, 1977)

Zakopane/Poland 1979

The 5th international conference was held at 2-6 October 1979. The participating countries were: Austria, Belgium, Bulgaria, Czechoslovakia, France, Germany, Great-Britain, Hungary, Italy, Portugal, USSR, Spain, United-States and Yugoslavia. The delegates gave information about their organizations and rescue jobs. Gyorgy Denes highlighted the importance of the prevention. Demonstrations were done by Bulgarian, Italian, Polish and Soviet cave rescuers. At the end of conference a new directorate was elected. Because the CRC activity widened three new positions were created as vice-president to be responsible for different geographical areas. So the elected directorate were as follows:

President	Alexis de Martinoff (Belgium)
Vice-president (American area)	Daniel I. Smith (USA)
Vice-president (East Europe area)	A. Efremov (USSR)
Vice-president (West europe area)	Giuseppe Guidi (Italy)
Secretary-general	Gyorgy Denes (Hungary)
Prevention	Petko Nedkov (Bulgaria)
Material	Hermann Kirchmayr (Austria)
Techniques	Mike Meredith (Great-Britain)

(Denes, 1980)

Aggtelek/Hungary 1983

The 6th International Cave Rescue Conference was held at 2-8 October 1983. More than 160 participants had arrived from 16 countries (Austria, Belgium, Bulgaria, Czechoslovakia, France, Germany, Great-Britain, Hungary, Italy, Portugal, Romania, United-States, USSR, Spain, Switzerland and Yugoslavia). More than 50 lectures were given about cave-rescue and communication equipements, methodology, first aid and other medical aspects, rescuer training, statistics on causes of accidents, organisation background of cave rescue, prevention of accidents and experiences of rescue operations. Rescue demonstrations were performed on the cliff at the entrance of Baradla cave by Hungarian, Austrian, Russian, French and Italian rescue teams. On the last day of the conference directorate election was held for next period as usual.

Alexis de Martinoff (Belgium) was recognized as the founding president

President	Mike Heredith (Great-Britain)
Vice-president	Gyorgy Denes (Hungary)
Equipement manager	Hermann Kirchmayr (Austria)
Technical manager	Pierre Rias (France)
Statistics and prevention manager	Aurélio Pavanello (Italy)
Secretary and documentation manager	André Slagmolen (Belgium)

(Denes, 1983)

Cividale/Italy 1987

The 7th international conference was held in Cividale del Friuli near Trieste at 30 Aug – 5 Sept, 1987. The participating countries were: Austria, Argentina, Belgium, Czechoslovakia, Dominican Republic, France, Germany, Great-Britain, Greece, Hungary, Italy, Romania, Spain, Switzerland, USA and Yugoslavia. The program incuded:

- 9 medical presentations on pharmacy, medical actions, the administration of drugs and histoplasmosis;
- 12 technical presentations about various stretchers, cave-diving rescue, drilling material and the UIS catalogue of materials;
- 18 presentations in prevention section about statistics of rescue operations and circulation of informations. (Urbain, 2011)

A discussion on the concept of cave rescue was conducted and there was a French presentation of some international rescue operations, as well as round-table conferences concerning diving, techniques and international relationships. Handling of a stretcher was demonstrated by an international team. A tribute to Alexis de Martynoff (who died in 1985) was also presented. André Slagmolen (Belgium) was elected as president and Gyorgy Denes (Hungary) as vice-president. The elected commission members were Edith Bednarik (Austria), Alejandro Tellez Gottardi (Spain), Trifon Daaliev (Bulgaria), Ercillio Vento Canosa (Cuba), Vladimir Pashovsky (Bulgaria), José L. Menjibar Silva (Spain), Bernard Urbain (Belgium). (Urbain, 2011)

Budapest/Hungary 1989

That meeting was the pre-congress event of the 10th ICS held at 9-13 August 1989. Participants nuber were 143 who had arrived from 21 countries: Australia, Austria, Belgium, Bulgaria, Canada, Czechoslovakia, France, Germany, Great-Britain, Greece, Hungary, Italy, Norway, Poland, Romania, Spain, Switzerland, Sweden, USSR, Venezuela and Yugoslavia. Thirteen lecturers presented 18 presentations and there were 15 practical demonstrations. The most imporant session dealt with medical aspects of cave rescue when 12 medical doctors sat around the table from 7 countries. A common cave rescue exercise was also organized in which the majority of participants took part. The participants showed the possibilities of solving problems in a cave in practice. Following the meeting of the commission composed were as follows:

President	André Slagmolen (Belgium)
Vice-president	Gyorgy Denes (Hungary)
Secretaries	Edith Bednarik (Austria) Alejandro Tellez Gottardi (Spain) Trifon Daaliev (Bulgaria) Ercilio Vento Canosa (Cuba)
Medical sub commission	Vladimir Pashovsky (Bulgaria)
Documentation	Jean-Louis De Bock (Belgium)
History	Bernard Urbain (Belgium)
Members	Alession Frabbricatore (Italy) Walter F. Gutt (Romania)

La Chaux-de-Fondes/Switzerland 1997

That event was organized as part of the 12th ICS at 10-17 August 1997. The presentations dealt with next: cave accidents in France, cave rescue in Switzerland, histoplasmosis, waterproof stretcher for diving rescues, victim's assistance and epidemic dangers in the caves of Middle Asia. During the commission meeting Gyorgy Denes (Hungary) was replaced by Trifon Daaliev (Bulgaria) and Grace Matts (Australia). Efrain Mercado was named as regional coordinator for the Federación Espeleológica de América Latina y del Caribe (FEALC).

Sart-Tilman/Belgium 2002

The 10th International Cave Rescue Conference was held in Sart-Tilman near Liège/Belgium at 1-3 November 2002. It was organized on the occasion of the 50th anniversary of the establishment of Belgian Cave Rescue (Spéléo-Secours Belge). There were 117 participants from 14 countries as follows:, Austria, Belgium, Corea, Cuba, France, Germany, Great-Britain, Hungary, Japan, Luxembourg, Morocco, Poland, Switzerland. USA. About 40 lectures were presented on the next topics:

- Cost of cave rescue operations and interest of a cave rescue team,
- Presentation of some rescue operations,
- Medical Presentations,histoplasmosis,
- Passage widening with hilti cartridge,
- Cave Ventillation,

Round table with international interventions as subject.

Aggtelek/Hungary 2007

83 participants were there from 26 countries (Austria, Belgium, Bosnia-Hercegovina, Bulgaria, Croatia, Spain, France, Germany, Great-Britain, Greece, Hungary, Italy, Japan, Lebanon, Mexico, Montenegro, Norway, Poland, Puerto Rico, Czech Republic, Romania, Serbia, Slovakia, Slovenia, Sweden, USA), 38 papers and video reports and demonstrations were presented on the following topics:

- Organizational aspects of cave rescue,
- Contributions of cave rescue squad for civil protection during disaster,
- Medical aspects of cave rescue activity,
- Cave rescue educations and trainings,
- Equipment, technique and radio transmission demo,
- Different serious rescue operations in different countries.

The following were present and elected:

Gyorgy Denes	honorary president
Christian Dodelin	CRC president
Gyula Hegedus	organizator of the 11th conference
Efrain Mercado	webmaster
Trifon Daaliev	Balkan countries correspondent
Satochi Goto	Asia correspondent
Badr Jabbour Gedeon	Minor Asia correspondent
Bernard Urbain	administration and history of CRC

The Aggtelek Agreement was created by representives of the 26 countries present at the 11th International UIS Conference of Cave Rescue and supports basic recommendations concerning cave rescue operations. Its focus is to give basic fundamentals for the formation of rescue teams which are legally approved and supported by states. This speleological federations validated document may serve as support in negotiations between rescue managers and administrations.

Dryanovo/Bulgaria2011

The 12th International Cave Rescue Conference was held in Dryanovo Monastery/Bulgaria at 8-15 May 2011. More than 100 cavers participated and 58 had arrived from abroad from 15 countries (Bulgaria, Croatia, France, Great-Britain, Hungary, Italy, Lebanon, Puerto Rico, Romania, Russia, Serbia, Slovenia, Spain, Ukraine and USA). 24 papers and 2 demonstrations were presented. The main subjects were:

- New rescue techniques on rock wall,
- New rescue techniques in cave,

- Equipment presentations,
- New rope techniques demonstrations,
- Medical demonstration,
- Diving demonstration,
- New diving equipment for rescue and
- Communication in caves.

The lectures were highlighted research on the "sit harness syndrome," work-related hypothermia, evidence of the usefulness of cooperation. The Italians presented their activity at an earthquake.

Switzerland 2015

The 13th International Cave Rescue Conference was held in Le Camp-Vaumarcus/Switzerland at 13-19 April 2015. 110 cavers participated from 14 countries as Austria, Belgium, Bulgaria, Canada, Croatia, France, Germany, Hungary, Italy, Netherlands, New Zealand, Russia, Slovenia and Switzerland. There were 32 presentations about

- Equipment tests;
- Introduction of
- cave rescue services of different countries and the
- European Cave Rescue Association (ECRA), and
- EU Civil Protection Mechanism;

Medical session was open to physicians, paramedics, first-aid specialists. There were presentations and discussions on medical equipment (suitable for underground rescue);

One session devoted to testing stretchers among the different teams who brought them;

Diving rescue was addressed to rescue beyond siphons. This type of intervention requires diving through totally submerged passages that are impossible to pump out, before accessing the victim;

Prevention and training session pondered how to deliver a message of caution without giving up the joys of discovery and exploration.

Emergency medical assistance by air and there were a practical demonstration about collaboration with helicopter.

Acknowledgements

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Is The Inscription Dated 1213 In Postojnska Jama Really The Oldest Known?

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Abstract

Many caves contain old inscriptions. Within the area of the former Holy Roman Empire of German Nation (dissolved in 1806) some of the better-known ones are: Einhornhöhle and Baumannshöhle (Harz Mountains, Germany), Drachenhöhle (Mixnitz, Austria), Sloup Cavern (Czech Republic), Postojnska jama (Adelsberger Grotte), Predjamski jama, and Vilenica jama (Slovenia). Volpi (1821) and Schaffenrath (in Hohenwart 1832b) published inscriptions from Imenski rov, the old passage in Postojnska jama. The oldest date given is 1213, taken to be the oldest cave inscription known. However, we have not been able to locate it, in spite of a detailed survey and documentation of all of the *ca*. 400 inscriptions in the passage (Kempe and Hubrich 2011). The newly discovered text by Rumpf (1816) suggests, that these signatures were located not in the old passage but in front of it and that they are today obliterated by show-cave construction. The main doubt, however, against the old age of the date is that it was written in Arabic numerals. These are stylistically identical or at least very similar to the numerals that were used in the inscriptions dating from the 16th and 17th century in the cave and throughout that time period. During the 13th century all dates were exclusively written in Roman numerals, no date is known from the early 13th century written in Arabic numerals. Thus, we must conclude (and that applies to at least three more dates from Postojnska jama) that the date was either misread or even faked. Therefore, the inscription of Pfarrer Otto from Bruck an der Mur of 1387 in the Drachenhöhle at Mixnitz (Klebel 1931) must now be considered to be the oldest known cave inscription. It is written in Roman numerals: MCCCLXXXVII.

Keywords: Speleohistory; inscriptions, oldest cave inscription, Postojnska jama

1. Introduction

Inscriptions are found in many caves. They document when caves were visited and, in most cases, by whom. Dates and names are what visitor leave the most. In some cases, more information is added, such as city of origin, titles, profession, purpose of visit, religious signs and phrases, or a coat of arms. These inscriptions offer a rich field for speleo-historians and epigraphists. Naturally, the caves that have been known for centuries and that were easily visited carry the most material.

