VOLUME 49 2024 ISSUE 107

Helictite

Journal of Australasian Speleological Research

Tham Kammatan,
Central Laos

Published by Australian Speleological Federation
ISSN: 2652-483X (Online)

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Journal of Australasian Speleological Research

ISSN: 0017-9973

Helictite was established in 1962 by its foundation editors, Edward A. Lane and Aola M. Richards. It is intended to be wide ranging in scope from the scientific study of caves and their contents, to the history of caves and cave areas and the technical aspects of cave study and exploration. The territory covered is Australasia – Australia, New Zealand, the near Pacific Islands, Papua New Guinea and surrounding areas, Indonesia and Borneo.

In 1974 the Speleological Research Council agreed to support the Journal with financial assistance and in 1976 took over full responsibility for its production. From 1974 to 1997 the Journal was edited by Julia James assisted by other members of the Speleological Research Council Ltd. In 1998 Susan White and Ken Grimes took over as editors with Glenn Baddeley as Business Manager. Stefan Eberhard joined the editorial team in 2003.

In 2000 ownership was transferred to the Australian Speleological Federation, Inc. (ASF) and the Journal is administered by the Helictite Commission of the ASF.

Greg Middleton took over as Chief Editor in 2016. The accidental death of Ken Grimes in August 2016 led to further changes in editors, with Tim Moulds and Kevin Kiernan taking on the role.

The aim of the Helictite Commission of the Australian Speleological Federation is to publish the results of scientific studies in all fields of speleology in *Helictite – Journal of Australasian Speleological Research*.

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Helictite

AUSTRALIAN SPELEOLOGICAL FEDERATION

Journal of Australasian Speleological Research
VOLUME 49 2024

Contents

Cover: Tham Kammatan; gallery with phreatic profile in the northeastern sector. Photo by Liviu Valenas.

Helictite, Volume 49, 2024 consists of single issue.

Helictite is published by the Australian Speleological Federation Inc.

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Editorial

Greg Middleton

A sincere thank you to our reviewers.

Journals like *Helictite*, which publish peer-reviewed papers, rely on reviewers to help maintain high standards of writing, accurate information, appropriate scientific procedures and good current awareness of issues and views across relevant disciplines.

Helictite has a policy of not disclosing the names of its reviewers to authors or anyone else. This is mainly to protect the privacy of the reviewers and save them from 'correspondence' from potentially, at times, disgruntled authors. It is also likely that annonymous reviewers will be less likely to feel intimidated and more likely to give 'frank and fearless' advice when reviewing manuscripts.

As a not-for-profit academic journal, *Helictite* is not in a position to provide any financial rewards to its reviewers but it is appropriate that, from time to time, we acknowledge the essential contributions that these individuals make and thank them for the time and effort that they contribute to the journal.

The following have undertaken the thankless task of reviewing one or more papers in the years since I took over the role of Chief Editor of *Helictite* in 2016:

Steve Bourne

Richard Cosgrove

Grant Dixon

Brian Finlayson

Julian Hume

Julia James

Kevin Kiernan

Anne McConnell

Jo McDonald

Anne Musser

Gilbert Price

Chris Sharples

Susan White

On behalf of the Editors, I most sincerely thank all these individuals for their invaluable contributions towards maintaining the high standards of the journal (and do hope that they will be prepared to step up again if called upon at a future time).

Helictite, (2024) 49**:** 1-10

Geomorphology and hydrogeology of Tham Kammatan – a tectonically-modified epiphreatic cave from Central Laos

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Abstract

Tham Kammatan is an extremely complex cave, with a very large epiphreatic maze. The 3,905 m of mapped galleries of Tham Kammatan lie within distance of only 336.5 m, which gives this cave a branching coefficient of 11.6. Tham Kammatan is a network arranged on two levels that communicate with each other. The cave has 20 entrances. Tham Kammatan is an interesting cave, especially in view of the successive stages of its formation: from phreatic, to epiphreatic and then to the fossil stage. The formation of the cave is the almost exclusive result of water table oscillations. The galleries are arranged on a tectonic pattern, but also on stratification faces. Active tectonics also played a role in the formation of the cave, especially of the Great Tunnel and the Roots Hall.

INTRODUCTION

Location

Tham Kammatan is located in the province of Khammouane (Figure 1) in the vertical south-east wall of Pha Soung Mountain (in translation: "The mountain that touches the sky"), 1,820 m west of the village of Ban Na Phondou and 1,675 m W-NE of the village of Ban Nahouangoua, at an altitude 156 m (Figures 2, 3).

Figure 1. Administrative map of Laos, showing provinces. Khammouane is located just south of centre.

Physical data

The cave has a total length of 3,905 m, a vertical range (VR) of 36 m (-6; +30) and the distance between extreme points is 336.5 m, giving a branching coefficient of: 11.6 (Figure 4).

Figure 2. Map of Khammouane province. Pha Soung Mountain is within the rectangle numbered '1'.

History of Investigation

The cave, as a natural access tunnel to the closed basin of Kouan Moo, has been known for centuries by the inhabitants of the villages of Ban Na Pondhou and Ban Nahouangoua. This is verified by the 16 golden statues discovered by Mehdi Boukhal and Liviu Valenas in 2018 in the cave of Tham Pha Kouan Moo (Valenas 2019b, 2019c, 2020), dating from the time of the famous King Setthatirath, who reigned in Laos between 1548 and 1571. This ancient underground temple is located opposite Tham Kammatan. In 2016, the cave was re-discovered by Liviu Valenas and the team he led as part of the SPELEO LAOS 2016 expedition. However, it was not until 2019 that the exploration and actual mapping of this imposing cave began. That year, the lower level was largely explored and mapped, over a length of 2,106 m. The results of the 2019 explorations were a surprise, because no one expected that in addition to the large natural tunnel, there would be an extensive maze (Valenas 2019).

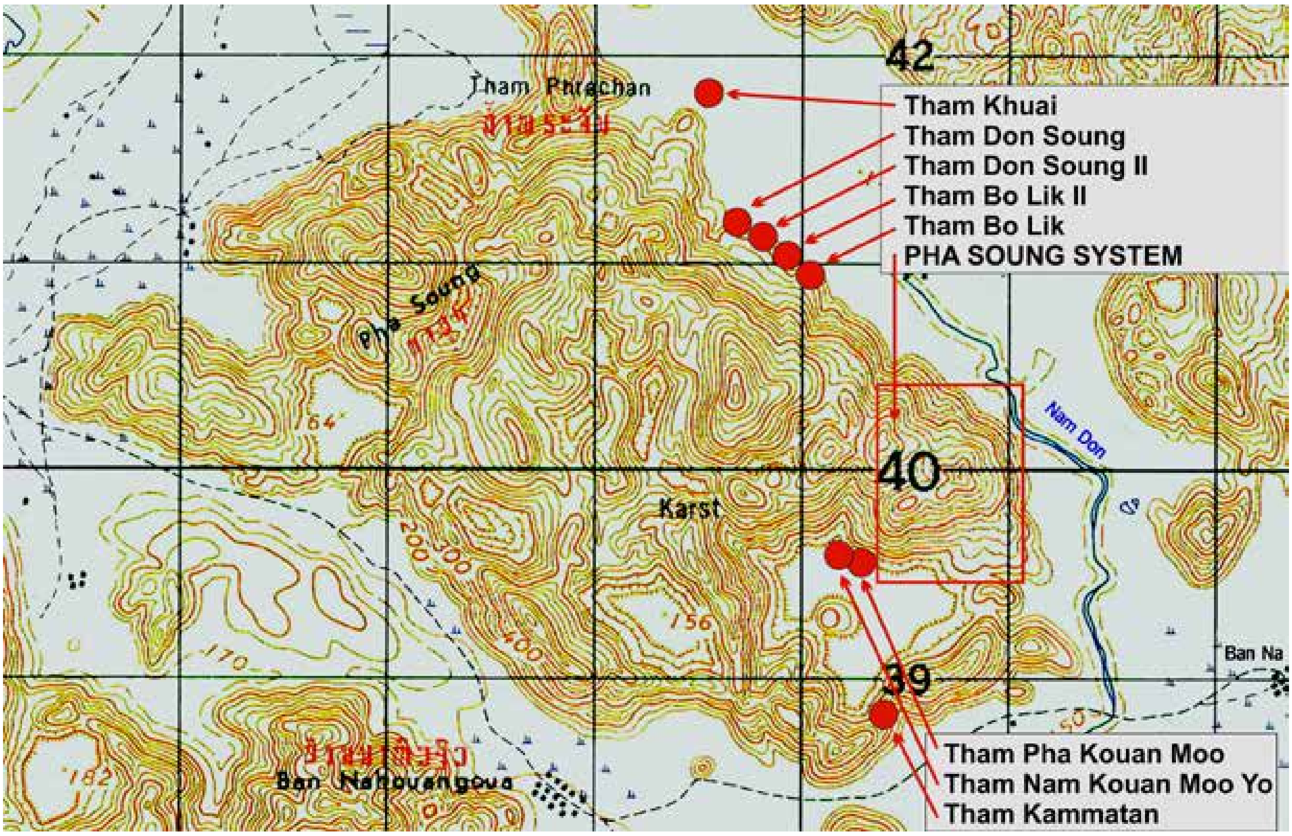

Figure 3. US military topographic map from 1965, showing Pha Soung Mountain (maximum altitude 630 m). Tham Kammatan is located near the southeastern end of this mountain (near northing numbered '39').

Also in 2019, Jean Philippe Dégletagne filmed the Grand Tunnel (Figure 5) with a drone, and also the massif in which the cave lies. In 2020, as part of the SPELEO LAOS 2020 expedition, the upper level, with two long and relatively difficult sectors, was discovered. The new total length of the cave went to 3,631 m. The "engines" of the explorations in 2020 were Paul Mackrill and Liviu Valenas. In 2023, the exploration of the upper level continued (Valenas, 2023a, 2023b, 2023c, 2023d) and during the last expedition, SPELEO LAOS 2024, the mapping of some small sectors of the lower level was completed, the length of the cave reaching 3,905 m (Valenas 2024a, 2024b, 2024c).

Climatology

On the lower level, in the area of the suspended lakes, on 19 February 2024, a temperature of 20.8°C and an air humidity of 84% were measured. On the upper northeast floor in the terminal area on 8 March 2023, the temperature was 22.7°C and the humidity was 95%. A temperature difference between the upper and lower levels is common to many caves in Laos. The high temperature in this north-western sector of the cave proves only one fact, the gallery where the temperature and humidity were measured has no continuation (it ends in the "bottom of the bag") and the hot air accumulates in this sector. In contrast, the relatively low humidity (for a cave) in the lower floor is a direct consequence of the 20 cave entrances, which provide continuous ventilation.

DESCRIPTION

It is difficult to describe an extreme maze cave, which has a total of 20 entrances. In short, all the galleries of the cave are arranged around the Great Tunnel, which connects terrace No. 1 of the Nam Don River to the closed basin of Kouan Moo. At the base of the vertical south-eastern wall of the Pha Soung mountain ridge is the main entrance, with a width of 42.5 m and a maximum height of 20 m. The eastern entrance has four other secondary entrances to the southwest and three more to the northeast. The Great Tunnel is near horizontal, 140 m long and with a maximum width of 61 m. The exit to the northwest is represented by two large entrances, one of 35 x 15 m, the other of 16 x 15 m (Figure 6). To the northeast there are three other slightly smaller entrances. The Great Tunnel is full of very large boulders. It is most likely that active tectonics produced these major collapses, and has resulted in this great underground space.