Within the area of the Holy Roman Empire of German Nation (roughly covering the areas of present Germany, Austria, Czech Republic, Hungary, and Slovenia; dissolved under Napoleon in 1806) inscriptions older than 1800 and written (with very rare exceptions) in German are known from a number of caves. These include primarily in Germany: the Baumannshöhle (Kempe *et al*. 1999; oldest dates from the end of 17th century) and Bielshöhle at Rübeland, Harz Mountains, the Einhornhöhle (oldest date possibly 1410, Faverau 1907; Reinboth 1978; Laub 1986; pers. com. J. Lampe 2016) near Scharzfeld, South Harz Mountains; in Austria: the Drachenhöhle near Mixnitz (127 inscriptions documented, oldest from 1387; Klebel 1934), and the Kartäuserhöhle near Gaming (inscriptions between 1512 and 1759; Wolfram 1958a, b); in the Czech Republic: Sloup Cavern; and in Slovenia: Postojnska jama (Adelsberger Grotte) (Nagel 1748; Volpi 1821; Hohenwart 1832b; Schmidl 1854; Kempe 2003, 2005; Kempe and Hubrich 2011; Kempe *et al*. 2004, 2006a, b), Črna jama (inscriptions almost illegible), Predjama cave (about 100 inscriptions on 22 panels; Kempe *et al*. 2006b; Kempe and Hubrich 2011), and Vilenica jama (Mihevc and Kranjc 2015; Kempe and Ketz-Kempe 2016). Outside of this area the Cave of Antiparos (Greece; Choiseul-Gouffier 1782), the Cueva de la Atapuerca in Burgos (Spain; inscriptions of the 13th century), Jasovska in Slovakia and the Grotta delle Fate (Italy; inscriptions of the 15th century) are known to have

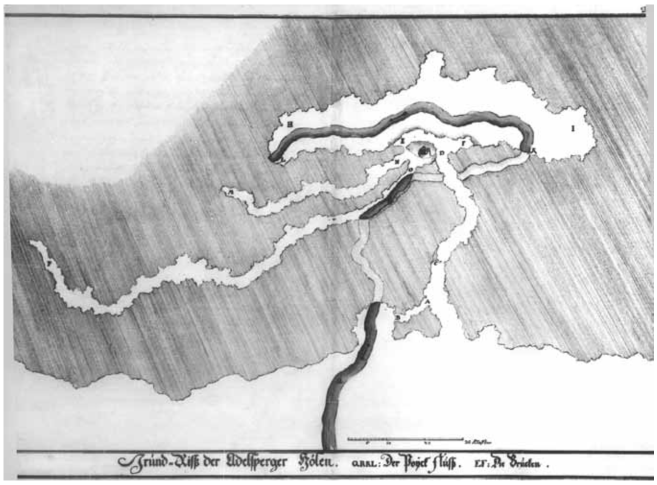


Figure 1. The map of Postojnska jama as known in 1748 (Nagel 1748). Imenski rov is the passage extending left. On the top is the Great Dome with the Poik flowing at its bottom.

old inscriptions (Shaw 1992). Even older inscriptions in caves or artificial cavities are known from antique times (we found e.g., “Menelaos” in a Roman aqueduct in Jordan).

Caves that were discovered in the second half of the 19th century or later were mostly quickly converted into show caves or are protected by law reducing the possibility and/or willingness to leave names. Signatures that are left now are considered vandalism. An exception are guest books that record visiting frequency.

Writing media used in caves are quite variable: The simplest means are scratching, using fingers “inked” with loam, the smoke of candles or torches, or pieces of charcoal from torches. Artists used charcoal and ochre pencils while richer visitors employed graphite, lead, tin or even silver pencils. The

Figure 2. Inscription Panel 17 at the end of Imenski rov.

modern, cheap graphite/clay pencil came in much later since it was invented only in 1790.

2. Inscriptions of Postojnska jama

Imenski rov (Rov starih podpisov), the Old Cave (Stara jama), was the only part of Postojnska jama (Fig. 1) known for several centuries until 1818 when Luka Čeč discovered the access to the inner parts of the cave. All inscriptions, several thousand and most of them undocumented yet, in the major part of the cave are therefore later than about 1820 (Kempe 2005; Kempe *et al.* 2004, 2006a). In Imenski rov we documented *ca*. 400 inscriptions on 17 panels (Fig. 2). It is here that the supposedly oldest known cave inscription was found, dated 1213 (Fig. 3). It also shows the double cross of the Bishop of Aquilea (Perco 1919) and the letters C M.

Information about this and the older inscriptions in Imenski rov rested, so far, on two publications, those of Volpi (1821; Plate 2) and of Hohenwart (1832b; Plate 19). Volpi visited the cave, possibly accompanied by a certain Phi(lip) Kniescheck, in 1820, leaving his name in the Old Passage (Fig. 4). In his booklet published a year later he listed 46 inscriptions (Fig. 5) (sorted by age in three columns and 16 rows and referred to as 1/1 to 3/14). Volpi states that they were given to him by Löwengreif. Joseph Petsch (or Poetsch) Ritter von Löwengreif (1775–1844) was County Clerk and member of the Cave Commission and one of the foremost explorers and promoters of the Postojnska jama. He left his name at least 14 times in the cave, more often than anybody else (Kempe and Hubrich 2011). His oldest signature in Imenski rov dates to 1813 and the youngest two are from 1825, found in Pisani rov (Kempe *et al.* 2004) and on the Tartarus Panel (Kempe 2005). Thus, it was not Volpi, but Löwengreif who identified the 1213 inscription.

Plate 19 of Hohenwart (1832b) reproduces much of the same names, this time as redrawings of the originals (Fig. 6). But, again, it was not Hohenwart himself (Franz Josef Hannibal Graf von Hohenwart, 1771–1844) that copied them, but the engineer, artist and successor of Löwengreif in the Cave Commission, Alois Schaffenrath (1794–1834). Hohenwart also described Imenski rov at length (Hohenwart 1832b; reproduced in Kempe 2004) relating that he did visit the Imenski passage twice (possibly 1816 and five years later, i.e. in 1821)

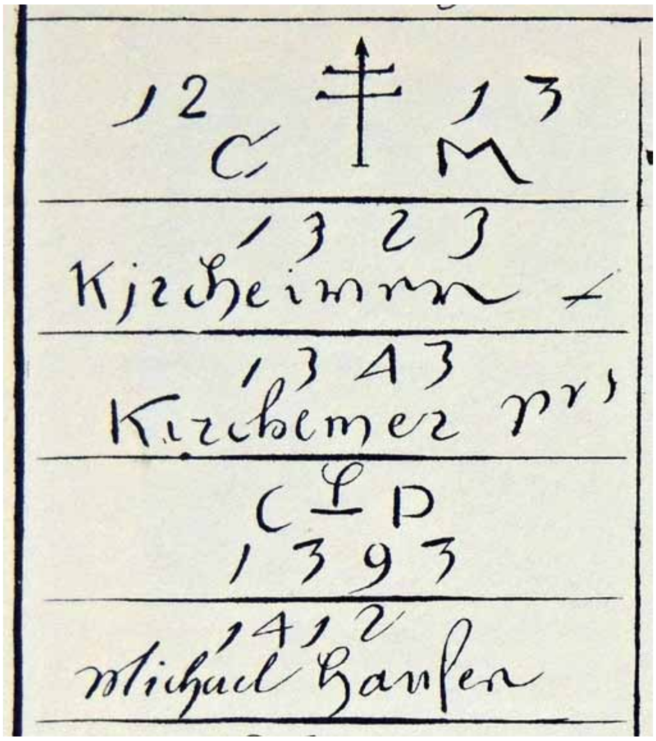
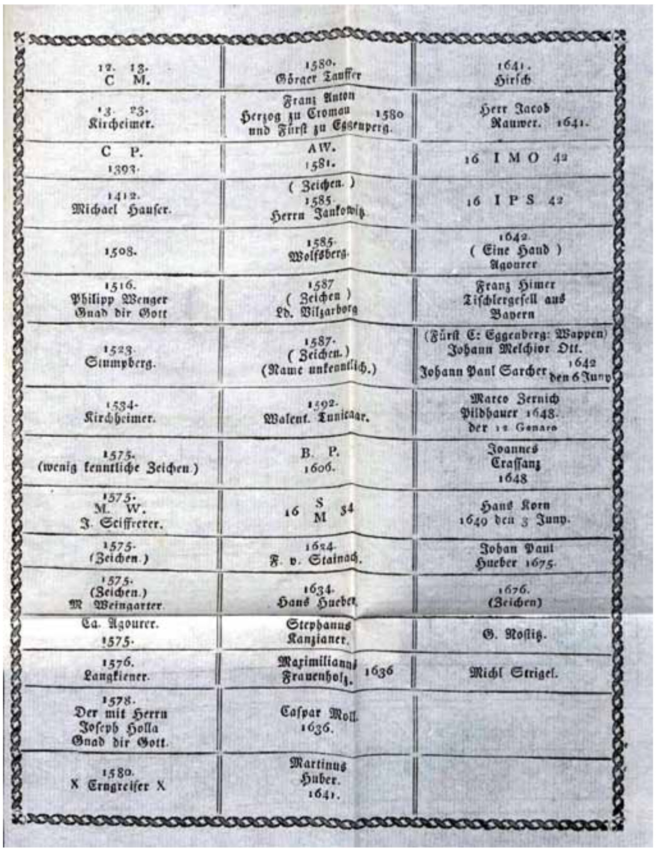


Figure 3. The supposedly oldest cave inscriptions from Imenski rov (clip-out Plate 19, Hohenwart 1832b).

Figure 4. Volpi's signature in Imenski rov, dated 1820.

but could not reach the end chamber because he had put on too much weight (*"habe ich am körperlichen Umfange so sehr zugenommen, dass ich diese Grotte nicht mehr betreten kann*".). Thus, he had to rely on Schaffenrath to copy the inscriptions.

The plate (Fig. 6) depicts 53 inscriptions sorted by dates in four columns and 13 rows (1/1 to 4/13). Schaffenrath himself left five signatures in the cave; two of them in Imenski rov,



12. 13. C M.	1580. Görger Tauffer	1641. Hirsch
13. 23. Kircheimer.	Franz Anton Herzog zu Cromau 1580 und Fürst zu Eggenberg.	Herr Jacob Rauwer. 1641.
C P. 1393.	AW. 1581.	16 I MO 42
1412. Michael Hauser.	(Zeichen.) 1585. Herrn Jankowitz	16 I P S 42
1508.	1585. Wolfsberg.	1642. (Eine Hand) Agourer
1516. Philipp Wenger Gnad dir Gott	1587 (Zeichen) Ld. Vilzarborg	Franz Himer Tischlergesell aus Bayern
1523. Stumpberg.	1587. (Zeichen.) (Name unkenntlich.)	(Fürst C: Eggenberg: Wappen) Johann Melchior Ott. Johann Paul Sarcher 1642 den 6 Juny
1534. Kirchheimer.	1592. Walent. Tunicaar.	Marco Zernich Pildhauer 1648. der 12 Genaro
1575. (wenig kenntliche Zeichen.)	B. P. 1606.	Joannes Craffanz 1648
1575. M. W. J. Seiffrerer.	16 S M 34	Hans Korn 1649 den 3 Juny.
1575. (Zeichen.)	1624. F. v. Stainach.	Johan Paul Hueber 1675.
1575. (Zeichen.) M Weingarter.	1634. Hans Hueber.	1676. (Zeichen)
Ca. Agourer. 1575.	Stephanus Kanzianer.	G. Nostitz.
1576. Langkiener.	Maximilianus Frauenholz. 1636	Michl Strigel.
1578. Der mit Herrn Joseph Holla Gnad dir Gott.	Caspar Moll. 1636.	
1580. X Erngreifer X	Martinus Huber. 1641.	

Figure 5. The table with names from the Name Passage in Postonjska jama as published by Volpi 1821.

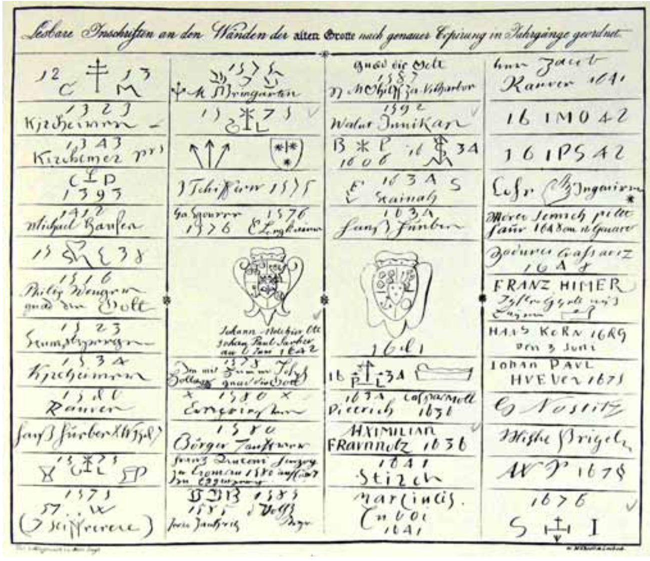


Figure 6. Copper etching with inscriptions copied by Schaffenrath from the "Old Grotto" in Postojnska jama (Hohenwart 1832b, Plate 19)

one dated 1829 in red crayon on Panel 9 and one undated in pencil in the final chamber, on Panel 17. It may thus have been in 1829 that he copied the names in Imenski rov. Both lists contain mostly the same inscriptions. Volpi lists four and Schaffenrath twelve additional signatures. This adds up to a total of 58 items distributed throughout 400 years. Many of those listed from the 16th and 17th century are still visible (Fig. 6, e.g., 1/12, 1/13, 2/2, 2/6, 2/10, 3/3, 3/7, 4/2, 4/2, 4/3, 4/13).

Schaffenrath's plate was reproduced (e.g., Šerko and Ivan 1958; Kempe 2003) or his names listed several times (e.g., Schmidl 1854; Perco 1929). Hohenwart and Perco give the impression that the 1213 date is found in the "Name Hall", the final chamber of Imenski rov (Panel 17). Perco published two photos labeled "Namenshalle"; but they actually show Panels 12 (p.41) and 9 (p.43). On the pictures inscriptions are enhanced by hand, but 1213 is not included.

1213 has been cited often as being the oldest cave inscription known (e.g., Shaw 1992; Kempe 2003; Kranji 2007 [but not in the German version edited by the author]; Mattes 2015). However, nobody states to actually have seen the date, nor was any picture of it published since Schaffenrath. Repeated search and our photo documentation has not turned it up and nobody from the Karst Institute and none of the cave guides can locate it or remembers having seen it. This applies also for the 1312, 1343 and 1395 dates in Schaffenrath's list. Date 1412 is found in the Namehall, but there it is Veit Hauser, not Michael Hauser (Fig. 7).

In preparation for this presentation two more papers were found dealing with Postojnska jama, mentioning the inscriptions. The older one is a commentary by a Dr. Rumpf (1816) to a poem about the Adelsberger Grotte written by Johann Gustav Fillinger. In § 24 Rumpf first mentions (near the skeleton that has been described also later by Hohenwart) Michael Hauser, 1412. Thus, there may have been two Hauser inscriptions, one Michael and one Veit. Then Rumpf continues with: 1393 C†M, 1213 C. M., 1636 Fv Sales Stainach, Philip Mengen, Gnad dir Gott 1516. These can also be seen in Volpi's and Schaffenrath's lists with slight variations but are not found any more. The next sentence, however, is important, saying: *"Mitten unter diesen und andern Namen aber steht an der Wand gleich neben der Brücke – Franz I, unser geliebter Monarch, welcher diese Grotte am 17. Mai 1816 besuchte; nahe an seiner Inschrift hat sich Louise, seine Tochter eingegraben"*. (*"But in the middle of these and other names on the wall immediately next to the bridge stands: Franz I, our beloved monarch, who visited this grotto on 17 Mai 1816; next to his inscription Louise, his daughter has inscribed"*).

In the second paper Prof. Richter reports about a trip that was intended to visit the grotto on 10 April 1817, but a snowstorm prohibited it. Instead Richter visited Löwengreif and his collection of "*admirable stalactites and stalagmites*", and was entertained with the story of the "calcinated skeleton" (also featured in Fellinger's poem) and obtained the following names from Löwengreif: 1516 Philip Wengen, gnad dir Gott; 1575 a Monogram with a salt container and a water jug; 1213 CM with a graph (Fig. 8); 1323 Kirchheimer, Stumperrg 1523; Gregor Tauferer 1580; Franz Anton Herzog zu und Fürst v. Eggenberg 1580; Jacob Rauwer 1641 (all also present on Schaffenrath's plate, Fig. 6).

3. Discussion

There was speculation why the first four oldest inscriptions cannot be found anymore. Should they all have been wiped out after 1829? Why? Or should they all have been covered by modern flowstone? Not very likely, considering that they supposedly survived 500 years before Löwengreif took notice of them. The text of Rumpf (1816) seems to clarify this problem: these signatures were located near the natural bridge leading

Figure 7. The „oldest“ inscription still visible in Imenski rov, Panel 17, reading “Veit Hauser 1412”.

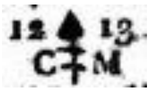


Figure 8. The 1213 date in Richter (1817).

towards the Big Dome and not within Imenski rov. To my knowledge, the Inscription of Franz I is not existing anymore either, it may have been obliterated with the other inscriptions missing when the railway bridge for the show cave was constructed. The natural bridge is now where the entrance train station is situated.

In addition to the location-problem there is serious doubt that the pre-16th century dates are genuine. The first to cast doubt as to the validity of the 1213 date was Adolf Schmidl (1858). He states (p. 8): *“die angeblich vorgefundene Jahreszahl 1213 soll wohl 1X13 (1413) heißen”* (X stands for a sign not printable as ASCII, depicting a late mediaeval “4”). (Translation: *“the supposedly detected date of 1213 could possibly mean 1X13 (1413)”.* Interestingly, even Schmidl had not seen the inscription (Schmidl, 1854, p. 65). Schmidl’s remark was highly justified because the style of numerals used in the 1213 date is equivalent to numerals used in the 16th century. This can be easily seen when comparing the styles of the numerals in Fig. 5 with each other. The same argument applies to all of the dates prior to those of the 16th century. Even the date 1412 Veit Hauser in the Namehall, the oldest still visible, must be doubted as being genuine. The “4” should be written much differently, i.e. as the upper half of an “8”. The writing of all of the numerals appear to be very modern.

The main argument, why the old dates are either misread or have even been faked is the fact, that they are written in Arabic numerals. Up to the 15th century all annual dates were written in Roman numerals. In fact, only a very few documents exist at all, that used Arabic numerals in that time in Europe and these looked much different compared to those used today. 1213 should have been given as MCCXIII, if genuine. In the series “Die deutschen Inschriften”, amounting to 100 volumes since 1942, there is not a single example of a date written in Arabic numerals prior to the 15th century (pers. com. J. Lampe, Göttingen).

4. Conclusions

The inscriptions copied by Löwengreif and Schaffenrath and published by Rumpf (1816), Richter (1817), Volpi (1821) and Hohenwart (1832b), showing dates of the 13th and 14th century, are most probably not original. If they were genuine they should have been written in Roman and not in Arabic numerals. The style of their Arabic numerals clearly reminds of 16th century dates. The oldest date still found in the cave, that of Veit Hauser 1412, appears to be even more modern. The fact, that the three oldest signatures have not been found in modern times, can now be explained by Rumpf’s report that these have been near the natural bridge and not in Imenski rov. They could therefore have been accidentally obliterated by the development of the show cave. But, if these oldest dates are not genuine, why, when and by whom were they written? One name always is mentioned in connection with the inscriptions is that of Löwengreif. Was he the faker? Could he have done it to make the cave more interesting prior to the visit of Franz I in 1816? In this context, it is also curious that Löwengreif signed himself in Imenski rov in 1813 but later insisted to have “rediscovered” it in 1816 (Hohenwart’s text, 1832b, reproduced in Kempe 2003, p. 39).

Whatever is the case, the oldest existing cave inscription seems to be the Latin inscription of Pfarrer Otto from Bruck an der Mur dated 1387 in the Drachenhöhle near Mixnitz (Klebel, 1931). It is written in Roman numerals: MCCCLXXXVII. Sic transit gloria mundi!

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OPERATION "CAVE" – The East German Secret Service 'Stasi' and its focus on cavers and SPELEOLOGY

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Abstract

Speleologists in former GDR (East Germany, German Democratic Republic) and those visiting, specifically from West Germany, were subject to observation by the Ministry for State Security (MfS), the largest GDR secret service, colloquially known as "Stasi". Its interest focussed on their contacts, the caves and cave areas visited and the potential military use of such knowledge by the West German secret services. Following the demise of the Ministry for State Security of the GDR in 1990, the "Federal Commissioner for the Records of the State Security Service of the former German Democratic Republic" (BStU) was created and opened the files. Previously secret archive material in the area of speleology has been available for historical analysis since then. Speleological research in this area is only at its infancy. Using these exemplary archive files, the mentality and ways of working of the GDR secret service is presented. This paper is hoping to encourage other speleologists to conduct similar archive research. Previously, the author worked to shed light on the involvement of speleological research in the Nazi suppression apparatus. A symbolic success of these efforts was the establishment of the Dr Benno Wolf award by the Verband der deutschen Höhlen- und Karstforscher VdHK (German Speleological Federation), see Knolle (2001), Knolle *et al.* (2007, 2013). It remains frightening to see how effectively the secret services not only of the Nazi but also of the GDR and other totalitarian regimes managed to gain control over speleological and geological information and those producing it. The reason for this is the power of dictatorial states, the apolitical naivety and/or the opportunistic willingness of researchers to collaborate, the lack of interest or a combination of all of these and other factors. Without jumping to conclusions in comparing the Nazi dictatorship with the political structure of GDR, there is clear evidence that secret services of both systems were actively targeting speleologists and geologists.

Keywords: Stasi, East German secret service, political control of speleology

1. Secret Service Operation "Höhle" ("Cave")

The first author's interest in direct contact with the then East Germany was formed by his father Friedel Knolle. He had been entertaining extensive contact with experts in the GDR for many years. Back then, in the middle of the Cold War, there were difficulties with these contacts and written correspondence had sometimes been problematic. Letters disappeared and telephone conversations were obviously monitored. This could only be intriguing and exciting for a politically interested son. As a youthful and open-minded scholar, later soldier and university student, he was not fully aware back then that his "harmless" interests in geology and the Harz region would ring the alarm bells of the GDR secret service Stasi, much more than the biological and natural science research interest of his father.

The secret service wanted to know whether the first author, acting as a geologist, speleologist and later also as the editor of the VdHK using German-German political arrangements for passing the border between West and East Germany for day trips to visit the eastern Harz Mountains, had contact to the military geographical services of the West German army or any other "enemy" service and the Stasi implemented an OPK ("operative personal control"), i.e. surveillance by the secret service first in the GDR and later also in West Germany.

The first author has been subject of Stasi surveillance for many years (Knolle 2011). Based on some information provided by one of the people spying on him (known as "informal collaborators" (IM or simply Stasi "informers"), the first author then decided to look into the personal data contained in his surveillance files catalogued by the BStU. Further material has been provided by other speleologist colleagues affected by surveillance in the same way. The correspondence letters of the first author with specialists in the former East Germany

Figure 1. Emblem of the GDR secret service Ministerium für Staatssicherheit vulgo Stasi.

Der Bundesbeauftragte für die Unterlagen
des Staatssicherheitsdienstes der ehemaligen
Deutschen Demokratischen Republik

Figure 2. Logo of the BStU, the Federal Commissioner for the Records of the State Security Service of the former German Democratic Republic.

have also provided supplementary information when reading them again in the new light of today's knowledge and with the benefit of hindsight.

An assessment of these documents reveals that the Stasi initiated the OPK "Cave" for the first author and two further persons. This was apparently triggered by the careless behaviour of the western German speleologist Dieter W. Zygowski (†) when contacting speleologists in the then Communist Bloc. Observation was authorised by Major Fiegert from the 13th Stasi division on 4 October 1982. This observation remained in operation until 1989, when the Berlin Wall fell, and affected "suspicious" speleologists and geologists Dieter W. Zygowski, Friedhart Knolle, Dr Klaus Stedingk and other target persons he was working with.

According to the files, activities were mainly carried out by the Stasi main administration for national economy, division XVIII/3. It included, amongst other things, surveillance of written letters, observation of travel into the GDR and back into West Germany, specific targeting by informers, tailing and observation in the field ("operative control"), sourcing of information from various informers (speleologists and non-speleologists), bugging of the private flat of the informer "Cridner", who had been visited by the first author in the town of Wernigerode and possibly also the surveillance of the private telephone of the first author in West Germany. Regarding the latter, it is not clear from the files if and to which degree of success this telephone has actually been listened to. The bugging of the private flat with the help of a microphone can be clearly concluded from notes found in the files. The evaluation of the audio track is discussed there in detail.

At least eleven informers and informer-candidates as well as an unknown number of Stasi employees were involved in the observation and surveillance of speleologist Knolle. Further employees of the state government were involved in investigating possible treason (by citizens of the GDR), were staff of the GDR Ministry for Geology.

Some of the Stasi files have a high value as historic documents. Even the personal character of some of the informers can be uncovered by reading the files. For example, informer "Paul" notably avoided to name specific people or to provide information that would compromise anyone. Conversations extracting information from informers took place in the Kyffhäuser Mountains. These often only included trivialities and quite broad topics and answers avoiding the real questions. However, the files also refer to written assessments provided by informers. These assessments are not included in the personal file for the first author. It is clear what the Stasi was looking for: leaks in the unofficial exchange of caving information. In the meeting report of Captain Scherpe from the main administration for national economy, division XVIII 3/4 with the informer "Paul" on 17 April 1985 under the category "New Orders and Behaviour" we found the following statement:

"Extend contacts to West German speleologist Knolle. Working on more information regarding unofficial exchange of literature between GDR speleologists and speleologists of western countries with the view to narrow down the number of people."