From the Great Tunnel, a smaller side room branches off to the south, from which a straight gallery oriented north-south starts, which ends abruptly after 131 m (Figure 7). From this gallery

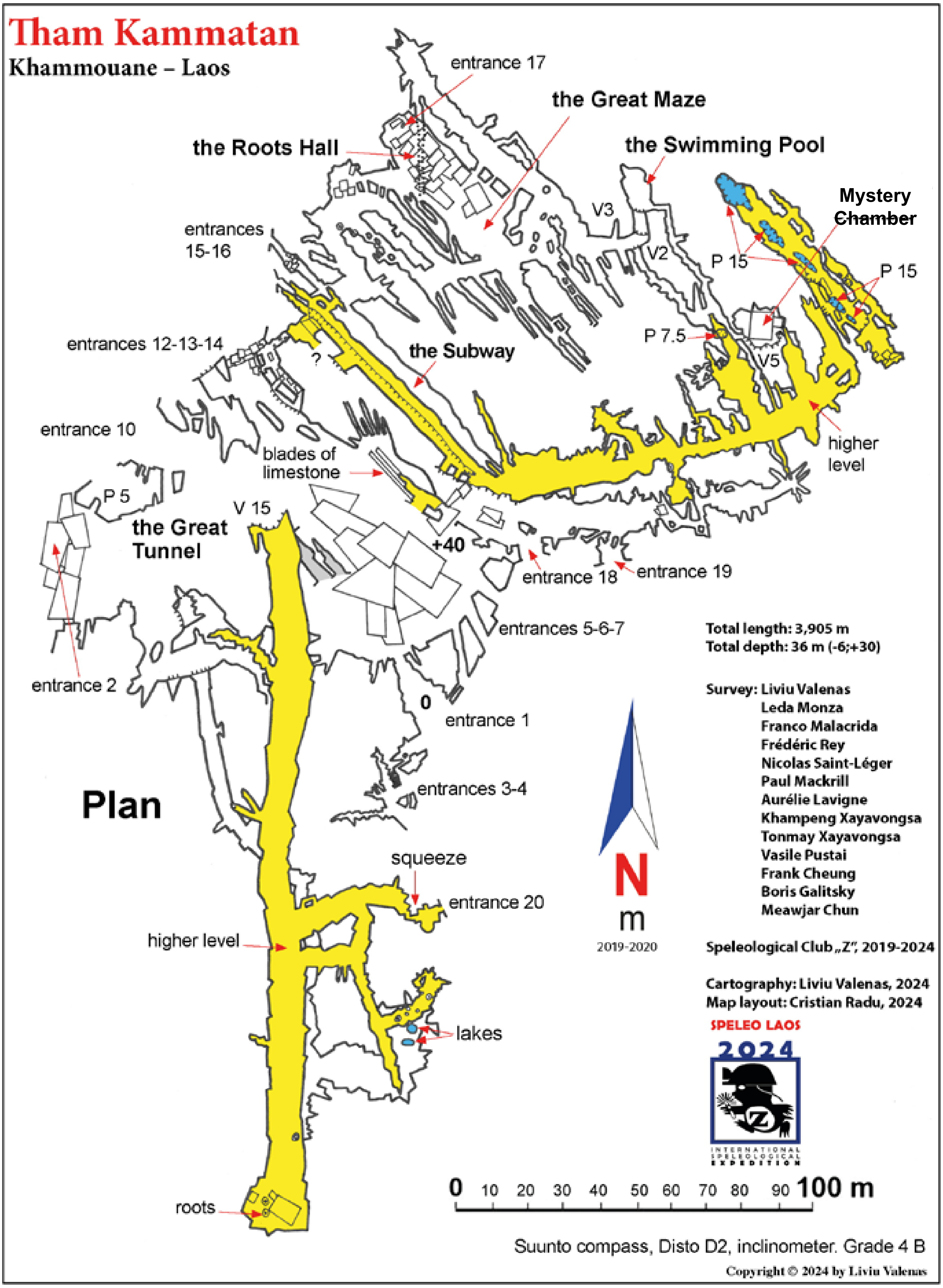

Figure 4. Plan of Tham Kammatan. Cartography by Liviu Valenas

branches off another gallery, oriented SW-NE, which contains beautiful concretions (Figures 8, 9) and three hanging lakes. From this sector, a vertical ascent of 7 m allows access to the upper level, which after 40 m presents a large straight gallery, 195 m long. The gallery has large sections, on average 10 x 10 m. The southern part ends with collapses; several roots clearly show that these are close to the surface. The northern part of the 195 m gallery opens onto the ceiling of the Great Tunnel.

Figure 5. The Great Tunnel of Tham Kammatan.

Figure 6. Tham Kammatan, entrance No. 10, a northwest exit of the Great Tunnel.

Figure 7. Tham Kammatan; the end of the lower gallery, facing south.

Figure 8. Tham Kammatan; cave pearls in the lower gallery, facing south.

Figure 9. Tham Kammatan; the beautifully decorated terminal room in the southern sector.

Also from the Great Tunnel, at the base of the northeast wall, begins the Subway Gallery of medium size (Figures 10 and 11), initially straight, but then zigzagging. This is a gallery with a generally triangular section (Figure 12), in the living rock, clearly a phreatic pressure tunnel.

Figure 10. Speleothems in the Subway Gallery.

At 165.5 m from the Grand Tunnel, the Subway Gallery leads to the Roots Hall (also full of large boulders), measuring 52.5 x 15 x 20 m (Figure 13). In the ceiling, in the terminal part of the room to the northwest, a small entrance casts a ray of light. Two or three 15-17 m long roots descend from the ceiling. Taking into account the distance to the surface and their length in the room, this means that these roots have an impressive length of between 40 and 45 m! From the Roots Hall begins a large phreatic loop, with several narrow and clayey portions (including a 6 m deep pit that leads to the water table) which after 254.5 m opens again to the surface, at entrance No. 19, in the immediate vicinity of the northeast entrance of the Great Tunnel. In the middle of this large loop, there is a side room, filled with enormous boulders, the Mystery Chamber (32 x 14 x 25 m).

Figure 11. Tham Kammatan; fine speleothems in the Subway Gallery. Photo by Leda Monza.

Figure 12. The Subway Gallery of Tham Kammatan, demonstrating its triangular section. Photo by Leda Monza.

Figure 13. Tham Kammatan; extreme phreatic forms in Roots Hall. Photo by Leda Monza.

From entrance No. 19 a horizontal gallery extends towards the west. After 40 m, rising vertically for 7.5 m and after another ascending part, the upper eastern floor is reached. It divides from the beginning into two branches. The northwest branch is an absolutely straight gallery, on a large fault, 80 m long. It communicates by a 15 m pit with the Great Tunnel. The branch that goes towards the east is much more complicated. It has numerous side galleries (cover, Figures 14 and 15), all oriented to the northwest and after 140 m it opens into a canyon, also oriented to the northwest. It has 5 pits 20 m deep that end in deep lakes, corresponding to the water table. The canyon is 72.5 m long and represents the definitive end of Tham Kammatan towards the northeast.

Figure 14. Tham Kammatan; the main gallery in the northeastern sector, with typical phreatic forms.

I believe that Tham Kammatan has been explored almost completely, but there are still galleries with small and very small sections, especially on the upper level, which could add a few hundred meters, but probably no more. It should also be mentioned that due to the relatively isolated geographical position, a junction between Tham Kammatan and other caves in the region (including the large Pha Soung System, located only 630 m to the north in a straight line) seems highly unlikely. It should also be noted that in 2019, filming with a drone on Pha Soung Mountain, just above the cave, did not reveal any potholes among the tsingy leading down to Tham Kammatan.

Figure 15. Tham Kammatan; the main gallery in the northeastern sector, with typical phreatic profile.

LITHOLOGY AND TECTONICS

Tham Kammatan has developed in Carboniferous limestones (Workman 1977, Ponta & Aharon 2014). The limestone layers have an inclination between 15° and 20°. The bedding faces played a relatively important role in the creation of the cave. The tectonics on which the galleries of Tham Kammatan rest are quite complicated. The main system of fissures and faults is oriented SE–NW. This system is mainly responsible for the maze character of the cave. A second system of fissures is somewhat perpendicular to the main system. Finally, a major fault, oriented North-South, allowed the creation of the 195 m long straight gallery in the upper western system and the gallery located below it.

The Tham Kammatan has also been strongly affected by active tectonics. Active tectonics manifest themselves in extremely varied ways, from sectioning (through vertical or horizontal mini-faults) of galleries and pillars, to massive collapses. In the immediate vicinity of the Tham Kammatan, the author from 2023 discovered clear forms of active tectonics in the Pha Soung System (Figure 16) and in the Tham See Don Soung and Tham Sia caves (Figure 17). Sectioned columns or pillars were found in these three caves. The vertical displacement was constant: 15 cm, and horizontally 9 cm.

Figure 16. Pha Soung System; rock pillar sectioned by active tectonics.

Apart from these sections, massive collapses occurred in all the caves in the area. After our field research, we estimate that 15,000 to 10,000 years ago in the Ban Na Pondhou area, a massive earthquake occurred. We believe this earthquake was directly responsible for the large collapses that formed the Great Tunnel, Roots Hall and the Mystery Chamber in Tham Kammatan.

GEOMORPHOLOGY AND GENESIS

The genesis of Tham Kammatan is directly linked to the hydrology of the closed basin of Kouan Moo. During the monsoon season, it is directly supplied with water by the Pha Soung system (by the resurgence of Tham Nam Kouan Moo). The waters in this closed basin found an outlet in the present Tham Kammatan Cave. At this point, the southeastern slope of Pha Soung Mountain is only 140 m wide and the height of the ridge is the lowest. In other words, the morphology and arrangement of the southeastern ridge of Pha Soung Mountain are directly responsible for the formation of Tham Kammatan. Initially, the cave was an epiphreatic network, located about 15 m above the present zero level of the cave. The stepwise descent (due to climatic oscillations from the Middle Pleistocene to the Late Pleistocene) of the Nam Don River fossilized the first level of the cave and a second, the present lower maze level, formed (Figure 18). Currently, it is clear that a third level has formed, corresponding to the phreatic table of the area, a level that is completely submerged. The Great Tunnel, which connects the closed basin of Kouan Moo and the first terrace of the Nam Don River, was initially formed. The waters that formed a very large lake in the closed Kouan Moo basin found an exit to the Nam Don River. This flow occurred in the phreatic zone. It therefore corresponds to the first epiphreatic level. Massive collapses on the stratification faces (disturbed by the major fault oriented N-S) have made the direct connection between the two distinct levels of the cave. These collapses are also a consequence of the active tectonics that are evident in the Ban Na Pondhou region.

Figure 17. Tham Sia; a sectioned column demonstrating active tectonics.

The eastern part of the cave is also typical of littoral caves type, because the formation of maze galleries in this sector is the consequence of

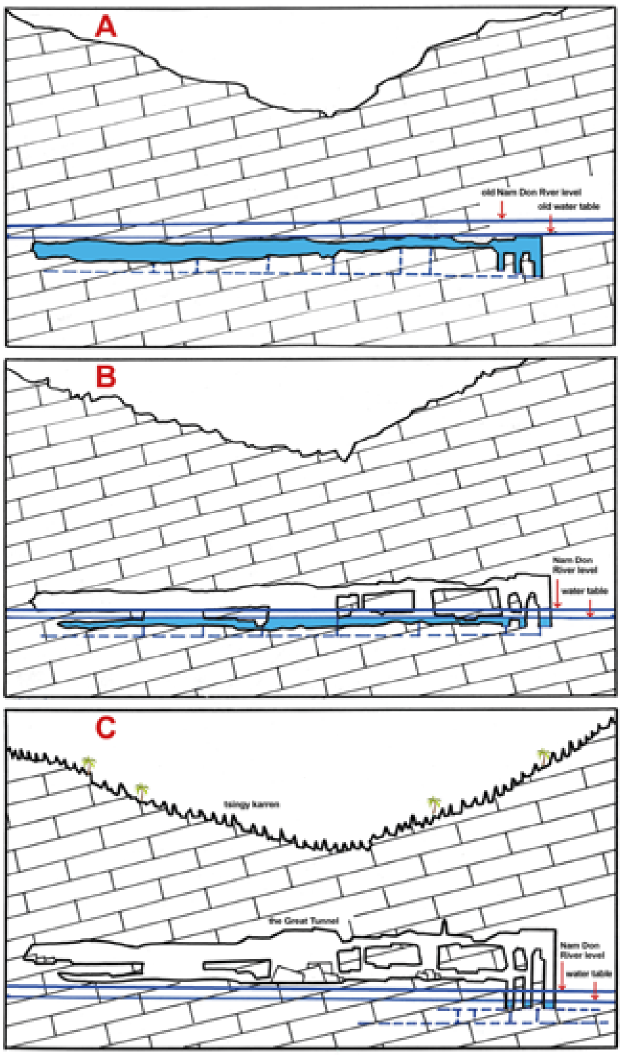

Figure 18. The stages in the formation of the epiphreatic labyrinth and the Great Tunnel of Tham Kammatan. A: Middle Pleistocene, B: Upper Pleistocene, C: Upper Pleistocene-Holocene. Graphic by Liviu Valenas.

the high level of the Nam Don River during the monsoon season (which during these 4-5 months floods the cave up to a height of 6 m, exceptionally up to 9 m). Tham Kammatan shows no evidence of vadose remodeling, which once again indicates the purely phreatic and epiphreatic genesis of the cave. An important, if not the most important, role in the formation of Tham Kammatan was played by the water table. The progressive descent of this water table is directly responsible for the horizontality of the galleries and the development of the cave on three levels. Between the two horizontal levels and the third completely submerged level (corresponding to the current water table of the area), the connection is made by pits up to 20 m deep. These are the so-called “phreatic loops”, described by Ford (1965, 1968, 1971) for the first time in the Mendip region of England, and then found all over the world. The 2019 drone image, mentioned earlier, clearly showing no entrance, sinkhole or potholes above Tham Kammatan, but only tsingy-type limestone pavements, is further evidence that the cave was formed exclusively in the epiphreatic regime, by the waters of the closed Kouan Moo Basin and the waters of the Nam Don River.

HYDROGEOLOGY

During the dry season, Tham Kammatan does not carry vadose flow. However, at lower levels there is circulation in the phreatic zone. This is evident from several pits in the northwestern sector, up to 20 m deep (the depth depending on the level of the water table) (Figure 19).

Figure 19. Tham Kammatan; the final canyon in the northeast sector. The canyon has five 20 m deep pits, which reach the water table.

The entire cave reflects the oscillations and the descent in stages, from the Middle Pleistocene to the present day, of the water table, fed directly by the Nam Don River. It cannot be excluded a priori that all the flooded wells of the cave communicate with each other and probably also with the flooded wells of the caves of Tham Pha Kouan Moo and the Pha Soung system. This is exactly how the cenotes of Yucatán in Mexico communicate with each other, creating a huge maze system, completely submerged. Unfortunately, until now, no cave diver has been interested in the submerged pits in the three caves mentioned above, so we do not know what the development of this drowned system may look like on the right of the Nam Don River. During the monsoon, the waters that flood the closed basin of Kouan Moo flow through the Great Tunnel, flood other galleries and then flow into the Nam Don River, which at that time has a maximum width of 3.25 km. It is also worth mentioning that three beautiful small lakes in the lower southern level (Figure 20) are fed exclusively by percolation water. These lakes, up to 1.5 m deep, have no connection with the current water table, being suspended above it.

Figure 20. Tham Kammatan; suspended lake in the southern sector of the cave.

CONCLUDING REMARKS

The area where Tham Kammatan is located was and is affected by active tectonics. Until the author's research carried out in Laos on this phenomenon, no one seriously dealt with the active tectonics of the caves in this country. Unfortunately, even today, many geologists and geomorphologists deny the role of active tectonics in the formation and evolution of caves. Although, since the 1960s, Polish karstologists have clearly shown that active tectonics have intervened and are constantly intervening in the formation of natural underground spaces. Their research has generally been carried out in the Western Tatras of Poland (Grodzicki 1970). Since 1980, the author has also intensively dealt with active tectonics, in the karst of the Romanian Western Carpathians (Valenas 1981, 1982, Valenas & Iurkiewicz 1981). Active tectonics manifest themselves in extremely varied ways, from sectioning (through vertical or horizontal mini-faults) of galleries and pillars, to massive collapses.

The horizontality of many caves in Laos has not been explained by speleologists who have worked in this country, or it has only been attributed to a structural factor. In reality, the horizontality has been determined almost exclusively by the gradual descent of the water tables. Most of the large caves in Laos are at terrace No. 1 of rivers or closed basins, including poljes. This is an essential difference compared to Europe or North America, where the largest caves are suspended above level 0. In the province of Khammouane, almost all large caves are horizontal and are located at absolute altitudes of 150-180 m, at the level of the current hydrologic network. This fact also shows that the age of the caves in Laos cannot be lowered below the Middle Pleistocene. The evolution of the caves located at the level of the valleys is continuous, and currently an even lower level is being formed – a completely drowned, phreatic level, which corresponds to the current water tables.

ACKNOWLEDGMENTS

I have to thank from the bottom of my heart the residents of Ban Na Pondhou village who helped us explore this difficult cave. Thanks to the village mayor, Khampeng Xayavongsa and his son, Tonmay Xayavongsa, who took part in many explorations in Tham Kammatan and helped me with the topography of the impressive maze.

Best wishes to the former mayor of Ban Na Pondhou village, Bunmin Pimachen, who was the first to lead us to this interesting cave in 2016. Thanks also to Somkiad Pineth, who, as the person responsible for tourism in the Khammouane province, very kindly issued us all the authorizations necessary to carry out the research.

Thanks also to the police and army officers in the area, who provided exemplary support to our speleological expeditions. For the computer graphics, my thanks to Cristian Radu and Eugen Kamp.

Photographs, unless otherwise attributed, are by Liviu Valenas.

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Moonmilk: Sample analysis and review of the literature

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Abstract

Moonmilk is a relatively common speleothem that usually has the appearance of a white clumpy substance or a thin coating on cave surfaces. It is defined by its appearance and physical properties, not its composition. This paper reviews the properties of moonmilk, as well as the definition, including its physical characteristics, composition, phosphorescence and origin. A review of historical references to moonmilk reveals that many conflicting research conclusions have appeared in publications over the years, and that it is difficult to identify how moonmilk is created.

Analyses of several moonmilk samples from NSW caves are presented that confirm just how variable moonmilk can be. A sample from Victoria, confirms that even rare minerals can be deposited as Moonmilk. Future research will no doubt shed further light on aspects of moonmilk's formation.

What is moonmilk?

Moonmilk is a secondary mineral deposit formed within caves (a speleothem), although it is not found in all caves. Most cavers have probably seen clumps of soft white material on cave walls or floors, but never thought much about it. Experienced cavers may generalize and refer to all white fluffy-looking material in caves as 'moonmilk', but the novice who has never seen it before, will be none the wiser. This is where a definition may help:

"Moonmilk is a term used to describe aggregates of microcrystalline substances of varying composition" (Hill and Forti 1997a). A particular morphology and texture, not composition, is implied by the term 'moonmilk'.

Physical properties

Moonmilk consists of fine-grained particles, and is typically soft and mouldable when damp. When wet, it looks like white cream cheese and is pasty when rubbed between the fingers, but if just moist it may feel like fairy floss (cotton candy). When dry it can be crumbly and resemble chalk or talcum powder. Moonmilk in caves typically retains a high water content, thus giving it plasticity, but when moonmilk is mixed into water, the fine particles become suspended and the mixture looks like milk.

Figure 1. Kevin Mott surrounded by moonmilk in cave 5L-339, South Australia. Photo by Garry K. Smith

Figure 2. Henry Shannon has a close look at moonmilk in cave 5L-339. Photo by Garry K. Smith

Moonmilk can be found as just a thin coating on cave surfaces or in layers many centimetres thick, as in 5L-339 cave (in South Australia's Lower South-East) where moonmilk has formed on the walls and ceiling (Figures 1 & 2). Some chunks of moonmilk up to 5 cm thick have naturally fallen or been dislodged by humans or animals and now lie on the floor (Smith 1995, 2007). Moonmilk is a very fragile speleothem that can be easily damaged, so cavers must be careful as carelessness or intentionally touching it can cause irreparable damage, as has occurred in parts of 5L-339 cave (Smith 2007).

Most moonmilks are white or cream in colour, however it can occur in other colour variations including black. It can be formed in the shape of shawls, stalactites, stalagmites, columns, flowstone, coralloids and even as cave pearls. Most occurrences are found in subaerial locations (Figure 3), however there are a number of occurrences where it has formed in permanent pools of still water e.g. Cataract Cave, Prince of Wales Island, southeastern Alaska, where balls of moonmilk, locally called "cottonballs", up to 10 cm in diameter have formed (Hill and Forti 1997a).

Figure 3. David Stuckey and Marcia Kaye in the Moonmilk Chamber of Stable Cave (A26-27), Abercrombie, NSW. Photo by Garry K. Smith

Composition

In limestone caves moonmilk usually consists of calcium carbonate ($CaCO_3$) in the form of calcite or aragonite, while in dolomite caves it is typically hydromagnesite, $Mg_5(CO_3)_4(OH)_2 \cdot 4(H_2O)$. Moonmilk can consist of many other carbonate minerals, either singularly or in combination. Less frequently it may consist of sulphates, phosphates, silicates and other minerals, particularly in non-carbonate caves (Hill and Forti 1997a).

Phosphorescence

Moonmilk typically possesses the property of luminescence, but more specifically, phosphoresence. Luminescence is the glowing (emission of light) of an object due to an increased energy level of its atoms, occurring without perceptible heat. The electrons orbiting the atom's nucleus can be excited by radiation (such as light from a camera flash or by electricity) and this radiation can be re-emitted at any wavelength, though is most familiar as visible light. Two forms of luminescence are "fluorescence" and "phosphorescence". Fluorescence is when light is emitted during absorption of radiation of some other (invisible) wavelength, but stops when the energy source is removed. Phosphorescent material can store the absorbed light energy (usually visible light) for some time and release light later (usually at a different wavelength - that is to say, colour), resulting in an afterglow that persists when the initial energy source has been removed.

Moonmilk's phosphorescent properties can be observed with the naked eye in a cave. The trick is to turn off all lights, cover your eyes with your hand while an electronic flash is set off close to and pointing toward the moonmilk. Make sure not to physically touch the moonmilk while in the dark. Immediately after the electronic flash is fired, take your hand away and look at the moonmilk. In most circumstances it will glow a bright green or blue for several seconds and in some cases up to 7 seconds (Smith 1995) as was the case in cave 5L-339, and also in Belfry Cave (TR-2), NSW (Smith 1996). The moonmilk remains glowing as its atom's electrons, with increased energy from the bright flash of light having moved them to higher orbits, then emit light as they return to their normal orbits around the nuclei.

If the moonmilk is of a very porous nature, the phosphorescent glow appears to last longer as the light from the camera flash and re-emitted light bounces around inside the moonmilk structure.

Historical references and medicinal uses of moonmilk

The likely first written reference to moonmilk in a cave was by Ko Hung about 300 AD (Shaw 1992). Agricola (1546, p. 465) described material that was probably moonmilk (which he called *galactites* = milk stone). Conrad Gesner (1555) provided a very clear description of moonmilk from a cave in Switzerland named Mondmilchloch (Moonmilk Cave) but he called the substance *fungus petraeus* (stone fungus) while recording that the locals called it *mondmilch* (Shaw 1992). Since then many articles have been written, discussing this material's properties and speculating about its origin.

Heller (1966) determined through literature searches that at least 79 names have been used to describe the speleothem moonmilk. Among them are *montmilch* gnomes's milk, *lac lunae*, *bergmilch* and rock milk.

Over the centuries humans have used moonmilk for medicinal purposes with various degrees of success as a remedy for many aliments and conditions including: haemorrhages, diarrhoea, dysentery, malignant fevers, to dry up ulcers and to stop wounds bleeding.

Origin of Moonmilk

Both biotic and abiotic mechanisms have been proposed to explain the formation of moonmilk. They include the effects of freezing, disintegration of bedrock or speleothems and microorganisms causing the material to precipitate.

Many studies have been undertaken which conclude that microbes, bacteria and/or other microorganisms are involved in the creation of moonmilk. A study by Danielli and Edington (1983) investigated the role of microbes in the formation of moonmilk. They isolated a wide range of colony types (the majority of them Gram-negative cells) from three caves in Wales, where calcite moonmilk was a common occurrence. These authors suggested that the cells were using the organic salt (negatively charged ions) for energy and dumping the calcium as a waste product. Calcite precipitation occurred when the solution saturation point was exceeded.

A study by Gradziñski and others (1997) that found *in vitro* culture of collected samples involved numerous genera of bacteria and fungi forming the microbial mat of moonmilk deposits. They concluded that, “The so called ‘knallgas-bacteria’, belonging to the chemoautolithotrophes, seem to play decisive role in calcification processes” and that other genera support the mineralisation processes.

A wide range of microbes, particularly bacteria and streptomycetes, but also fungi, algae and protozoa, can be cultured from moonmilk, often in very high densities (Northup and others 2000). However a later paper by Northup and Lavoie (2001) reviewing available literature concluded that “The evidence that microbes may play a role in formation of moonmilk is largely circumstantial and based on presence”.

Northup and Lavoie (2001) also noted that, “Putative cells and an organic matrix can frequently be seen with SEM or in thin sections, but not in all cases. There is no known benefit of calcium carbonate precipitation in bacterial metabolism, although detoxification of calcium has been suggested (Simkiss 1986).”

However, culture studies have demonstrated the ability of bacteria from caves to precipitate calcium carbonate. The wide variety of physicochemical conditions and mineral types that have been identified indicates that microbes are clearly involved in the formation of moonmilk by dissolution or acting as nucleation sites, and they may play a minor or negligible role in other cases (Northup and Lavoie 2001).

A study by Borsato and others (2000), determined that moonmilk samples collected from 14 caves in the Italian Alps (1500 - 1900 m asl.) were created through crystal growth triggered by slow degassing of solution and capillary flow under very low discharge. The optimal microclimatic conditions for the formation of calcite moonmilk in the caves they studied were temperatures of 3.5-5.5°C and relative humidity that is at or close to 100%. “Available evidence from these deposits indicates that microbes did not play a direct role in the calcite precipitation” of the moonmilk. The calcite crystals making up the moonmilk, ranged between 50 and 500 nm wide and 1 to >10 μm long.