One has to give credit to informer "Paul" that he always was interested in the actual topic of speleology and that he presumably tried to play cat-and-mouse with the Stasi. When visiting the show cave "Heimkehle" as part of using the local arrangements for passing the border between West and East Germany on 28 July 1985, informer "Paul" warned the first author of the dangers and dropped the hint that he (the informer) would seek to avoid him more in the future. While the first author could not fully interpret this advice at the time, in hindsight it can be considered the most open "tip-off" by an informer to his "target object" that happened to our knowledge within the observation operation "Cave". The behaviour of informer "Paul" shows a lot of courage in a complicated situation. He revealed himself to the primary contact of the first author, Wernigerode speleologist Hannes Tschorn (†). They agreed to coordinate their reports to the Stasi and both took a big risk by doing so.

What informer "Paul" did not deliver was reported by informer "Berger". He was obviously eager to share news. Many of the hand-written reports for meetings with the Stasi and transcripts from audiotapes are available on file. The informer "Berger" mentions, among other things, detailed contributions in newsletters and in the West German caving magazine, which he quoted in great detail including year and issue number. "Berger" was a meticulous informer, who paid attention to individual letters of the alphabet. He was also an editor of GDR speleological publications. He and the first author were colleagues on opposite sides of the "iron curtain" during the cold war. For example, he shared his assessment with Major Klinner and Captain Scherpe during an information exchange meeting on 5 December 1984, that the letter "T.", which can be found several times in the magazine, stands for the Wernigerode speleologist Tschorn. Unfortunately, this assessment was correct and caused the person in question a lot of trouble, disadvantages and a house search warrant. Informer "Berger" denounced the first author as a potential member of the military geographical service of the West German army and/or of a western secret service (probably the Federal Intelligence Service, BND), at least this is what we can assume from the records in the files.

On the 20 August 1985, there is a four-page filled-in personnel questionnaire in Cyrillic letters about the first author on record – with this dataset he was put into the SOUD system, the "System of Collective Register of Records on the Enemy" of the Eastern Bloc states (see Grúňová 2008). The questionnaire describes Knolle explicit as "speleologist" with expert knowledge and many contacts – in these times enough to be a potential enemy. According to secret service experts, the data on the first author probably still are in the follow-up register now run by the Russian secret services.

In September 1998, the secret service had a bit of a mishap: Dieter W. Zygowski, who was acting suspiciously and was under surveillance as a West German speleologist and editor

z l/sec floß am 30. 12. 1983 und am 3. 1. 1984 von Norden entgegen.

In einer Entfernung von 62 m hinter dem Hochstpunkt der zweiten Sinterbarriere wurde der letzte Meßpunkt in einer Höhe von 1,6 m über dem Boden auf die linke (West-)Wand gesetzt. Die auf den Meßpunkt 1/0 bezogenen Koordinaten lauten: Y = - 127,7; X = 324,7; H = -16,4. Der Weiterforschung steht nichts im Wege.

Zur Weitervermessung

Die topographische Aufnahme wurde mit einer 4b-Vermessung am 30. 12. 1983 von CLAUDE CHABERT und DANIEL GEBAUER mit Suunto-Bussole und Dressler-Topofil begonnen und am 3. 1. 1984 von DANIEL GEBAUER, GISELA ROTHAUPT und SIBYLLE WOLFGRAMM mit Suunto-Bussole, Suunto-Neigungsmesser und Fiberglasband weitergeführt. Die Vermessung wurde aufgrund der enormen Wärme eingestellt und später aus Zeitmangel nicht wieder-aufgenommen. Doch führt der Haupthöhlengang zunächst etwa gleichbleibend rund 100 m weiter, bis eine Versturzzone erreicht wird, die überklettert werden kann. Danach folgt ein Abstieg, für den eine 10 m-Leiter vorteilhaft ist. Hier beginnen wassererfüllte Höhlenteile.

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KOPIE

Mollusken als Kerne von Höhlenperlen

von

ANDREAS ARNOLD, Langenbach (Erzgeb.)

Im Rahmen der »Expedition Iskar-Durchbruch 1982« des Studentenzirkels für Speläologie der Bergakademie Freiberg hatte ich Gelegenheit, u. a. einige Höhlen bei Karlukovo am Iskar im Westlichen Balkangebirge (Sapadna stara planina)/ VR Bulgarien zu befahren.

Der Iskar hat sich hier bis 300m in das Karbonat-Karstgebiet (Kalkstein mit Dolomitbändern) eingetieft (Iskar-Durchbruch) und die Randlagen der Steilhänge sind durch überwiegend vertikale und unterirdische Entwässerung gekennzeichnet, was die Verkarstung und die Ausbildung zahlreicher Schachthöhlen mit bis zu 40 m tiefen Eingangsschächten begünstigte.

Eine typische Schachthöhle dieses Gebietes ist die etwa 3 km von der bekannten Höhle »Haiduschkata« (Haiduckenhöhle) entfernte, links des Iskar bei Karlukovo gelegene »Bjeßimena« (= »Die Namenlose«), welche erst kürzlich von bulgarischen Höhlenforschern entdeckt und mit uns am 8. 8. 1982 zum zweiten Male befahren wurde. Der Eingang des 16 m tiefen Schachtes befindet sich im tiefsten Punkt einer sehr flachen Doline. Im Dolinenbereich treten die Karren besonders dicht und weit hervor, so daß sich dazwischen nur eine sehr spärliche Vegetation mit nur vereinzelt kleinen Büschen entwickeln kann. Diese trockene Karstlandschaft stellt für Mollusken ein Extrembiotop dar. Einige Arten von Gehäuseschnecken weichen vor dem in der Tageshitze stark erwärmten Boden aus, indem sie sich einige Dezimeter über dem Boden an Zweigen aufhängen.

Der Eingangsschacht der Bjeßimena beginnt mit einem meterbreiten Mundloch am Dolinengrund und erweitert sich bis 16 m Tiefe kegelförmig bis auf 15 — 20 m Durchmesser. Vom Schachtgrund führt ein 5 — 10 m langer, horizontaler Gang zu einem weiteren größeren Raum mit Tropfsteinge-

10

Abb. 1: Expedition »Iskar-Durchbruch 1982«

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Figure 3. Even copies of papers published in the West German speleological journal of the VdHK are to be found in the Stasi files.

of the VdHK, visited the 3rd International Czechoslovakian Speleology Congress in Sloup. There the secret services had their cover blown. Zygowski realised that he was being observed and spied on. The Czechoslovakian secret service must have acted quite unprofessionally. Indeed, Zygowski told the first author later that this incident has spoiled his appetite for travelling to the Eastern Bloc. In 1985, the first author increased his travel activity to the then GDR, not knowing the background developments. This was interpreted by the Stasi as that the new visitor Knolle was taking over the spy role from Zygowski. The first author travelled seven times to the GDR between 1985 and 1986, according to the files of the operation "Cave", he himself had not recorded how often he had travelled there.

2. Full Control – the GDR "Cavity Law"

The GDR tried to control and "secure" everything underground. The government of the GDR ratified the "Order on Subterranean Cavities", colloquially known as the "Cavity Law" on 17 January 1985. It was published on the official legal register of the GDR in 1985, part 1, no. 5 on 22 February 1985, supplemented by orders how to implement it. The organisation of speleology in the GDR was also tightened. From 1 January 1985 onwards, only the "Kulturbund" (Cultural Association), in particular the "Central Expert Committee for Speleology and Karst Research of the Central Committee of the Society for Nature Conservation and the Environment", to give it its full name – was responsible for speleology in the GDR.

This is when it became serious business for us and our GDR speleology colleagues, and by including the HVA (Stasi department for Exterior Affairs), also for the VdHK. We did not foresee what was coming. In an undated document, Lieutenant Colonel David assessed the danger arising specifically from speleologist Knolle that important, that he considered his arrest. If that had happened, this conference paper would probably not be as objective as it is.

The Stasi started a new operation "Wismut" because the first author and other geological colleagues travelled to the Erzgebirge Mountains in the south-east corner of the GDR in 1986. There they visited geological outcrops and abandoned polluted areas where contaminated waste was stored. To answer questions related to "enemy contact" the operation was extended to West Germany as well. Even the flat of the first author was under observation. But despite intensive surveillance efforts the Stasi could not find any evidence about any work of the first author for a secret service. How should they, they did not know that they were completely on the wrong track. Consequently, additional resources were planned for 1988.

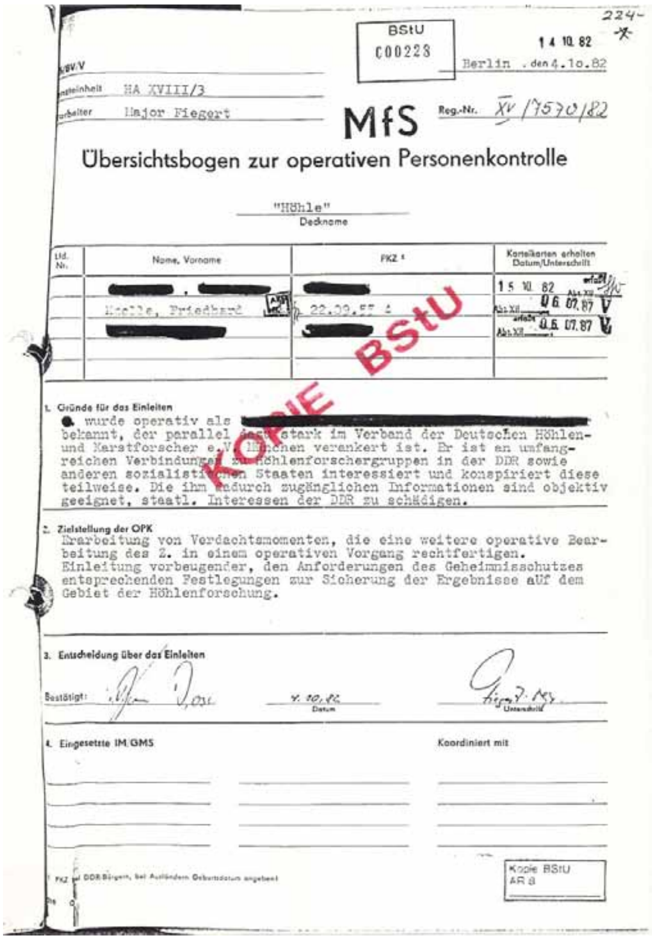
There is only partial evidence on record to support some verbal information that the informer "Paul" shared with the first author after 1989, i.e. the use of secret service resources "money" and even a female informer with "enemy contact". A woman was about to be set on the first author to create a "honey trap". The pressure to present evidence regarding the "Case Knolle" must have been extremely high.

In 1988 the Stasi planned to engage the candidates "Sch." from Wernigerode and "Z." from Uftrungen as new informers. The identity of the candidate "Sch." was uncovered after the Berlin Wall fell. It was Regine Schulz. Her then husband, who was in correspondence with the first author at the same time, pressed her, according to her own statement, to get actively involved in speleology. That means he may have had a role in the Stasi or a similar organisation, but this is still to be substantiated. Regine Schulz confirmed to the first author the attempts to engage her as an informer, she was told to be slim and ideally suited for caving. Mrs Schulz refused consistently to get involved stating health reasons and a lack of interest. According to her own statement, she has never again heard anything about this matter, i.e. the attempt by the Stasi to make her an informer apparently was abandoned.

Mrs Schulz was able to resist this recruitment attempt without any obvious consequences, the Stasi was in fear of exposure. By the way, the first author was never offered money. This fact is probably fortunate, because, to be honest, nobody can be really quite sure how he would have reacted under some very special circumstances.

The role of the Stasi department HVA, however, remains still unclear. This is not really a surprise, as that department was one of most "top secret" parts of Stasi. Despite this, there are several tracks of informers leading to West Germany. The Stasi had probably placed one or several informers directly in the VdHK, because news travelled very fast to East Berlin.

Despite years of surveillance, the Stasi has never found any evidence about the first author or any of his colleagues collaborating or working for a western, i.e. "imperialistic" secret service. After a detailed evaluation, the file of the operation "Cave" was closed. It consists of two volumes with 432 pages and was placed into archive on 5 December 1989 by the successor to the Stasi administration, the "Office for National



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Diensteinheit HA XVIII/3

Mitarbeiter Major Fiegert

Berlin, den 4.1o.82

MfS

Reg.-Nr. XV/17570/82

Übersichtsbogen zur operativen Personenkontrolle

"Höhle"
Deckname

Lfd. Nr.	Name, Vorname	PKZ *	Karteikarten erhalten Datum/Unterschrift
	[redacted], [redacted]	[redacted]	15 10 82 Abt. XII
	Knolle, Friedhart	22.09.57 4	Abt. XII 06.07.87
	[redacted]	[redacted]	Abt. XII 06.07.87

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1. Gründe für das Einleiten

● wurde operativ als [redacted] bekannt, der parallel sehr stark im Verband der Deutschen Höhlen- und Karstforscher e.V. München verankert ist. Er ist an umfangreichen Verbindungen zu Höhlenforschergruppen in der DDR sowie anderen sozialistischen Staaten interessiert und konspiriert diese teilweise. Die ihm dadurch zugänglichen Informationen sind objektiv geeignet, staatl. Interessen der DDR zu schädigen.