Hill and Forti (1997a) list four methods by which moonmilk may originate:

1. *Freezing of limestone by water ice causes carbon dioxide to be expelled from the limestone, and a milky fluid is produced on the limestone wall.* (However, they accept that this method of moonmilk creation would only apply to caves which experience temperatures that drop to below freezing point.)

2. *Moonmilk is formed as part of the life cycle of microorganisms. Species of bacteria, algae and fungi have all been isolated from moonmilk deposits.* (As previously mentioned, the existence of microorganisms in moonmilk samples does not automatically imply the organisms played a part in its creation. There is still much research that needs to be undertaken to conclusively determine the role of various life forms.)

3. *Moonmilk is a disintegration product of bedrock or speleothems (i.e., it is a rotten concretion).* (This method of moonmilk creation has only been attributed to a very few documented instances and typically does not stand up to the analysis of most moonmilk deposits.)

4. *.... Moonmilk precipitates directly from groundwater as do other speleothems such as stalactites and stalagmites, but that, for some reason, the crystals in the deposit never grow large.* (This theory explains the majority of moonmilk deposits, particularly the magnesium carbonate minerals, that

> naturally form as finely microcrystalline to cryptocrystalline deposits. However this theory does not readily explain calcite and aragonite moonmilks that form as microcrystalline or cryptocrystalline deposits. This is contrary to the typical deposition of these two minerals that usually form large crystals when deposited as stalagmites and stalactites etc.)

Forti (2009) suggests that microbiological reactions frequently seem to be responsible for moonmilk deposition by: "1. biochemical corrosion of bedrock by organic acid produced by microorganisms (*Arthrobacter, Flavobacterium, Pseudomonas)*; 2. active precipitation of moonmilk by bacteria (*Macromonas bipunctata*)." Bacteria that utilize CO_2 (like *othrix* in the sulphur cycle) have been found to cause accelerated carbonate speleothem growth.

Given the many conflicting research conclusions that have appeared in publications over the years, it is impossible to identify a single cause for the formation of moonmilk. No doubt there is still much research to be undertaken before science can fully explain how different moonmilks are created.

SEM and XRD analysis of moonmilk from NSW caves

Twenty pea-size samples of moonmilk were collected by the author from caves across NSW. Samples collected in National Parks were covered under an agency permit, while those from private property required permission from individual owners. Scanning Electron Microscope (SEM) images were prepared and chemical analyses were undertaken by Brian M. England (Principal Geological Consultant) at BHP Billiton Research Laboratories in Newcastle, NSW (England 2000).

Part of each original sample was prepared as a fresh fracture surface, coated with a layer of gold (around 40 nanometres thick) and examined by SEM to determine its morphology (England 2000). This data was recorded as micrographs, both as hard copy (Polaroid prints) and digital images. Some of these very high resolution SEM images are reproduced here. Analysis of each sample was achieved by X-ray powder diffraction (XRD), using a Siemens D500 diffractometer and then Fein-Marquart Associates µPDSM search/match software was used to interpret the pattern and determine its mineralogy. Part of each sample was then analysed by energy dispersive X-ray spectrometry (EDS) on a scanning electron microscope (SEM), to determine its chemical composition, especially the presence of major impurity elements such as strontium, manganese and iron, which may influence growth and morphology.

Many of the moonmilk samples were of similar needle-like shape and size as shown in Figure 4. Some other variations of moonmilk fibres are shown in Figures 5 to 11.

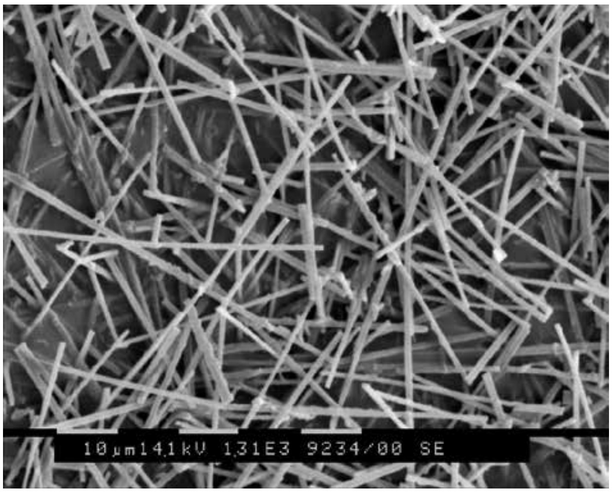

Figure 4. Moonmilk from Barber Cave (GP14), Cooleman Plains NSW. Average fibre size is ≈1.4µm (0.0014 mm) wide. The sample only contains calcium carbonate. Image by Brian England

Figure 5. Moonmilk from B4, Kunderang Brook, NSW. Calcium carbonate strands are approx. 7.08µm (0.00708 mm) thick. Image by Brian England

All images are greatly magnified under an SEM. Note the many variations in shape of the microcrystalline to cryptocrystalline crystals. Out of many samples collected across NSW, there was only one sample which clearly showed evidence of being produced by a life-form, most likely bacterial. The calcite micro-structures are tubular with a spiralling shape (Figure 10).

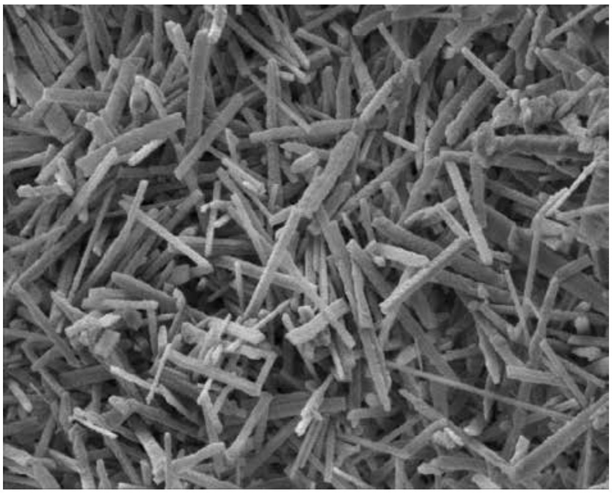

Figure 6. Moonmilk from Rock-me Cave (TR52), Timor, NSW. The thickest fibre in this photo is ≈ 2μm (0.002 mm) wide. The sample only contains calcite fibres. Image by Brian England

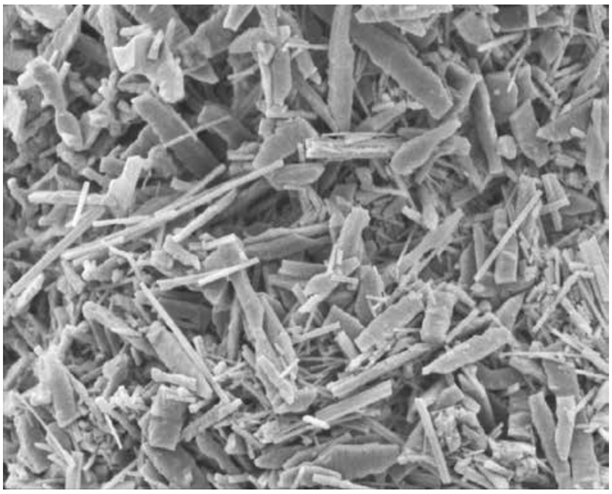

Figure 7. Moonmilk from Rock-me Cave (TR52), Timor Caves. The thickest calcite fibres of moonmilk are ≈ 4μm (0.004 mm) wide. Image by Brian England

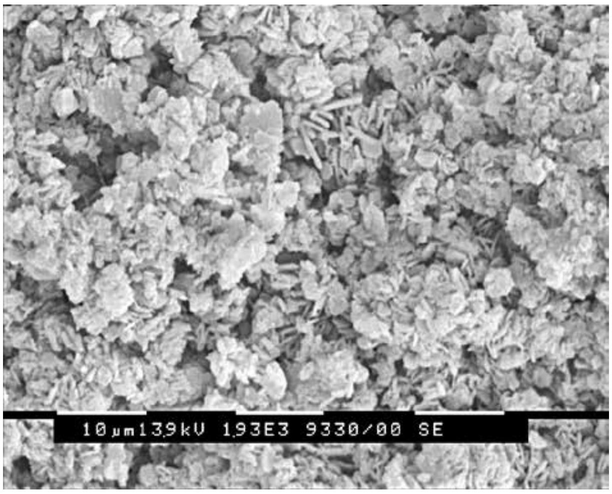

Figure 8. Moonmilk from Wiburds Lake Cave (J58), Jenolan NSW. White section on scale bar is 2μm (0.002 mm) long. Image by Brian England

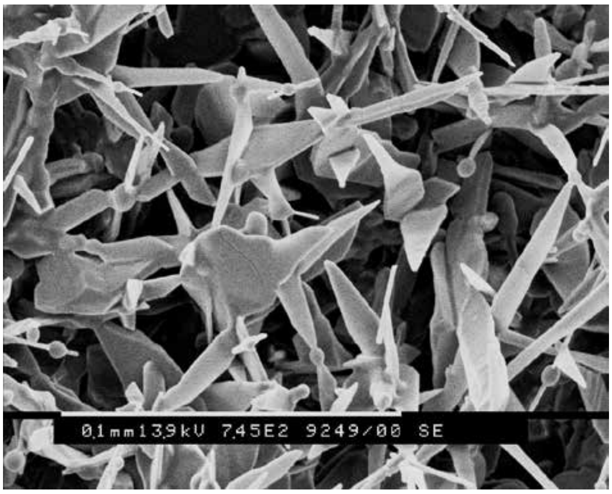

Figure 9. Moonmilk from Punchbowl Cave (WJ8), Wee Jasper. Analysis indicates that the majority of this sample is calcite, however some calcium sulphate hydrate (Gypsum) CaSO4.2H20 is also present. The largest calcium carbonate fibre of moonmilk in photo is approximately 24.3μm (0.0243 mm) wide. No Gypsum is present. Image by Brian England

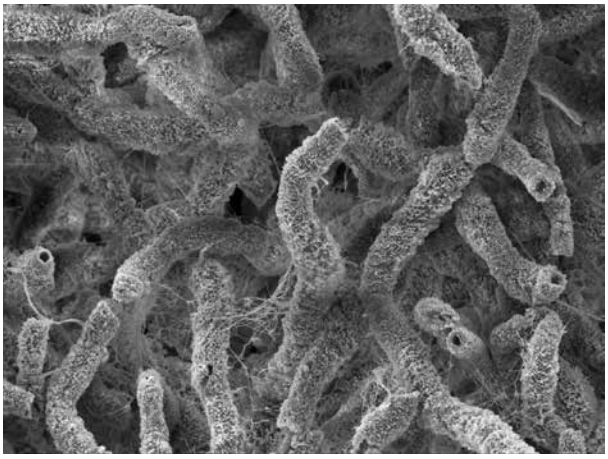

Figure 10. Moonmilk from Moses Cave (MP7), Moparrabah NSW. Image width is 250μm (0.25mm). Sample that indicates a biological influence in the creation of moonmilk. Each of these worm-like hollow structures are approximately 20μm in diameter with a 3.8μm hole in the middle. Image by Brian England

Figure 11. Moonmilk from Mammoth Cave (J13) Jenolan NSW. Sample contained both calcite and aragonite. Fibrous calcite strands are approximately 1.5μm thick. Image by Brian England

Most samples consisted of calcite with no trace of aragonite. From the 20 samples, only one from Deep Hole at Walli (WA-17), showed aragonite to be present as a major phase.

The results of a sample collected from Mammoth Cave (J-13), NSW clearly showed that the sample contained both calcite and aragonite (Figures 11 & 12). One could assume that the rice-grain size speleothem was first deposited as aragonite and over thousands or millions of years, the outside crystal structure changed to calcite while the internal crystal structure remained as aragonite. The external appearance of the sample kept the needle-like shape of the original aragonite (England 1997, Smith 1997).

In addition to the abovementioned samples from NSW limestone caves, a pee-size sample of moonmilk was collected from amongst the floor scoria of Tunnel Cave (3H-9) a lava cave at Mt Eccles, Victoria. Although the look and feel of the moonmilk was the same as the samples collected from limestone caves, the analysis revealed that it was a rare mineral called Taranakite, $K_3(Al,Fe)_5(HPO_4)_6(PO_4)_2 \bullet 18(H_2O)$ (Figures 13 & 14) (England 1999). This is a good example of how the term moonmilk applies only to morphology and texture, not composition.

Figure 13. Taranakite, $K_3(Al,Fe)_5(HPO_4)_6(PO_4)_2 \bullet 18 (H_2O)$, moonmilk from Tunnel Cave (3H-9) a lava cave at Mt Eccles, Victoria. White section on scale bar is 2µm (0.002 mm) long. Image by Brian England.

Discussion: $CaCO_3$ polymorphs

Calcium carbonate has three polymorphs: calcite, aragonite and vaterite. This means that all three of these minerals have the same composition ($CaCO_3$), however they crystallise with different atomic structures. Vaterite is rarely found in caves because it requires temperatures above 35°C to form. On the other hand calcite is the most abundant, since cave temperatures and pressures fall completely within its stability field.

Aragonite is the second most common mineral in caves after calcite. Because cave temperatures and pressures fall below the range at which aragonite crystallises, it theoretically should not exist in caves. However it does form even in caves at high altitude where the temperature approaches 0°C. Given enough time (thousands to millions of years) aragonite will change its internal crystal structure to calcite, while externally keeping the needle-like shape of the original aragonite (Hill and Forti 1997a).

It is now generally accepted that the presence of magnesium (Mg) and\or strontium (Sr), in the precipitating solution is the prime factor which influences aragonite deposition in preference to calcite (England 1984). However another factor that may cause aragonite to precipitate is the degree of supersaturation with respect to the rate of CO_2 loss from the solution.

In 1971, Fishbeck and Müller found that when the Mg/Ca ratio reached about 2.9:1, aragonite is the main calcium carbonate mineral to form, and at a ratio of 4.4:1, it is the only calcium carbonate mineral to form. Evaporation of the precipitating solution (rather than carbon dioxide loss) has a large effect in determining which $CaCO_3$ polymorph or magnesium carbonate mineral is deposited. Ironically, the magnesium ion is excluded from the aragonite crystal structure. One theory is that the magnesium ion poisons the crystal growth of calcite, allowing the supersaturation level to build up to the point where aragonite can precipitate (Hill and Forti 1997b).

Conclusion

Moonmilk consists of microcrystalline particles that can vary considerably in shape and composition. As moonmilk has four known modes of creation it is almost impossible without thorough research, to identify how an *in-situ* moonmilk has formed in a cave. The texture and feel of moonmilk can vary considerably depending on its moisture content. Also the mineral composition can't be determined merely by observation or from its location in a cave.

The presence of microbes in analysed moonmilk samples, is not a basis to automatically assume that they have played a role in its creation. There is still much research to be undertaken before science can fully explain how different moonmilks are created.

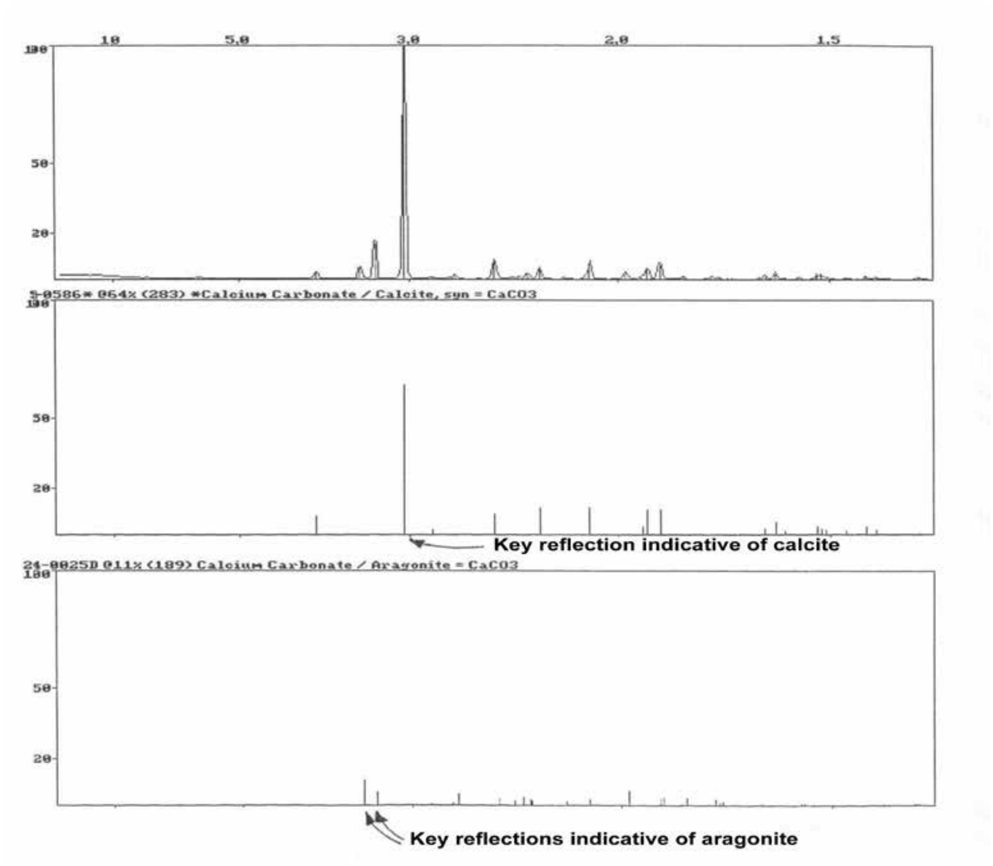

Figure 12. Moonmilk analysis by X-ray diffraction (XRD), using a Siemens D500 diffractometer and then Fein-Marquart Associates µPDSM search/match software to interpret the pattern.

The first chart shows the actual X-ray reflections from the atomic lattice structure. The second chart is the normal X-ray pattern for Calcite. The third chart is the normal X-ray pattern for Aragonite.   Graphs by Brian England.

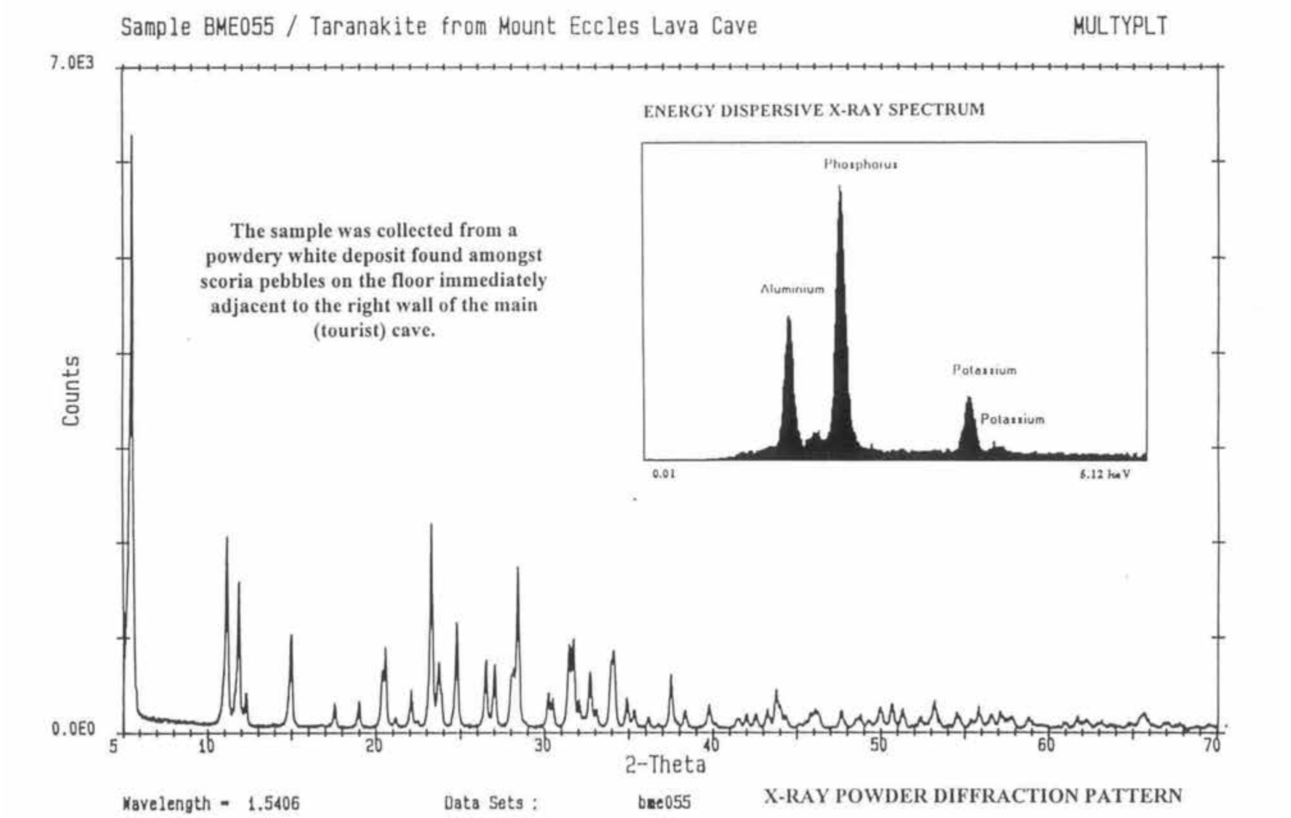

Figure 14. X-ray diffraction (XRD) analysis, that determined the moonmilk sample from Tunnel Cave (3H-9) is rare mineral called Taranakite.   Diffractogram by Brian England

Acknowledgements

Thanks to Brian England for undertaking the chemical analyses of moonmilk samples and for permission to reproduce the SEM and XRD images and graphs. Also to Katerina Fulton for proof reading this article.

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Karst geomorphology on sandstones in the area of Ban Dong Tong (Nong Khai), Thailand

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ABSTRACT

Tham Din Pieng (cave) is by far the largest and deepest sandstone cave in all of Thailand. Its entire maze has a total length of 2,510 m and a vertical range (VR) of 31.3 m (Valenas, 2024b). The area around the village of Ban Dong Tong presents a surface karst and a typical endokarst, similar to karst and endokarst in limestone but in the Ban Dong Tong area there is no limestone, only Cretaceous sandstones, with a carbonate cement (binder). In all of Thailand, the Ban Dong Tong area is an absolutely special case.

INTRODUCTION

The area is located in Nong Khai province of Thailand (Figure 1), 10 km from the Mekong River, heading south, in the territory of the village of Ban Dong Tong, within the large Buddhist temple Wat Tham Si Mongkhon. The upper entrance of Tham Din Pieng has the coordinates: 48Q 214218 1987915, alt. : 349 m, the lower entrance (which is in the center of the studied area): 48Q 214218 1987890, alt.: 339 m (Ellis 2017).

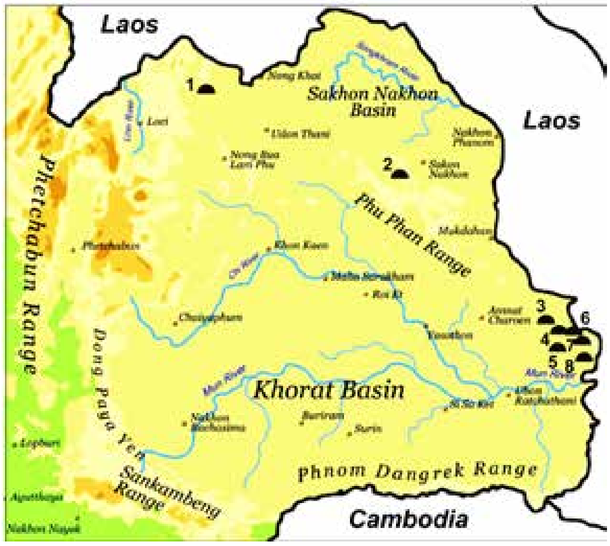


Figure 1. Map of Northeast Thailand, with the main sandstone caves. No. 1: Ban Dong Tong area.

The main valley, which is in front of entrance No. 2 of Tham Din Pieng, disappears 30 m away from the cave in a typical ponor. In the immediate vicinity of the cave there are also two large sinkholes (Figures 2 and 3), with diameters between 50 and 60 m. The sinkholes are not suffosion sinkholes, but typical sinkholes developed in the same rock. Tham Din Pieng probably drains by a more important karst spring, located in the dry valley next to the cave. The main spring is located approximately 100 m north of the terminal sump of the Tham Din Pieng (Figure 4). There are three other karst springs in the area, but it is not known whether they are hydrologically related to the cave. The karst landscape is completed by five smaller potholes (Figures 5 and 6), two of which have not

Figure 2. Sinkhole with a small pothole near entrance no. 2 of Tham Din Pieng (photo Liviu Valenas).

Figure 3. Great sinkhole with a small cave near entrance no. 1 of Tham Din Pieng (photo Liviu Valenas).