2. Zielstellung der OPK

Erarbeitung von Verdachtsmomenten, die eine weitere operative Bearbeitung des Z. in einem operativen Vorgang rechtfertigen.
Einleitung vorbeugender, den Anforderungen des Geheimnisschutzes entsprechenden Festlegungen zur Sicherung der Ergebnisse auf dem Gebiet der Höhlenforschung.

3. Entscheidung über das Einleiten

Bestätigt: ______ 4.10.82 Datum ______ Unterschrift

4. Eingesetzte IM/GMS

Koordiniert mit

* PKZ bei DDR-Bürgern, bei Ausländern Geburtsdatum angeben!

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Figure 4. Secret Stasi instruction to intercept the private telephone line of the first author.

Security" (Amt für Nationale Sicherheit). Today it is available under the BStU law conditions.

3. Conclusion and looking ahead

The psychological aspects of speleology in the former GDR are complex. Caving was a piece of "internal freedom" in the system. From very normal cavers to "Cave Stalinism" via selfish speleologists and "fellow travellers" to people who expressed an explicit criticism of the system and many shades in between, everything was represented. The Stasi with its "big ears" was omnipresent. However, the circumstances should not be interpreted with a pure black-and-white thinking. With some distance now, the colleagues from the former GDR could write this story much better anyway, if they wanted to.

The still missing analysis of files and other evidence should be conducted by as many speleologists as possible. It cannot and must not be a means to trigger a witch-hunt on any speleologist living today. The aim should be, in the spirit of the BStU, to use these records to create dialogue and to constructively reappraise the past. This should include both personal and institutional entanglement in Stasi work as well as the brave defence against Stasi activities. There are impressive examples for both ways of dealing with the system.

The analysis of these files can also contribute to discover how difficult the circumstances for East German speleologists for their research were. This has no comparison to the freedom we had in the West. It is not about "good" or "bad" (maybe with the exception of clear legal offences), but rather about jointly writing the history of speleology. This is a historically unique opportunity to jointly work through the files, and not just decades after the end of system and the death of many activists, like we did it with the first German dictatorship. This is not easy for some people, of course, and still takes courage to overcome barriers.

Surely, it would also be exciting to look at the role of other organisations, like the BND, CIA, NSA, MI5, MI6 or even ASIS and other secret services regarding their respective interest in karst and cave research within the context of democracy. The interest of military geologists in karst and caves are well known. It is not easy to get any documentation, of course, but speleologists are used to that in their work underground.

The first author received a few anonymous and threatening calls while working on this topic. A previous version of this text (in German) has been published on the internet for some time now. At the time of this first web publication, he was asked by telephone to remove these texts as quickly as possible or otherwise he would get serious problems. Nothing followed these threats. You have to stand up to them. Our democracy and our writing of honest history depends on it.

Acknowledgements

We are very grateful to the BStU for their informative support of our research. We also thank the GDR cavers and those informers who gave us additional and explanatory information. We are not going to thank the informers who still have not talked to us.

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(Abstract) Karst And Caves Throught The Eyes Of The Brazilian Emperor, Dom Pedro II (1831-1889)

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Abstract

Dom Pedro II, the second and last emperor of Brazil, can be considered a scholar and enthusiast of arts and culture. He was also known as an important sponsor of science, although this is little known by most Brazilians. The Emperor was respected by European scientists like Graham Bell, Louis Pasteur and Charles Darwin, among others. There are 43 personal journals written by Dom Pedro II during his travels during the 49 years of his reign. The emperor was educated based on Enlightenment ideals, concentrating his studies in Politics and Sciences. He studied Natural History, Geography, History, Literature, Latin, French, English, German, Italian, Spanish, and Greek, among other subjects. While travelling through Brazil and around the world, he wrote detailed accounts of fauna and flora, as well as recorded his geographical impressions of the various places visited. The importance of these accounts is so great that several imperial documents were included in the UNESCO Memory of the World Program (MoW), including the documents related to his travels. Such personal records are considered valuable documents of the second half of the nineteenth century, worthy of preservation. Less well known are his records regarding physical geography, caves, and karst areas through which he passed. Thus, it is the main objective of this work is to highlight the emperor's impressions on the karst landscape in Brazil and in other countries, identifying the places where he visited. To do so, the authors carried out research in the travel journals (1840-1889) that were scanned by the Imperial Museum (Museu Imperial), unit of the Brazilian Museums Institute, federal autarchy attached to the Ministry of Culture. The material was transcribed into about 1,064 pages, divided in two thematic axes: Travels in the Colony and Travels Abroad. About 29 records or mentions were found regarding the term lapa (meaning cave); 67 for the word grotto (gruta); 4 for the word cave (caverna); 1 for ponor (sumidouro) and 10 for underground (subterrâneo). From all 43 volumes, the ones that stand out with the research theme are Volumes 02 and 09, 11 to 15, 17 and 19, 20 to 25, 27, 29 and 30. Although it is not possible to affirm that the records were strictly karstological or speleological, the notes are to some extent very scientific. Thus, it is impossible to deny the importance and cultural value of these documents.

Keywords: Karst; Caves; Brazilian Emperor; D.Pedro II.

(Abstract) Karst, Caves And Geodiversity In The "Travels In Brazil (1817-1820)" By Johann Baptist Von Spix And Carl Friedrich Philipp Von Martius

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Abstract

Johann Baptist von Spix (1781-1826) and Carl Friedrich Philipp von Martius (1794-1868) were two important German naturalists of the eighteenth century. In 1817, they were part of the Austro-German mission that accompanied the Princess Maria Leopoldina of Austria who later became empress of Brazil. The main objective of the expedition was to create records and collections of Brazilian fauna and flora. The results of the research were published in two volumes entitled "Viagem pelo Brasil, 1817-1820" or Travels in Brazil, 1817-1820. While traveling throughout Brazil, in addition to detailed accounts of fauna and flora, the naturalists recorded their geographical impressions of the various places visited. In this case, less known than the records of biodiversity, are those regarding karst, caves and geodiversity of the areas visited. Thus, it is the main objective of this work highlight the general impressions of Spix and Martius about the Brazilian karst areas, identifying some of the sites mentioned. In order to do so, the authors carried out a research in the two volumes of the work. Available in about 690 pages, it can be divided in seven thematic axis, which starts in Munich and ends in the Amazon (1-preparation for the expedition, and the trip from Munich through Vienna to Trieste. 2) departure from Trieste. 3) Gibraltar and the arrival in Brazil. 4) from Rio de Janeiro to Vila Rica. 5) from Vila Rica to Diamantina and Minas Novas. 6) from Minas Novas to the São Francisco River to Bahia. 7) from Bahia to Maranhão and the Amazon). There were 15 records or mentions to caves; 20 regarding cavities; 01 for lapa (meaning cave), 03 for grotto, and more than 50 records regarding limestone. Particularly when mentioning limestone or calcareous formations, the naturalists make very detailed observations. Therefore, it is possible to determine that the records of Spix and Martius are a noteworthy historical-geographical testimony of many regions in Brazil by means of written reports and illustrations of great scientific value.

Keywords: Karst; Caves; Geodiversity; Spix; Martius.

The Karstological Subterranean Laboratory Of Bossea Cave (N Italy)

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Abstract

The Bossea Cave is a show cave with an important underground river located in southern Piedmont (NW Italy). This cave was opened to public in 1874, and since the 1970s it hosts an underground laboratory for the monitoring of the subterranean water flow. This laboratory, located inside the cave environment, has been equipped over the years with increasingly sophisticated instruments and works in four different scientific fields: hydrogeology, meteorology, natural radioactivity, and biospeleology.

The hydrogeological research concerns both the hydrodynamics of the flow and the geochemistry of the waters. Both the main underground river and the many small tributaries and some dripping sites representing the vadose zone are monitored. The main river has been continuously monitored since 1983 which has allowed the gathering of an impressive amount of data in different hydrodynamic conditions, from the extreme floods to the most important droughts. Sampling of water from the main river and from many drip sites under different hydrodynamic situations and the chemical analyses (main elements, lanthanides, and metals) have allowed to understand the way in which the water flows through the different types of drainage networks. Several tracing experiments and the continuous monitoring of the dye tracer arrivals in different spots have enabled to build an increasingly detailed map of the different zones that recharge the Bossea karst aquifer.

The meteorological monitoring comprises air temperature and relative humidity variations, evaporation and condensation, and CO_2 levels. Rainfall and snowmelt are also measured above the cave, and the response of these infiltration events are recorded inside Bossea in different sites.

The study of the natural radioactivity of the underground environment is very interesting, because the cave is developed at the structural contact between the underlying Permian volcanic rocks and the covering Mesozoic carbonates. Radon (^{222}Rn) deriving from the radioactive decay of ^{238}U diffuses rapidly into the cave atmosphere and also into the percolating and flowing waters. The research relates to the dynamics of gas exchange between rock, water and atmosphere. Different types of instruments and dataloggers are tested in the cave for the detection of Rn in the water.

The biospeleological investigations have lead to the discovery of over 100 different species of cave dwelling fauna, making Bossea one of the most important biological hotspots in Italy.

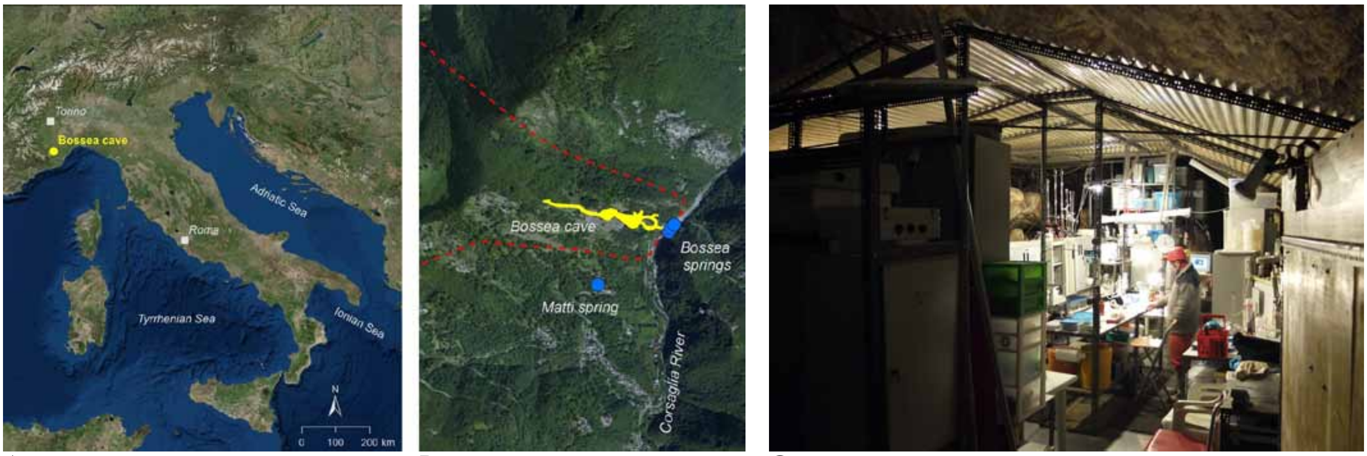
The laboratory is managed by the Scientific Station Bossea of the Alpine Club of Cuneo (CAI Cuneo) and the Central Scientific Committee of CAI in collaboration with the Polytechnical University of Turin (DIATI department). Unfortunately most scientific publications produced by this laboratory are in Italian and remain mostly unknown to a wider international audience.

Keywords: Underground laboratory, monitoring, biospeleology, hydrogeology, meteorology, radon

1. The subterranean laboratory and the Bossea Cave system

The underground laboratory in Bossea Cave has been installed in the years 1969-1972 by a group of volunteer cavers of the Speleological Group "Alpi Marittime" of the Italian Alpine Club (CAI) of Cuneo. This laboratory has been increasingly equiped over the years, progressively carrying out scientific research thanks to the continuous financial support of public administrations. In parallel, collaborations have started initially with the "Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture" (DIATI) of the Polytechnical University of Torino, later on also with the Environmental Protection Agency (ARPA Piedmont) of Cuneo, with the Dipartimento Radiazioni of ARPA Valle d'Aosta, with the Faculty of Nuclear Sciences and Physical Engineering of the Technical University of Prague, with the Marine Environmental Research Centre ENEA of Lerici-S.Terenzo, and last but not least with the Radiation Department of Ivrea (ARPA Piedmont). The originally called "Scientific Station" is now known as the "Underground Karst Laboratory of Bossea" (Laboratorio Carsologico Sotterraneo di Bossea), managed in equal parts by the Scientific Station of CAI Cuneo, the DIATI Department of the Polytechnic University of Torino, and the Central Scientific Committee of the Italian Alpine Club (CAI).