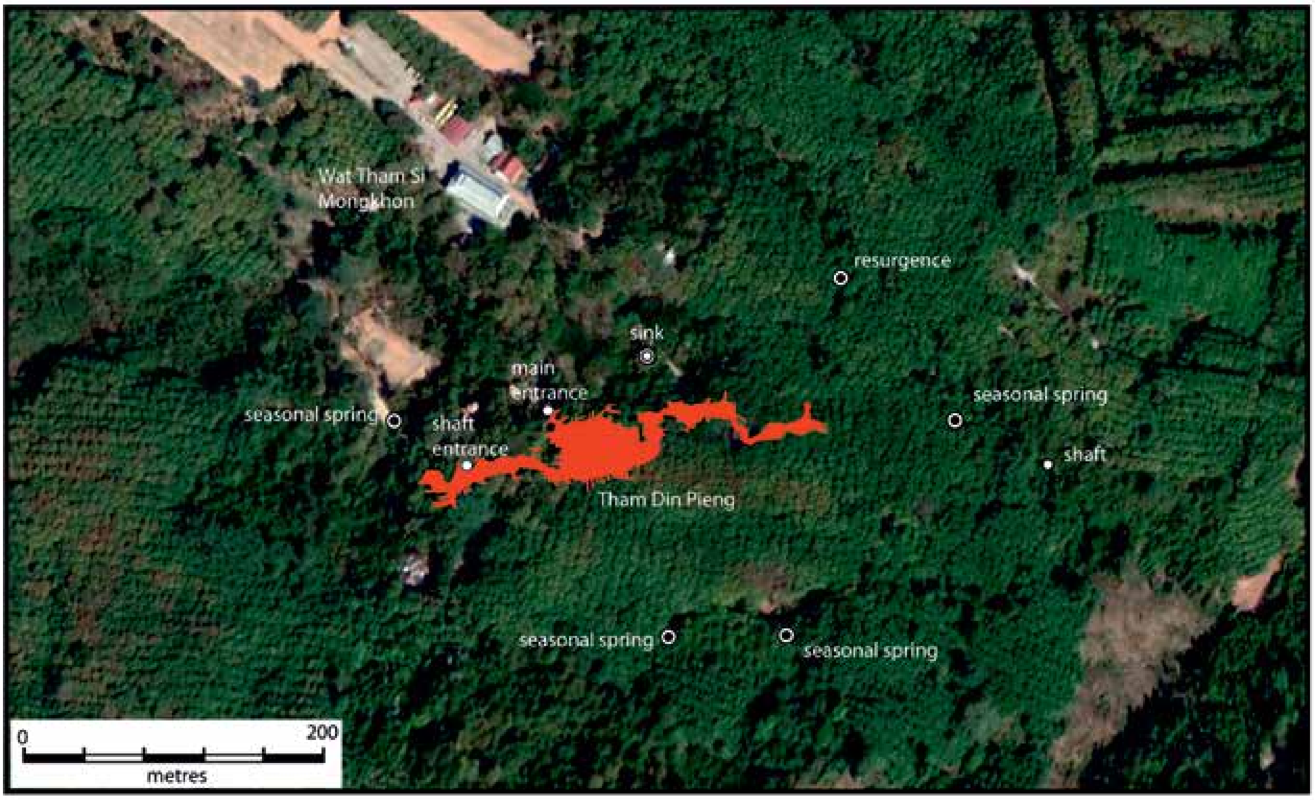


Figure 4. Tham Din Pieng in relation to the surrounding area. Base image from Google Earth. Cartography by Martin Ellis, Liviu Valenas and George-Emil Pleş.

Figure 5. Small pothole to the east of Tham Din Pieng (photo Liviu Valenas).

Figure 6. Small pothole to the east of Tham Din Pieng (photo Liviu Valenas).

been explored yet. All of them are morphologically related to the Tham Din Pieng. It is interesting, however, that no karren appear in the area, although the karst landscape is otherwise almost complete here. Probably the lack of karren can be explained by the fact that the whole area is completely forested and very rarely does the sandstone bedrock appear on the surface.

MATERIALS AND METHODS

The geological map used was the 1:50,000 map of Nong Khai province, made by the Department of Mineral Resources (DMR) in Bangkok (Figure 7).

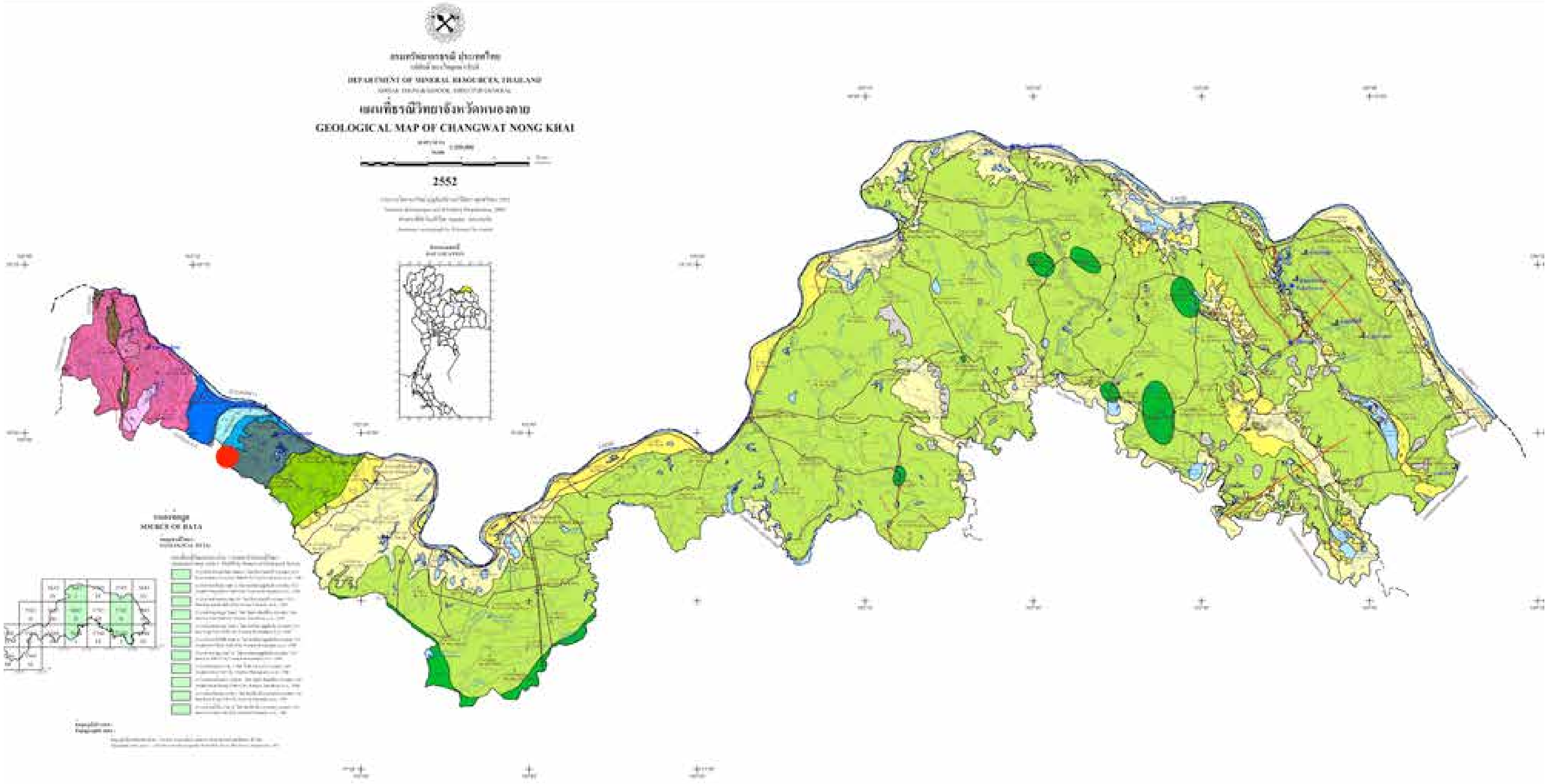
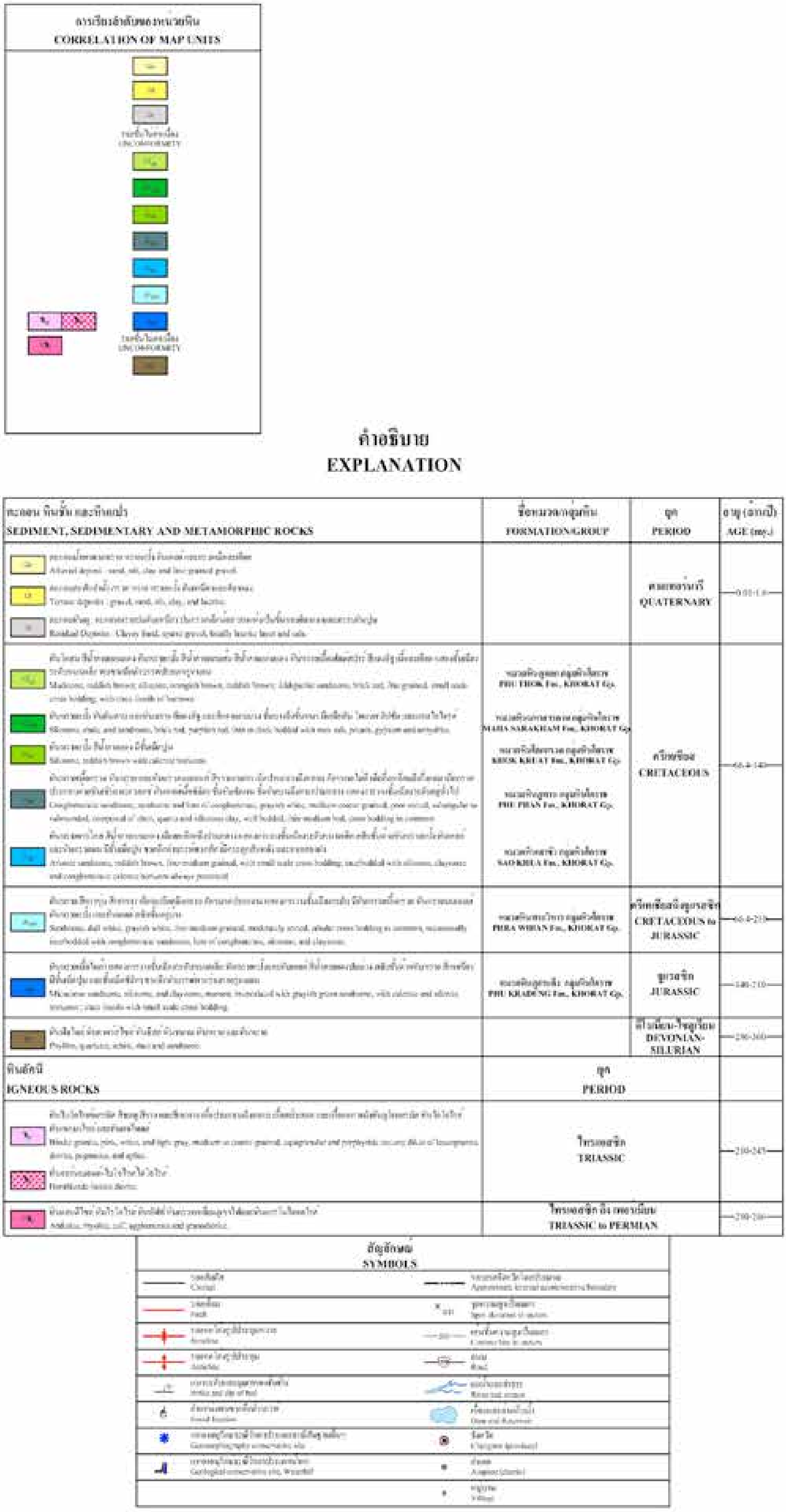


Figure 7 Geological map of Nong Khai province, made by the Department of Mineral Resources (DMR) in Bangkok. The red circle in the North-West extremity of Nong Khai province represents the Ban Don Tong area.

For key/explanation, see Figure 7A. p. 22



CORRELATION OF MAP UNITS

UNCONFORMITY

UNCONFORMITY

คำอธิบาย

EXPLANATION

SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	FORMATION/GROUP	PERIOD	AGE (my.)
🟨 Alluvial deposit 🟨 Terrace deposits ⬜ Residual Deposits		QUATERNARY	0.01-1.6
🟩	PHU THOK Fm., KHORAT Gp. MAHA SARAKHAM Fm., KHORAT Gp. KHOK KRUAT Fm., KHORAT Gp. PHU PHAN Fm., KHORAT Gp. SAO KHUA Fm., KHORAT Gp.	CRETACEOUS	66.4-140
🟦	PHRA WIHAN Fm., KHORAT Gp.	CRETACEOUS to JURASSIC	66.4-210
🟦	PHU KRADUNG Fm., KHORAT Gp.	JURASSIC	140-210
🟫		DEVONIAN-SILURIAN	290-360
IGNEOUS ROCKS	PERIOD		
	TRIASSIC		210-245
	TRIASSIC to PERMIAN		230-290

SYMBOLS

Figure 7A. Key to geological units shown in Figure 7, p. 21.

Tham Din Pieng was surveyed and mapped with Suunto compass, Disto D2 and inclinometer. The cave entrances were positioned with GPS, Garmin 62s. The area was photographed with a Nikon D 5200 camera, Tamron lens, 18-270 mm, UV filter. The galleries of Tham Din Pieng and the main springs have been positioned on a Google Earth map (Figure 4).

LITHOLOGY

Thai geologists have not completely agreed on which particular Cretaceous formation the sandstones in the Ban Dong Tong area belong. Even the geological maps published in Thailand are a little unclear, especially since they are drawn up by province, and the Ban Dong Tong area is just north of the administrative border between Nong Khai and Udon Thani provinces. However, Australian caver John Dunkley has written that the sandstones in which Tham Din Pieng has formed belong to the Phu Phan Formation, which occurs from Ubon Ratchathani province to Nong Khai (Dunkley 2011, Dunkley and others 2018).

According to Martin Ellis (pers. comm. 2024) the Phu Phan formation is composed of conglomeratic sandstone, sandstone and lenses of conglomerate, grayish white, medium-coarse grained, poorly sorted, subangular to subrounded, composed of chert, quartz and siliceous clay, well bedded, thin-medium bed, cross bedding is common.

The 1:50,000 geology map (Figure 7) of the quadrant to the north of Ban Dong Tong area has this description of the Phu Phan Formation: *Sandstone and conglomeratic sandstone, pinkish white and whitish gray, medium- to coarse-grained, poor sorted, subround, moderately to well cemented, cross bedded. The Thai geologist Assanee Meesook, in an interesting work published in 2011, dedicated to the Cretaceous in Thailand, describes the Phu Phan Formation, from the northern sector (close to Tham Din Pieng): The Phu Phan Formation is well exposed along the Mae Khong River banks and in most parts of the Phu Phan Range where it forms cuestas which delineate the outer rims of the range. The rocks generally consist of greyish-white-medium-to coarse-grained cross-bedded sandstones and thin lenses of grey siltstone and mudstone with subordinate conglomerate. In the northern and central parts of the Phu Phan Range, the formation overlies the reddish-brown claystones of the Sao Khua Formation with a distinctvely sharp but conformable contact. Sandstone conglomerates are locally exposed* (Meesook 2011).

Geologists John Booth and Nares Sattayarak describe the Phu Phan Formation as follows: *The Phu Phan Formation consists of a stacked series of thick-bedded to massive medium- to very coarse-grained, often pebbly, cross-bedded white sandstones interbedded with minor thin red-brown siltstones and claystones. Where this formation crops out in breached anticlines of the Phu Phan Uplift and around the edge of the Khorat Plateau, its resistant sandstones locally form distinctive cuestas. Generally the formation is 75-150 m thick. The sandstones are interpreted as having been deposited as a stacked series of meandering to locally braided rivers. It is observed that while only pebbles of quartz and chert are found in the centre of the basin, various lithic clasts are found along the southern and northern margins. Palaeocurrent directions from studies of cross-bedding indicate that the river systems generally flowed westwards, having entered the basin from the north, east and south. On seismic sections the Phu Phan Formation is imaged as a more-or-less continuous peak-trough-peak cycle and is too thin to display any internal reflection pattern. When drilling wells, the top of the formation is readily apparent as its almost continuous white sandstones contrast with the dark reddish-purple to red-brown claystones and siltstones of the overlying Khok Kruat Formation* (Booth & Sattayarak 2011).

What surprises us in all the geological works (including the authors cited above) and maps that refer to the Phu Phan Formation, is that no reference is made to the fact that both the sandstones and the conglomerates have a calcareous cement. Chemical analyses of the water samples collected by the author in 2023 and 2024 from the two underground rivers in Tham Din Pieng (Figures 8 and 9), clearly showed that there is this calcareous cement. The three water samples analysed have a pH between 7.30 and 7.99, and the content of calcium carbonate ($CaCo_3$) reaches values of up to 185 mg/l. While these values are typical of caves developed exclusively in limestone, this is not the case at Tham Din Pieng (Valenas 2024b).

DISCUSSION

Since the early 20th century, when the term “pseudokarst” was apparently first used (Knebel 1908, cited by Halliday 2004) (with the subsequent unfortunate consequences of this word – see Eberhard & Sharples 2013), there has been heated and contradictory discussion about this term. In recent times, many researchers have denied the existence of “pseudokarst” and simply classified

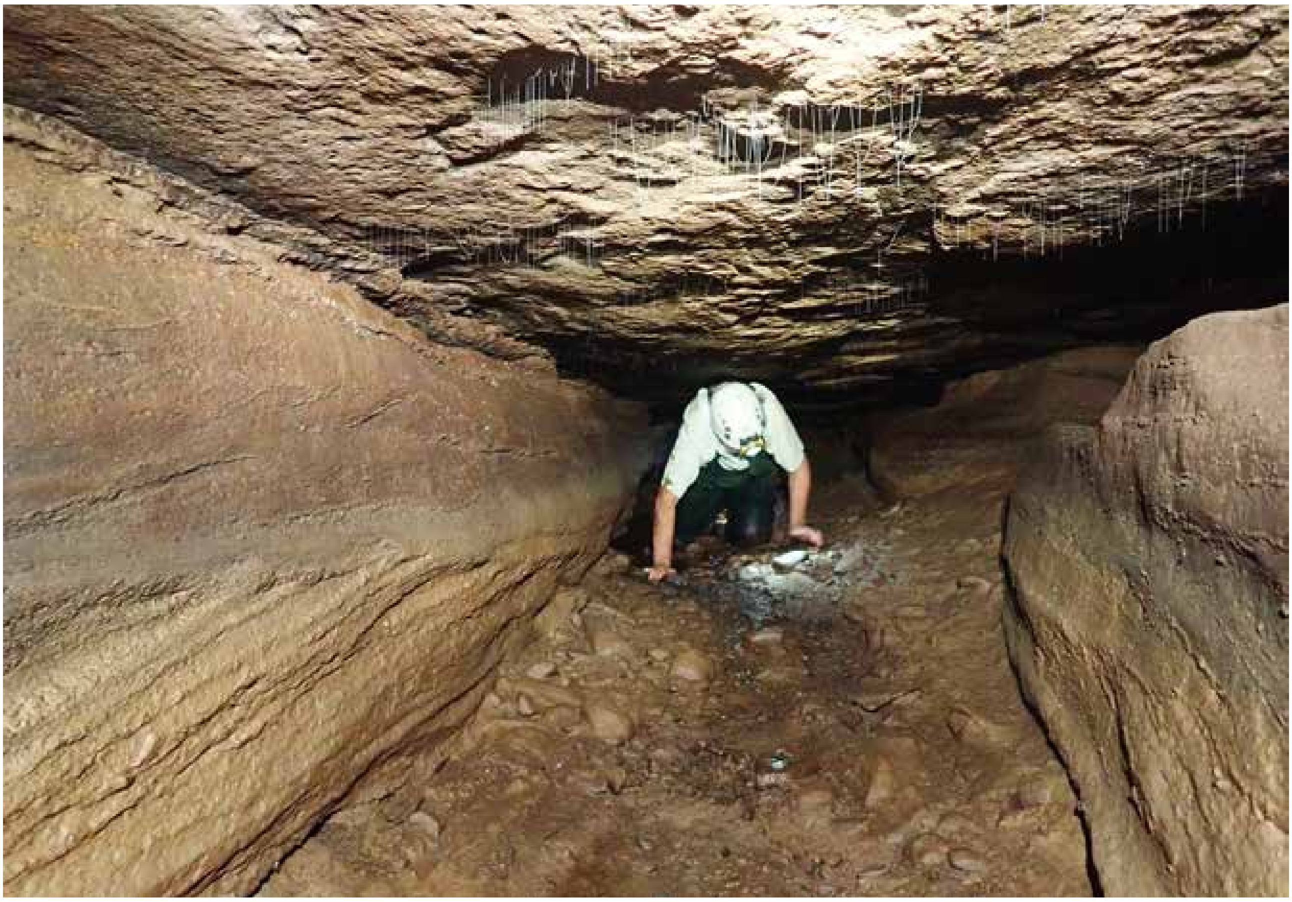


Figure 8. Many of the galleries in Tham Din Pieng are narrow and low. In this photo it is clearly seen that the cave was excavated between different layers of sandstones and conglomerates (photo Mindy Johnson Filer).

Figure 9. The carbonate cement (binder) of the sandstones in which the Tham Din Pieng has developed is directly responsible for the specific shapes in this cave. The picture shows sandstone columns in the Hall of a Thousand Rooms (photo Liviu Valenas).

karst-like relief forms on non-carbonate rocks as karst. Brazilian researchers (Pereira and others 2022) write very clearly that “Karstification in quartzite sandstones is a reality demonstrated globally through the exploration and research of caves in sandstones”. However, the French geologist Claude Mouret reached another, in our opinion slightly absurd, conclusion: “Caves must be separated; those that belong to typical karst and those with a complex speleogenesis, which belong to pseudokarst” (Mouret & Urban 2022). In reality, all caves, including those in carbonate rocks, have a complex genesis.

At the international symposium dedicated to ‘pseudokarst’ in Karlow, Poland (May, 2023) there were heated discussions about whether the term ‘pseudokarst’ has a scientific basis or not. Most of the participants denied the validity of the term ‘pseudokarst’. It is certain that the karst on the quartzite sandstones of Northeast Thailand, on which the author presented (Valenas 2023a), was universally appreciated as a true karst and not a ‘pseudokarst’. In our opinion, the term ‘pseudokarst’ is completely outdated. In the case of the karst in the Ban Dong Tong area, another factor is significant: the sandstones have a carbonate cement and the term ‘pseudokarst’ could not in any way be justified in this case.

CONCLUSION

In summary, the Ban Dong Tong area presents all the “classic” karst forms, dry valleys (where the water course exists entirely underground), sinkholes, potholes, karst springs and a large maze cave, Tham Din Pieng. The sandstone bedrock was dissolved not only by arrenisation, but also by dissolution of the calcium carbonate that makes up the cement (binder) of these sandstones. Hence, in the Ban Dong Tong area we are dealing with a typical karst and not a pseudokarst. A very important role in the dissolution of sandstones was, and is, played by the extremely high precipitation in the monsoon season, but also by the biocorrosion produced by the roots of tropical vegetation in the area (Valenas 2023b, 2024a). The research in this area is only just beginning; we hope that the new research and explorations that we intend to do intensively in this area in 2025 will bring new data and new clarifications (Valenas 2024b).

ACKNOWLEDGEMENTS

I would like to express my gratitude to Martin Ellis, Dr. Jan Urban, Prof. Dr. Traugot Scheytt, Dr. Rudolf Pavuza, Dr. Anika Rogoll, Prof. Dr. Thorsten Nagel, Stephanie Gimmler and Christoph Späker for the data collecting, chemical and petrographic analyses, comments and verification. Our thanks also go to the Buddhist monks from the Wat Tham Si Mongkhon temple, who allowed us in 2024 to research both the surface area and Tham Din Pieng.

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Helictite, (2024) 49**:** 27-31

Vale Bill Halliday – a tribute and some personal reflections

Greg Middleton

It is with deep regret that we record the death, at age 98, of William Ross Halliday, M.D., on 24 September 2024, at Shoreline (north of Seattle), Washington, USA.

Bill was born 9 May 1926 in Atlanta, Georgia, the son of Jane Wakefield Halliday and William Ross Halliday.

Medical Career

During his medical career, Bill was a thoracic surgeon, medical consultant and specialist in vocational rehabilitation. He first graduated in 1946 with a Bachelor of Arts in Zoology from Swarthmore College, a Quaker liberal arts college near Philadelphia, Pennsylvania. Two years later he graduated M.D. from the George Washington University School of Medical and Health Sciences, Washington, D.C. – among the most selective medical schools in the U.S.

A young Dr William Halliday
(photo – Patton Funeral Home 2024)

Initially he worked at the Huntington Memorial Hospital in California (1948-49) and then served as a medical officer in the U.S. Navy, in Long Beach, California (1949-50). He remained in the Naval Reserve until at least 1957. Subsequently he became a thoracic surgeon, medical consultant and Director of the Department of Labor and Industries from 1971 to 1976. From 1976 to 1982 he was Medical Director for the Washington State Division of Vocational Rehabilitation.

Initial Caving

In parallel with his medical career, Bill became a speleologist and it is in that sphere that he became most widely known.

He was introduced to caving in 1946 when, working at a summer camp near Washington, he went to see Clarks Cave in company with the owner. Bill later recalled, "It was everything a cave should be – a network of passages, it smelled old and musty, just enough mud to get your attention, stalactites and stalagmites, old artifacts. We didn't know at the time, but I found out much later that the ladders had been constructed by saltpeter miners" (Halliday, Fleury & Chavez 2007).