The Laboratory is built inside the Bossea Cave, along the tourist path used during regular visits by schools and visitors. The cave, situated in southern Piedmont in the Ligurian Alps (Fig. 1), hosts an underground river with flow-rates ranging between 50 and 1200 $L\ s^{-1}$ (Civita et al. 1984, 1990). This collector receives a series of small tributary flows that are representative of the fracture network that feeds the subterranean river (Vigna & Doleatto 2008).

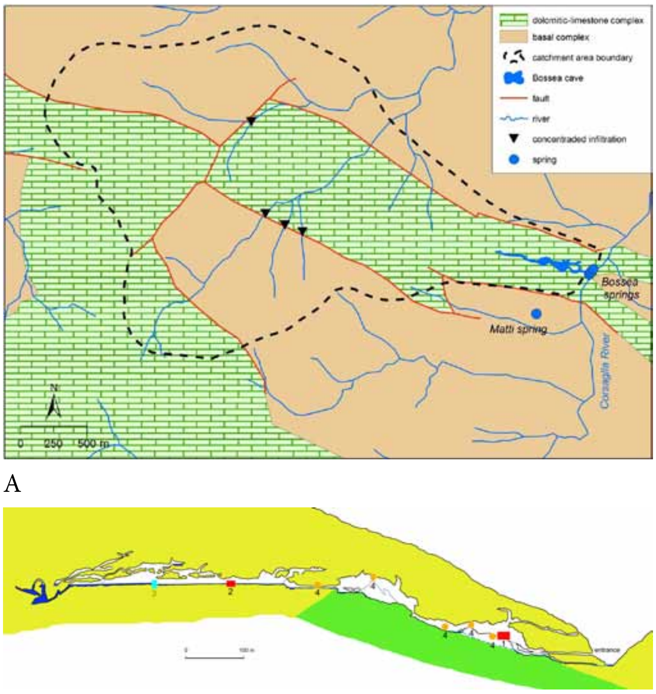


A B C

Figure 1. Bossea cave: A. Location of the cave in Piedmont; B. Cave map on an orthophoto. The dashed lines show the recharge area of the cave; C. The scientific laboratory inside the cave.

The karst aquifer is hosted in a Mesozoic carbonate sequence (limestones and dolomitic limestones) laterally confined by less permeable Permian-Triassic volcanic and quartzi-rich rocks (Fig. 2A). The contact between soluble rocks and the basement is through close-to-vertical faults (Fig. 1). This structural asset controls the both the surface and the subterranean drainage pattern in this area (Banzato et al. 2011). The surface drainage network is characterized by the presence of a series of small rivers (forming deep entrenched valleys in the metamorphic basement rocks) that lose their waters in swallets localised along the main tectonic contacts.

At present the Laboratory is composed of a main station located in the lower part of the cave (closest to the artificial entrance), a station deeper into the cave along the river, and a complex network of periferic station placed in different sectors of the cave (Fig. 2B). Research activities mainly develop along four branches: hydrogeology, hypogean meteorology, natural radioactivity, and biospeleology.



A

B

Figure 2. A. Geological sketch map of the karst aquifer of Bossea cave. B. Profile of the cave with the main monitoring stations: 1. Main laboratory, 2. Deep laboratory, 3. Hydrological weir, 4. Peripheric stations

2. The hydrogeological research

The study concentrates on the hydrodynamics and geochemistry of the waters flowing in the underground river and in the many small tributaries that are fed by the fracture network in the carbonate bedrock. The monitoring of the main subterranean stream started with continuous measurements in 1982, after the installation of a reinforced concrete weir in the downstream part of the cave (closest to the entrance). Water levels were initially measured with a float level sensor with analogue (paper) registration, substituted in 2000 by an automatic digital logger (Civita et al. 1984, 1990). Since autumn 2015 a new monitoring system has been installed that transmits in real time the acquired data with an interval of 15 minutes. This system measures water levels, temperature, and electric conductivity in the main flow and in one of the secondary tributaries. The waters of these two stations are brought through a network of tubes to the main laboratory where other measurements are taken. A series of sensors (electric conductivity, pH, dissolved oxygen, turbidity and radon) register their values on an hourly basis. An automatic water sampling device is used in some periods to study the variations of the main ions during the main recharge events (i.e. floods). Other waters (drips, different small tributaries) are sampled on a seasonal basis and analyzed in the laboratories of DIATI (Torino) (Fiorucci et al. 2015 a, 2015 b).

In this manner an enormous amount of data have already been collected, comprising some very special hydrogeological conditions such as long droughts with absence of rainfall over many months, and also extreme flood events (Civita et al. 2004). With over 30 years of activity and flow-rate measurements the mean annual depletion curve of the underground river has been defined in detail (Fig. 3). The variation in flow-rate of the collector in a typical hydrological year shows a winter base flow, reaching its minimal values caused by the snowfall and the low temperatures registered during this period (Fig. 4). This is followed by floods during springtime, lasting some months and caused by the melting of the snow, triggered also by rainfall. During summer the low rainfall amounts and the important evapotranspiration lead to low flow conditions in the cave, broken by sudden and

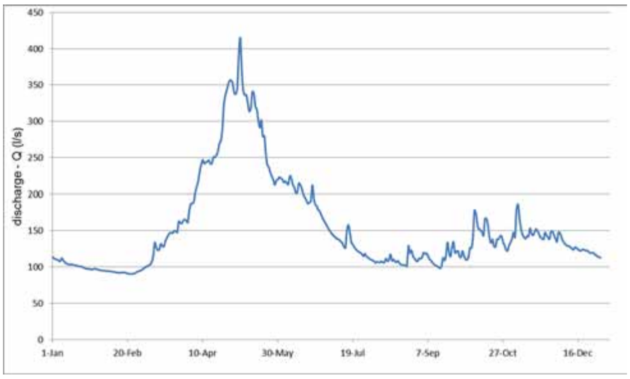


Figure 3. *The mean hydrological year of the main river based on 32 years of continuous monitoring.*

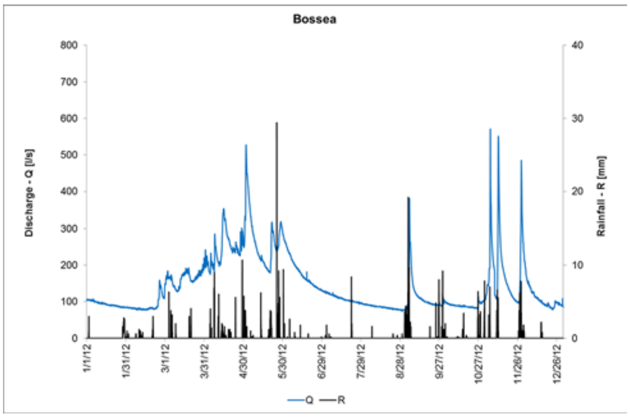


Figure 4. *Yearly variations in flow-rate and rainfall (for the year 2012)*

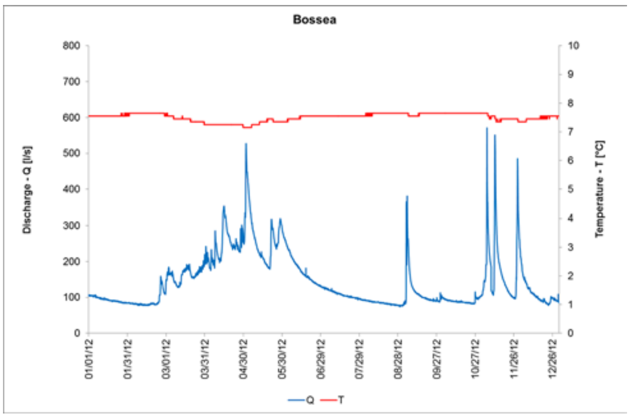


Figure 5. *Yearly variations in flow-rate and temperature (for the year 2012)*

short increases due to summer storms, normally toward the end of August and in September. In autumn the heavy rainfall, typically between end October and November, generate flood events that sometimes can cause the highest flow-rates in the underground river.

During the year the water temperature remains more or less stable, with excursions of less than 1°*C* during spring caused by the incoming melt-waters, and during autumn due to rain-waters (Fig. 5).

Also the electric conductivity values of the waters are more or less stable during the year, with only slight changes (around 30 $\mu S{\cdot}cm^{-1}$) during the flood periods (Fig.6). Mineralization

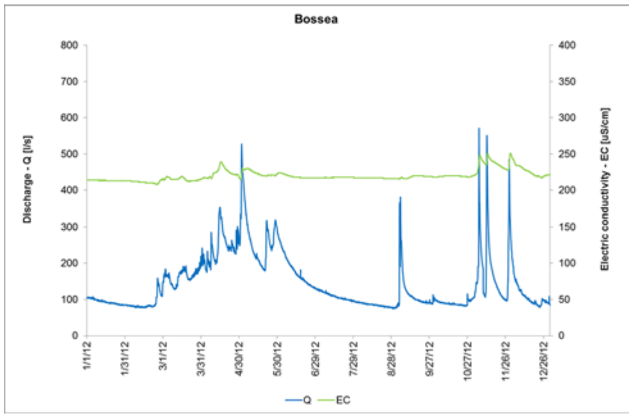


Figure 6. *Yearly variations in flow-rate and EC (for the year 2012)*

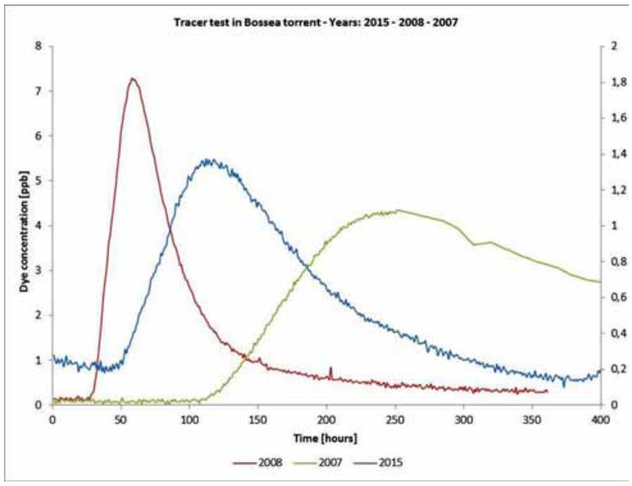


Figure 7. *Tracer breakthrough curve in the main underground river in different hydrodynamic conditions (base flow 2007, normal flow 2015, and flood 2008).*

of these waters is rather low, around values of 230 $\mu S{\cdot}cm^{-1}$, because part of the water derives also from the adjacent volcanic rocks.

A set of tracing tests and continuous monitoring of the dye tracer arrival at the monitored points have allowed to get insight into the hydrological behavior of the fractured karstified aquifer that feeds the various arrivals. The main sinking streams have been dye traced in different hydrological conditions, showing a rather

heterogeneous flow velocity of the main drainage routes comprised between 600 $m\ d^{-1}$ and 2.400 $m\ d^{-1}$ (Fig.7).

In the unsaturated fracture network the mode of water circulation is completely different from that of the main drains, with flow velocities ranging between 5 $m\ d^{-1}$ and 60 $m\ d^{-1}$.

3. The meteorological research

The meteorological research is tightly connected to the hydrogeological activities, monitoring the changes in the underground environment related to the arrival of infiltrating waters, especially the one caused by the snow melt above the cave. The climate of Bossea cave area, and the underground air flow, temperature and humidity are measured in connection with the changes observed in the collector. The main monitored parameters are air temperature, wind speed,

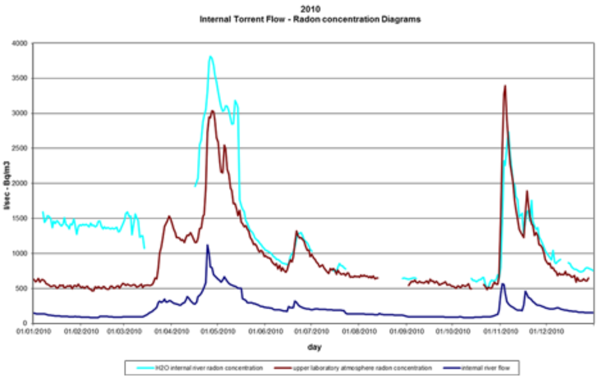


Figure 8. Mean annual flow-rate of the underground river, and radon concentration in air and in the water.