Founder of Speleological Groups

It was Mr Clark (of Clarks Cave) who told Bill about the National Speleological Society (NSS). It had been founded in 1941 but was not widely known and Bill had trouble making contact. Eventually (1947) he located the District of Columbia Grotto and got to know Bill Stevenson (the founder of the NSS) who became his friend and mentor. Stevenson encouraged Bill to set up grottoes in the west as there were none west of the Mississippi. He subsequently founded the Southern California Grotto (1948), the Cascade Grotto (Seattle 1951), the Colorado Grotto (Denver), the Salt Lake Grotto (Utah) (and, much later, in 1989, the Hawaii Grotto). These achievements led to Bill often being referred to as the "Father of Western Caving".

Not only was Bill a mover in getting new grottoes established, he went further and set up groups focussing on cave recording and surveying. His first was the Washington Speleological Survey (a unit of the Western Speleological Survey)(Cole 2002, Halliday 1963, p. 3), of which he was the Director from 1955 to 1981 (Patton 2024). He founded the Hawaii Speleological Survey in 1989. He founded the Vancouver Island Speleological Survey (late 1950s; Cole 2002). Also, about this time he co-founded the Northwest Cave Rescue Association (Cole 2002).

Bill was made an Honorary Member of the NSS in 1965, and in 1988 he was awarded the Spelean History prize for his work in documenting cave histories. He was elected to the NSS Board of Governors, many times between 1950 and 2001 (Encyclopedia.com. 2005). He was made a Fellow of NSS and of the Explorers Club.

Because of the huge encouragement that Bill gave to John Pint when John moved to Saudi Arabia, John regards Bill as the "Father of Speleology in Saudi Arabia" (Pint, pers. comm. Oct. 2024).

Role in Vulcanospeleology

Bill encountered volcanic caves early in his caving career. In compiling his comprehensive report on the caves of Washington State (1963) he observed:

> Persons concerned with broader implications of speleology will find Washington a fruitful area of study. This is particularly true of the student of lava tubes and of vulcanism in general. Ape Cave, the longest lava-tube cave known in the continental United States, and perhaps the world's longest, is in Skamania County. The concentration of lava-tube caves in Washington is not so great as in Lava Beds National Monument in California, or perhaps in the Bend area of Oregon. However, Washington's numerous and extensive lava tubes provide a great variety of features of these caves and their enveloping bedrock.

While his suggestion that Ape Cave may be the longest volcanic cave was not subsequently borne out, he embraced lava caves at a time when other cavers tended to discount them in favour of karst caves. Although he maintained an interest in karst, his strong advocacy of volcanic caves – particularly from his organisation of the first International Symposium on Vulcanospeleology (ISV) in 1972 – led to the establishment, by the International Union of Speleology, of first a working group, and then (1993) a fully-fledged Commission on Volcanic Caves – with Dr Halliday as its founding chairman/president. Under Bill's oversight, the Commission has become one of the International Union's most active and productive. Bill personally organised the first, third and sixth international symposia and, while running the Commission, encouraged and assisted others to organise them at appropriate locations so that they have become a regular biennial event.

Author of Cave-related Books

Bill examining lava speleothems in Cave #13 at Mt Suswa, Kenya, on the field trip following the 8th ISV, February 1998.

Bill was a prolific writer. Early on, he was a major contributor to Celebrated American Caves (Halliday 1955a, 1955b). His first major book was Adventure is Underground (1959), followed by Caves of Washington, published by the Washington State Division of Mines and Geology in 1963, Depths of the Earth: Caves and Cavers of the United States (1966, followed by an enlarged edition in 1976), and American Caves and Caving: Techniques, pleasures, and safeguards of modern cave exploration (1974). He also wrote or co-authored a series of more focussed booklets: Discovery and exploration of the Oregon caves with Frank K. Walsh (1971), The Paradise Ice Caves with Charles H. Anderson (1972), Ape Cave and the Mount St. Helens Apes (1983), Carlsbad Cavern: The Early Years with R. Nymeyer (1991) and Floyd Collins of Sand Cave: A photographic memorial (1998). In addition, Bill wrote and edited numerous reports on various caves and papers recording his exploration and documentation of caves in the USA and elsewhere.

He contributed no less than ten entries to Gunn's Encyclopedia of Caves and Cave Science (2004): America, North: History; Caves in History: The Eastern Mediterranean; Crevice Caves; Disease; Hawaii Lava Tube Caves; Piping Caves and Badlands Pseudokarst; Pseudokarst; Talus Caves; Volcanic Caves; Vulcanospeleology: History. This was more in number, and over a broader range of topics, than any other contributor.

His books have been highly influential in encouraging new generations of cavers and cave scientists in the USA and around the world. His first book, Adventure is Underground, was pirated by Russians and 65,000 copies were printed – "the most my books have ever sold" Bill later joked (Halliday and others 2007). It is reported the book was influential in encouraging speleology in Russia. Bill Halliday was probably the greatest contributor to popular works on caves since Casteret.

Family

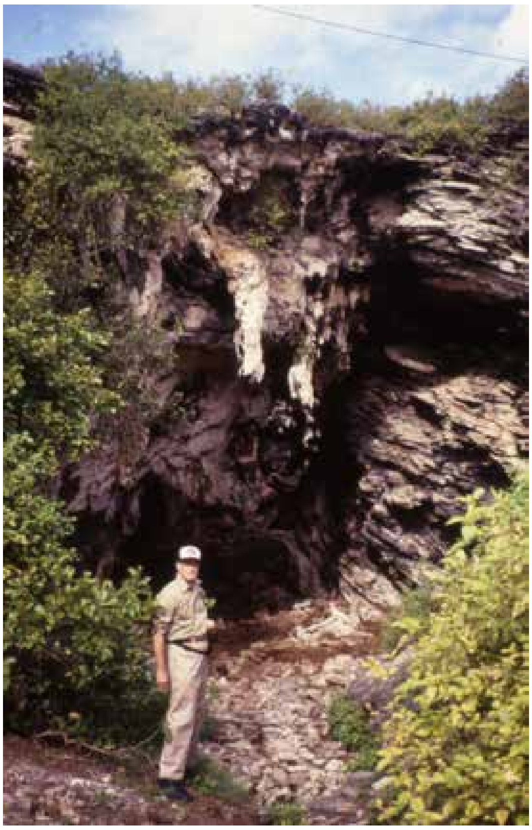
Bill had married Eleanore in 1951 but she passed away in 1983. He married Louise ('Sis') in 1988 and she passed in 2018. He is survived by daughters Marcia Gojan and Patricia Halliday and son William Ross Halliday III, two grandsons, four stepchildren and a number of great-grandchildren, step-grandchildren and step-great grandchildren.

Some personal reflections

I first met Bill Halliday after he contacted me while I was working on the Indian Ocean island of Mauritius in 1994. He was a keen speleophilatelist but he didn't just collect stamps with caves on them – he liked to visit the depicted caves himself. He had found a stamp of Mauritius featuring a cave and wondered if I could help him locate and visit it.

A side entrance to Caverne Patate
featured on a Mauritian stamp of 1985

Bill arrived in Mauritius on 12 May 1995, having just visited Kenya to check out the possibility of holding a symposium there for the Volcanic Caves Commission. I showed him some lava caves within minutes of the airport and next day we flew to Rodrigues (the second island of Mauritius, 650 km to the north-east). There I was able to take him to the very spot shown on the 1985 stamp.



Bill at the entrance to Caverne Patate
shown on the 1985 stamp.

As Bill expressed it later:

> *I have used postage stamps as a cave hunting technique in several places, with particular results in the Republic of Mauritius, where the Patate Cave on the island of Rodrigues, is shown on one of their postage stamps. An Australian caver and I got together to go check out the whole new cave area that had not been studied before.* (Halliday and others 2007).

He was very pleased to actually visit the cave shown on the stamp and he agreed to help me finish the survey. What I didn't tell him was that this was the wet part of the cave – beyond the 'show cave'. He took it all in his stride, however, and, despite getting very damp, we completed the survey.

The author and Bill Halliday after surveying
in Caverne Patate, 14 May 1995.

On that visit to Mauritius Bill invited me to attend the meeting of the Commission on Volcanic Caves which was being planned for Kenya. I became a member of the Commission and did attend the 8th International Symposium on Vulcanospeleology in Kenya in 1998. It was a significant meeting for Bill as it was there he handed over chairmanship of the Commission to Jan Paul Van der Pas.

The actual hand-over of chairmanship from Bill to Jan Paul at the Commission meeting in Nairobi.

Naturally Bill continued to be involved and was made Honorary Chairman.

Bill was responsible for my documenting the lava caves of the Comoros Islands. As I put it:

> *When Dr Bill Halliday, chair of the IUS Commission on Volcanic Caves, appointed me to the Commission in 1996 he asked me to assume responsibility for the Indian Ocean islands (because of my efforts in documenting the lava caves of Mauritius and my interest in Madagascar) and pointed out that the Comoros Islands in that region were virtually unknown [vulcanospeleological] territory.* (Middleton 1997).

I later learned I had been 'conned' (in the nicest possible way), when Bill revealed in an interview:

> *The Commission on Volcanic Caves, for instance, has been a tremendous success—its members are the people in the forefront of exploration throughout the world. When we find a void, we see if we can get some sucker to go fill that void.*
>
> *Interviewer: (laughs) Do you usually find one?*
>
> *WH: Yes. Greg Middleton of Australia was kind of flabbergasted when I appointed him to cover the whole Indian Ocean. But he rose to the challenge and went to places like [the Comoros] islands off Madagascar, and turned up some unsuspected but important lava tube areas.* (Halliday and others 2007).

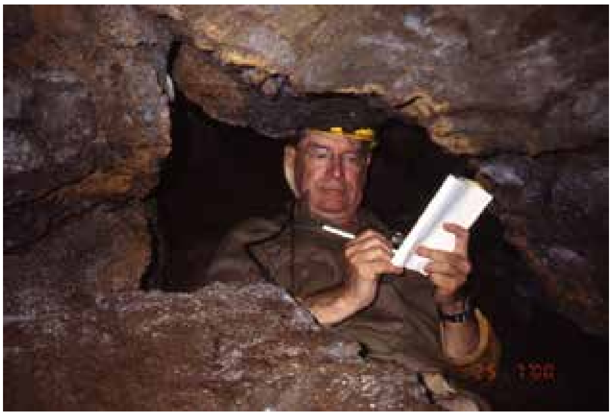
Bill took a particular interest in the numerous volcanic caves of Hawaii (well documented in Bosted 2019). In his later years he carried out a project to document the little-known lava cave features of the Kilauea Caldera and invited me along during his July-August 2000 field season (Middleton 2001). (Unfortunately, most of the features Bill recorded in the caldera were destroyed when it collapsed in 2018 (Bosted 2019) – but at least there is a record of the caves that had been there.)

In 2000, after surveying a number of small features in the caldera, we visited caves where rubbish had been dumped as Bill prepared for a conference he was organising on lava caves and groundwater contamination.

We also visited the Kalaupapa Peninsula on the small island of Molokai where he continued surveying the caves and we visited Kauhako Crater.

Bill pointing to his Kilauea Caldera study area July 2000

Bill campaigned against the dumping of rubbish in lava caves – under a Kaumana garbage puka.



Taking survey notes in Kaupikiawa Cave, Kalaupapa, Molokai, 25 July 2000

In November 2003, as a result of Bill Halliday's recommendation, I was asked to advise on the possible tourist development of a most unusual cave in the Eastern Desert of Egypt. Though very impressed by the cave, I was also aware of the difficulties of providing safe access and was unable to recommend an inexpensive way to open the cave safely (Middleton 2005). I expect the Egyptian authorities were not especially pleased with my findings; in any case, Bill didn't recommend me for any future such projects.

With Bill's passing volcanic caves have lost their greatest ever champion and speleology has lost one of its foremost promoters and practitioners.

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Graphics

Maps and line diagrams should be provided as separate files, **not** pasted into text files. LZW-compressed TIF or PNG formats are preferred. Graphics may be in black & white, greyscale or colour. Text should be large enough to be readable even if reduced. Scale should only be shown in bar form (not expressed in words). It is preferred that individual graphics be designed to be published no larger than A4. If images are scanned from original artwork they should be at no less than 300 dpi.

All figures (including photographs) should be numbered and referred to by number at the appropriate place in the text (e.g. "Figure 2"). Captions should be provided for all figures at the end of the main text.

Photographs should be provided in JPG/JPEG format as separate files. Photographs should be attributed in their captions, unless by the sole author, or names may be included within images.

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Journal of Australasian Speleological Research
End of Volume 49

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