Figure 9. Eukoenenia strinatii *(Arachnida, Palpigradi). Bossea Cave. Ph. Valentina Balestra.*

relative humidity, evapo-condensation, and the concentration in CO_2, all measured in a continuous way, or through point analysis in different parts of the cave. These measurements aimed especially to control the impact of the visits on the cave environment.

In the area close to the cave entrance an experimental device that monitors the water volumes due to the snow melt has been installed since a few years (Vigna & Banzato 2012). In wintertime the area above the cave can be covered with over 1.5 *m* of snow. The commonly used rain gauges use a heating system that forces the snow to melt, and thus measures the quantity of snow that has fallen. In nature, however, snow stays on the ground for several months and snowmelt introduces water into the system in a more gradual way, and certainly delayed respect to the snowfall episodes. These experimental data, that measure the water deriving from the natural snow-melt, can be put in relation with underground flow in a much more detailed and realistic way.

4. Research on natural radioactivity in the cave environment

The study of the natural radioactivity in Bossea Cave has proven to be extremely interesting because the cave is bordered by Permian volcanic rocks. These lithologies, that are intensely fractured and broken, contain important concentrations in radioactive elements that, because of radioactive decay, cause higher levels of radiation than in normal caves. The natural decays of the U^{238} series causes Rn^{222} to be formed and diffused into the cave atmosphere and into the waters. In Bossea Cave forefront research is being carried out to understand the exchange of Rn^{222} between the rock, the water and the cave atmosphere. These studies are being carried out with the collaboration of several scientific organizations working in this specific field: the Radiation Department of ARPA Valle d'Aosta and ARPA Piedmont Ivrea, the Marine Environmental Research Centre ENEA of Lerici-S.Terenzo, and the Faculty of Nuclear Sciences and Physical Engineering of the Technical University of Prague. Fieldwork was made possible thanks to the availability of innovative monitoring equipment for the continuous measurement of radon in water. During this research interesting information has been obtained regarding the relationship between flow-rate of the underground river, and the release of radon from the rock's discontinuities (Peano et al. 2011). The data gathered has shown a strict relationship between radon levels measured in the cave atmosphere and in the running waters (Fig. 8). Following the spring floods the radon concentrations both in the air and water increase progressively. The peak concentrations in radon are reached around 7-10 days after the peak flow is measured in the cave river. This behavior can be put in relation with the piston flow phenomena that characterize Bossea's karst aquifer.

5. Biospeleological research

Biological researches have allowed discovering a wide variety of cave dwelling species, and Bossea cave is a biological hotspot of North Italy. Up to now 108 species (5 endemics) have been found in the karst system, making Bossea one of the best-studied caves of Italy from a biological point of view (Lana 2014, Lana 2016).

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(Abstract) 50th Anniversary of the UIS

Boris Watz

Abstract

This is a documentary film about 50 years of history of the Union international de Speleologie - UIS placed in a broader historical context of the history of the Speleology.

(Abstract) 16th ICS Brno

Boris Watz

Abstract

This is a short documentary film about 16th ICS in Brno 2013.

Procedure And Organisational Structures Of The Rescue In The Riesending Cave

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Abstract

The Riesending Cave (total length > 20 km / depth > 1100 m) is currently the longest and deepest cave in Germany. During Pentecost in 2014, a German caver had an accident caused by rockfall while ascending on a rope at a depth of 1,000 m and suffered a heavy traumatic brain injury. The first aid and the construction of a bivouac at the place of the accident by comrades stabilized the health of the injured and 14 hours later the alert reached the central office. The rescue of the injured individual required the construction and maintenance of wide ranging logistics around the headquarters, at the cave entrance, as well as in the cave itself. For the transport to the cave entrance on the plateau of the Untersberg, a fleet of 4 helicopter operators was used, conducted by the incident command that was provided with the building complex of the local fire brigade. The barracks of the military were provided for the logistics. The bi-national rescue team was continually extended up to an international team consisting of 7 rescue organisations from 5 countries. The patient was permanently looked after and provided for by physicians. For the stretcher transport, as well as the supply of food and material for the rescuers, an extensive rope installation was arranged and maintained inside the cave. Starting with a short initial and consolidation stage of the rescue effort, the patient reached the surface and was transported to an accident hospital after 12 days with the help of 728 rescuers.

Keywords: Cave rescue operation Riesending cave (Riesendingschachthöhle), - 1,000 m

1. Introduction

The Riesending cave, which currently has a length of 19.5 km and a depth of 1,148 m, is the longest and deepest cave in Germany. This very challenging cave has been investigated since 1996 by the caving group Arbeitsgemeinschaft für Höhlenforschung Bad Cannstatt. The entrance to the cave system is located on the plateau of the Untersberg near Berchtesgaden (Bavaria, Germany) and is only accessible following a climb of several hours or after approx. 45 mins from the Alpine Club mountain hut.

1.1. Accident event

Over the long Penetecost weekend in 2014, two groups of three and two speleologists respectively descended into the cave on the 7 June 2014. On Sunday 8 June 2014 around 1:30 am, a speleologist climbed up a rope and received a head injury from a rock fall at a depth of around 1,000 m. Consequently, he sustained a severe, traumatic brain injury accompanied by an immediate loss of consciousness. The injured speleologist was brought down from the rope, given appropriate, rudimentary first aid and bedded using materials from the nearest bivouac. A companion remained with the patient and provided care, including warmth. The third member of the team climbed out of the cave in 14 hours and alerted the need for rescue from the Alpine Club's mountain hut, the Stöhrhaus, on the Untersberg at 2:40 pm. The central rescue coordination centre Traunstein of the Berchtesgaden district was contacted.

1.2. Legal regulations for rescue in mountain regions and from caves in Bavaria

According to the Bavarian Law on Rescue Services, rescue missions in mountain regions and from caves are controlled by the Bavarian Mountain Rescue Services (Bergwacht). Since 1999, the Bavarian Mountain Rescue Services have had their own cave rescue division with eight cave rescue stations. In the caving areas of Northern and Southern Bavaria, people suffering injuries from accidents are regularly rescued from caves.

1.3. Initial phase (8 - 10 June 2014)

The rescue coordination centre at Traunstein alerted all local, mountain rescue teams on stand-by, and all cave rescue teams of the Bavarian mountain rescue services. Furthermore, all available helicopter units in Southern Bavaria were made ready for deployment.

To support the Bavarian emergency personnel, the cave rescue team of the Austrian cave rescue service (Salzburg region) was alerted, as were the Österreichische Höhlenrettung (Austria), Corpo Nazionale Soccorso Alpino e Speleologico (Italy), Hrvatska Gorska Služba Spašavanja (Croatia) and Speleo-Secours (Switzerland). Additionally, experienced speleologists were available who did not belong to any rescue organisation and could therefore only be deployed conditionally, for insurance reasons.

Further information regarding the condition of the injured individual was provided by the companions of the victim who reached the surface every 12 hours. They reported a deterioration in the state of the injured man's health.

The following points were of utmost urgency: stabilising the victim's condition, setting up a functional communication system between the head of operations – cave entrance – location of accident, providing the companions with provisions, and deploying rescue teams. Additionally, medical staff climbed down to the accident victim and installed Cave-Link

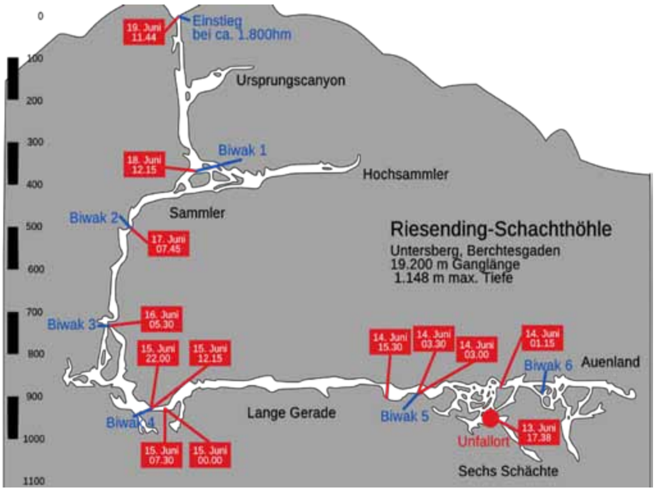

Figure 1. Timeline of the return transport. Graphics: Bad Canstatt working group of the Bavarian mountain rescue services.

devices in the cave. Technical staff improved the infrastructure at the cave entrance and laid a cable for a telephone system to bivouac 1 (- 380 m). A two-shift plan was established for the head of operations.

The head of operations was confronted by the following items regarding the further course of the operation.

- Would it be possible to re-establish the injured person's mobility?
- How long would the healing process take until mobility could be re-established?

A situation and logistics centre was set up in the valley in Berchtesgaden, in the Schellenberg district. It was set up on a green field and included landing space for helicopters to the cave entrance. The construction work was supported by the local fire brigade and was secured by the police. All transport to the cave entrance was accomplished by helicopter.

1.4. Consolidation phase (11 - 13 June 2014)

Positive feedback regarding the patient's state of health reached the surface, indicating the possibility of transporting him.

Increased development of infrastructure at the cave entrance and in the cave began immediately. On the surface, a shipping container was flown in by the Federal Armed Forces as a shelter for an emergency medical supply station, additional tents were set up, a helicopter landing site was manually stacked up, the communication system was further expanded and depots for material and supplies were established for the teams underground. Inside the cave, difficult passageways were neutralised through technical installations and cable hoists or pulleys were set up for the vertical and horizontal transport of the injured man.

On 13 June 2014 at 5:38 pm it was possible to begin the return journey, under constant medical supervision, of the now conscious patient.

A cave rescue team of the Bavarian mountain rescue services made up of six members was continuously on stand-by at the Stöhrhaus as an extra safety measure in case of secondary

Figure 2. Transporting the patient to the helicopter. Photo: Bavarian Red Cross, Berchtesgaden district.

accidents of the emergency personnel. In the event of weather conditions making helicopter flights impossible or causing failure of the communications system, the cable lift for goods and the telephone of the Stöhrhaus could have been used.

Due to the disruptions caused by the media, the head of operations was moved to the premises of the Berchtesgaden fire brigade and the emergency personnel were moved to the Bundeswehr (Federal Armed Forces) "Jägerkaserne" barracks. The cave entrance was secured by the alpine police and the Untersberg no-fly zone was cleared for the emergency flights.

1.5. Routine phase (14 - 19 June 2014)

Once the return transport of the patient began, the long waiting period for the involved parties finally came to an end. Depending on the situation underground, the systems of the Italian, Swiss or Bavarian rescue organisations were used. The material logistics had to be maintained over the course of the six day return journey and the rescue teams needed to be regularly replaced. The timetable can be inferred from Fig.1. The patient was conscious during the transportation and could partially assist the rescuers in narrow areas. On 19 June 2014 at 11:44 am, the patient reached the surface and was immediately examined by the emergency medical staff in the supply station which had been set up at the cave entrance.

After determining that he would be able to fly, the patient was transported to the waiting helicopter (Fig. 2) by representatives of all of the cave rescue organisations participating in the operation. He was then flown over the Stöhrhaus to the trade association's Casualty Hospital in Murnau – a very emotional and moving moment for all participating emergency personnel.

Subsequently, all rescue teams were withdrawn from the cave entrance to the valley; it was possible to partially carry out large amounts of material.

On the evening of 19 June 2014, the final briefing for all rescue organisations and the closing event in Berchtesgaden's Hofbräuhaus marked the end of the biggest operation in the history of cave rescues.

Figure 3. Closing picture from 19 June 2014. Photo: Bavarian mountain rescue service.

2. Operational structure

The operation was structured as follows under the general management of the Bavarian mountain rescue services:

- Head of operations for the valley, barracks, cave entrance and cave
- Staff: Foreign (Italian, Austrian, Swiss and Croatian) crisis intervention service,
- stress management following strenuous operations, 2-shift operation, 12-hour shifts,
- monitoring the emergency personnel, implementing preventive measures
- Logistics, barracks: Registry, accommodation, main materials depot, catering, medical supplies, helicopter landing area, fuel supply for the helicopter units, security area for helicopter transport, paymaster, purchases, acquisitions, packaging team, transport service, transport timetable for the foreign organisations
- Logistics cave entrance: Registry, accommodation, emergency medical supply station, material depot, catering, helicopter landing area, communications centre relay station valley-cave, electricity supply
- Logistics Stöhrhaus: Accommodation, cable lift for goods, helicopter landing area, redundant communication system
- Public relations: Press team, photography and film team, external press officer, Internet platform
- Police: Securing the operative unit and cave entrance, helicopter
- Fire brigade: Provisioning the operative unit, securing the operative unit
- Federal Armed Forces: Provision of the barracks, granting use of a transport container, airlifting the container, helicopter
- Support for the patient's relatives and for members and relatives of the research team: crisis intervention service, stress management following strenuous operations.

3. The patient's recovery

The patient was discharged from the hospital after 10 days for a three week rehabilitation programme. After finishing a six week reintegration programme, integration in the work process was concluded.

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Perceptions And Recommendations After The Cave Rescue In Riesending Cave

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Abstract

During the main phase, the rescue efforts in the Riesending cave exhibited a great impact on the local, as well as the international, community of cavers. The public argued about the reason and utility of speleology. The high costs for the rescue of one person that pursued an exotic hobby were pilloried on social media. Even in politics, measures for regulation were discussed. Furthermore, the pressures exerted by the media and financial interests did not contribute to relieve the rescuers.

Retrospectively, many lessons were learned internally regarding the operational command of large-scale operations. The cooperation of international rescue teams, the local rescue organisation Bergwacht Bayern (Bavarian Mountain Rescue) and first aid in cave rescue. External advisers proved to be of valuable assistance for example in the interaction with the press and relieving stress from the rescue personnel. Sufficient insurance has become a topic more important than ever for each individual caver.

Keywords: Cave rescue operation, Riesending cave (Riesendingschachthöhle), perceptions and recommendations

1. Introduction

The Bavarian Mountain Rescue Services and the Verband der deutschen Höhlen- und Karstforscher e.V. (VdHK) (German Speleological Federation) would like to thank all participating cave rescue organisations for the accident-free implementation of the entire operation. From the perspective of the head of operations of the Bavarian Mountain Rescue Services and the VdHK's executive board, the most important results of these eventful weeks in June 2014 were rescuing our companion from a depth of 1,000 m, the integrity of the emergency personnel, the safe return of all participants and the quick recovery of the patient.

The perceptions and recommendations arising from this rescue operation at the Riesending cave can be separated into two phases:

2. Situation during the main rescue phase (8 - 19 June 2014)

2.1. Responsibility

Rescues in mountains and from caves are regulated in the Bavarian Law on Rescue Services. Accordingly, the Bavarian Mountain Rescue Services are responsible for rescues from Alpine terrain and caves as per the Bavarian Law on Rescue Services (BayRDG).

Alerting the foreign cave rescue organisations

Irrespective of the good European networks between speleologists, in cases of rescue or catastrophe, cross-border relief efforts are variably regulated. The Bavarian Mountain Rescue Services are obliged to observe the legal regulations.

Measures for alerting foreign organisations

Immediate contact was established with the relevant Bavarian Ministry of the Interior to request foreign support. Accordingly, requests for support were made, via the committees of the Federal Government, to the Interior Ministries of the respective countries.

Considering that the accident occurred over a long weekend, many employees of the government agencies were on leave. Due to the time constraints, the offered assistance was accepted on site by the head of operations (at their own, personal responsibility!).

Recommendations for alerting foreign organisations

A cross-border agreement in the EU regarding alerting, implementing and reimbursing rescue operations is urgently needed. The appropriate sections in the EU are already working on a pan-European solution. It is necessary to further develop contacts between national speleology and cave rescue associations in Europe. In addition to exchanging alarm lists and standards for materials and rescue techniques, regular cross-border rescue exercises will improve cooperation for future operations.

2.2. External communication: Media and public relations

The accident occurred during the holiday period in 2014, before the start of the civil war in Syria and the Football World Cup in Brazil. Due to the fact that there were no other major current events worldwide, the accident in the Riesending cave was exploited by the media and circulated globally. Even in the first days, all sectors of the national and international media overwhelmed the patient's relatives, the families of the research team's members, the official representatives of the German Speleological Federation and the members of the head of operations on site. With the full spectrum of the media industry's legal and illegal tricks (offers of money, attractive reporters, unlawful entry etc.), attempts were made to generate final statements and rating enhancing headlines.

One newspaper chartered a helicopter, landed it directly in front of the cave entrance and, in this way, blocked the operation for several hours. At the same time, the fine for ignoring the no-fly zone was accepted. Reporters tapped telephones and cellular phones. Information regarding the drug administration for the patient was published in the biggest German daily newspaper. Headlines were freely invented. Towards the end of the operation, five broadcasting vans transmitted the incident live from the operation centre.

Countermeasures

The patient's relatives and family members of the research team were shielded by the police at their homes. A spokesperson of the VdHK was made available to the press on the sidelines to answer *speleological questions* regarding the purpose of speleology and the high costs of the rescue via email and by telephone. Additionally, specialist articles were published in the print media. The executive board additionally answered questions personally in interviews on site. A spokesperson from the Bavarian Mountain Rescue Services, together with the head of operations, was available daily at 2 pm to answer *technical questions* regarding the rescue operation during a press conference. This information was expanded through in-depth background discussions. After several days, the pressure from the media continued to increase and a desire to inspect the head of operations was voiced. This request was granted. Due to the lack of pictures from the current operation, the press requested that photographic and video footage be made of the ongoing operation. A team of professional cameramen from the Bavarian Mountain Rescue Services was established. The photographs and film material obtained in this way were made available to the media. Under the circumstances, it was particularly difficult to present the situation on the ground and the related activities that were required (access, position of the cave entrance, challenging cave, long and profound transport routes, no cell phone coverage) to the press in our highly technological times. The site of the head of operations in the valley was secured with a privacy fence, additional fire engines and the police. The area surrounding the cave entrance was secured by the alpine police and the flight area around the Untersberg was cleared for transport flights.

Recommendations for media and public relations

- It would be sensible for representatives of professional associations and rescue organisations to attend continuing education on correct, professional interaction with the media.
- An external media consultant is a valuable support, especially with regards to unpleasant topics.
- When there is nothing to report, it is possible to keep the media busy by, for example, visiting a show cave or a rescue team which is not currently in operation.
- Do not try to conceal anything. Submit transparent reports and be available for regular press conferences during longer operations as measures to increase reliability and confidence in the operation and the actors.
- Supply the press with approved photographic and film material from the current or older operations, or exercises respectively.
- Should reporters use unfair or illegal methods, it may be sensible to implement tactics such as expulsion from the premises or exclusion from press conferences.
- Isolate the emergency personnel from harassment and disruption from the media. The barracks in Strub (suburb in Bischofswiesen, Berchtesgaden) was optimal for this operation. However, even a football field, as was used in the operation at the Frickenhöhle cave in April 2016, is suitable for the head of operations and rescuers to work undisturbed.

2.3. Internal communication of the cave rescue organisations

The operation began as a monolingual, German, activity, but was expanded to include Austrian German, Swiss German, Italian and Croatian by the end of the operation. A major problem included the partial English language deficits for a common communication language.

Countermeasures

For communication with the Italian colleagues, a bilingual colleague from the Southern Tyrol mountain rescue was organised. Thanks to his language abilities, this problem was resolved quickly. Daily discussions took place with the head of operations of each cave rescue organisation – separately after the respective demands, several times a day or combined in one session. The operational orders were transcribed and the rescue teams were briefed regarding their duties. Other foreign rescue organisations were not requested to assist due to the language barriers.

Recommendations for communication between cave rescue organisations

Multi-lingual, written operational orders with verbal instructions have proven to be practical. Language differences can obstruct the deployment of cave rescue organisations. Therefore, a dictionary for cave rescues is required in both global languages: English and Spanish.

2.4. Problems for emergency personnel on the ground

When an alert goes out, members of rescue organisations feel the urge to actively participate in the situation under any circumstances. This was the case with individuals during this operation. Unfortunately, blind action and a lack of structural readiness did not lead forward in this case. Only structured work, the only strategy with no alternatives, is the path to success. During the clean-up work, large quantities of strong pain killers were found in the cave. Deployment under the influence of medication or alcohol is forbidden in Germany.

Countermeasures

It was necessary to disciplinarily insist on active inactivity (i.e. waiting until deployment was granted on location). Some emergency personnel were sent home immediately due to insubordination.

Recommendations for problems with the emergency personnel

There is only one head of operations for every operation. This structure and the decisions made must be acknowledged and complied with. In severe cases, the personnel in question must be immediately discharged from the operation. In the case of substance abuse, the organisation must emphasise the consequences (lapse of insurance coverage in case of accident or injury) of such actions.

2.5. Handling the Internet and digital platforms

During the course of the operation, an indignant social media storm broke out regarding the expected high costs of the rescue as well as the purpose of speleology in general. Unfortunately, pictures and films of the patient in the cave, as well as information regarding the operation were uploaded onto the Internet, bypassing the head of operations. The legal basis for the operation is the Bavarian Law on Rescue Services. Among other things, the rescue organisation is bound by law to keep the accident victim anonymous.

Countermeasures

There is very little that can be done to avoid a "shit storm" on the Internet. Expert arguments can and must be placed in all media; however this measure takes a very long time to be successful.

Recommendations for handling the Internet and digital platforms

The Bavarian Mountain Rescue Services have made some deductions from the experience of uncontrolled dissemination of data and information in the Internet. During and since the operation at the G7 peak in Garmisch-Partenkirchen in 2015, private dissemination of photographs, films and information on the Internet or digital platforms is strictly forbidden with an indication of the penal consequences. Foreign rescue organisations will be expected to recognise the local laws unconditionally and in writing during future operations.

2.6. Closure and reduced access at the Riesending cave

Demands for caves to be permanently closed or access to them reduced were already being made during the operation by the public and the authorities. The cave entrance to the Riesending cave was closed briefly with a grille after the operation.

Recommendations against closure and reduced access

An access regulation was established as a compromise to the permanent closure in order to allow for scientific research to continue. The work inside the cave may continue with reasonable conditions for speleology.

3. Situation following the main phase of the rescue (20th of June 2014 - to date)

After the closing event for all rescue staff in the Berchtesgaden Hofbräuhaus and the subsequent homeward journey, the operation officially ended for the public. For the Bavarian mountain rescue services and the VdHK there has not been a moment's pause since 20 June 2014. Neither this operation nor its consequences have been concluded to date. Returning the materials from the cave, invoicing for the operation, regular processing of questions from the media, the industry and the public, as well as from lobbyists for cave rescue and research characterise the activities.

As the responsible rescue organisation, the Bavarian mountain rescue services settled all bills and demands in full from the participating national and foreign organisations.

3.1. Perception in the media, politics and the public

Thanks to the spectacular rescue operation, speleology has reached the German media, politics and the general public. The Bavarian Mountain Rescue Services' lobbying and that of the VdHK is not being questioned in any way. As a consequence of the global media coverage, the patient, some of the members of the research group, members of the head of operations as well as the executive board of the VdHK have completely lost their anonymity. Regularly, around the anniversary of the incident, press and presentation requests pile up.

3.2. Commercial exploitation of the rescue

Even during the operation, attempts were made on the part of the media to profit economically from the incident. The members of the research team and the Bavarian Mountain Rescue Services are not available for a screen adaptation of the rescue, or for any other commercial exploitation.

3.3. Publications from participating and non-participating organisations

To our great surprise in Germany, we became aware of two foreign publications from the internet regarding the operation. Considering that no coordination took place with the Bavarian Mountain Rescue Services or that no approval from them exists, the principle of confidentiality still holds according to the Bavarian Law on Rescue Services.

Another publication regarding the operation was produced by Christian Dodelin in the UIS Bulletin in January 2015. The depiction of the operation which is given in this report does not correspond to reality. The author neither participated in the operation nor did he request information regarding the operation from the participating organisations.

Recommendations for publications following an international operation

In general, foreign organisations who work for a national rescue organisation are bound to the latter's legal sovereignty. The legal regulations of the country in which the accident occurs are valid. It is not only a matter of courtesy, even the international speleology codex demands consultation and approval from the local and involved rescue organisation for publications.

4. 3. Outlook

What tasks resulted for the active speleologist?

- Basic education and regular training in transit techniques, companion rescue, structured and prudent fieldwork under ground
- Joining a cave rescue organisation
- Safeguarding against accidents in advance with insurance, assets and property

- In Germany, the insurance industry does not provide satisfactory insurance coverage for caving accidents. This insurance gap was partially closed by a solidarity fund established by the VdHK. On the basis of solidarity, organised speleologists voluntarily pay a once-off amount into the fund which is then paid out in the case of insurance gaps. The fund only pays out if the individual member made a contribution. With regards to the claim from the Riesending cave rescue, no payment was made.
- Activespeleological research requires speleologists who can act autonomously.

What tasks result for the national organisations (associations and federations)?

- Offering education and training opportunities
- Bringing in offers for insurance and redistribute them as group insurance to the association/speleologists
- Establishing a national solidarity fund
- Increasing lobbying
- Exchanging all contact details of the cave rescue organisations
- At the political level, pressure must be put on the national government to establish cross-border regulations in case of an operation
- Establishment of a European/global cave rescue fund.

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