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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).

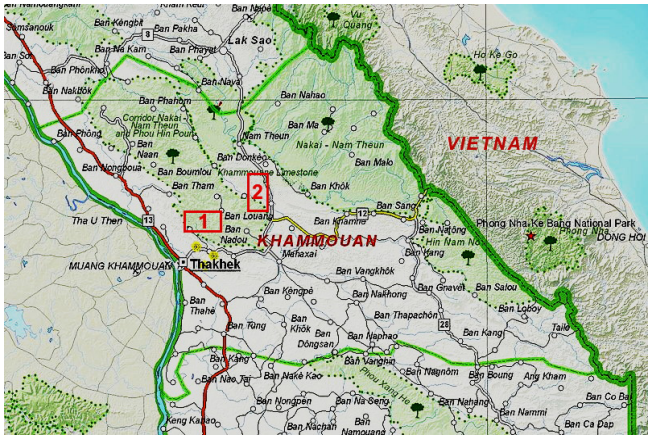

Figure 2. Map of Khammouane province. Pha Soung Mountain is within the rectangle numbered '1'.

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).

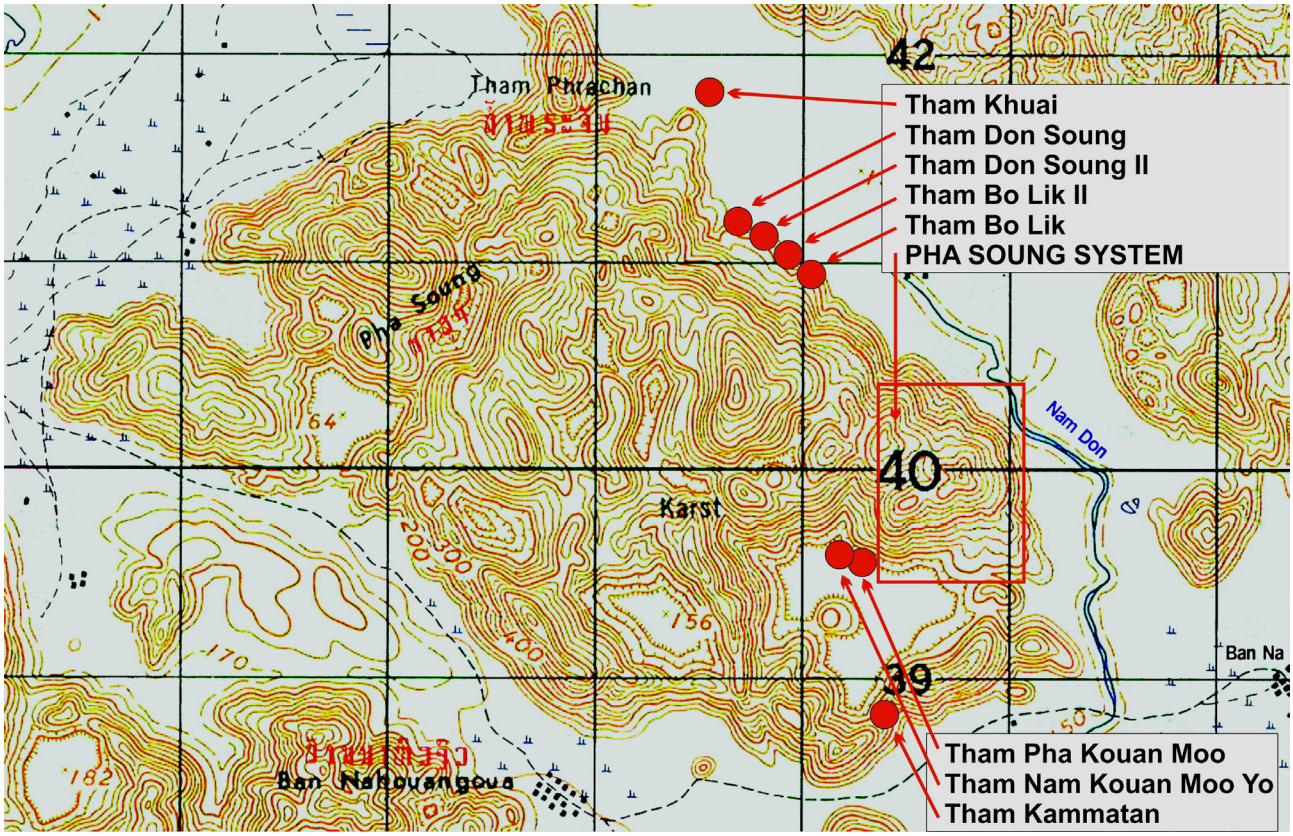

Figure 3. US military topographic map from 1965, showing Pha Soung Mountain (maximum altitude 630 m). Tham Kammatan is located near the southeastern end of this mountain (near northing numbered '39').

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

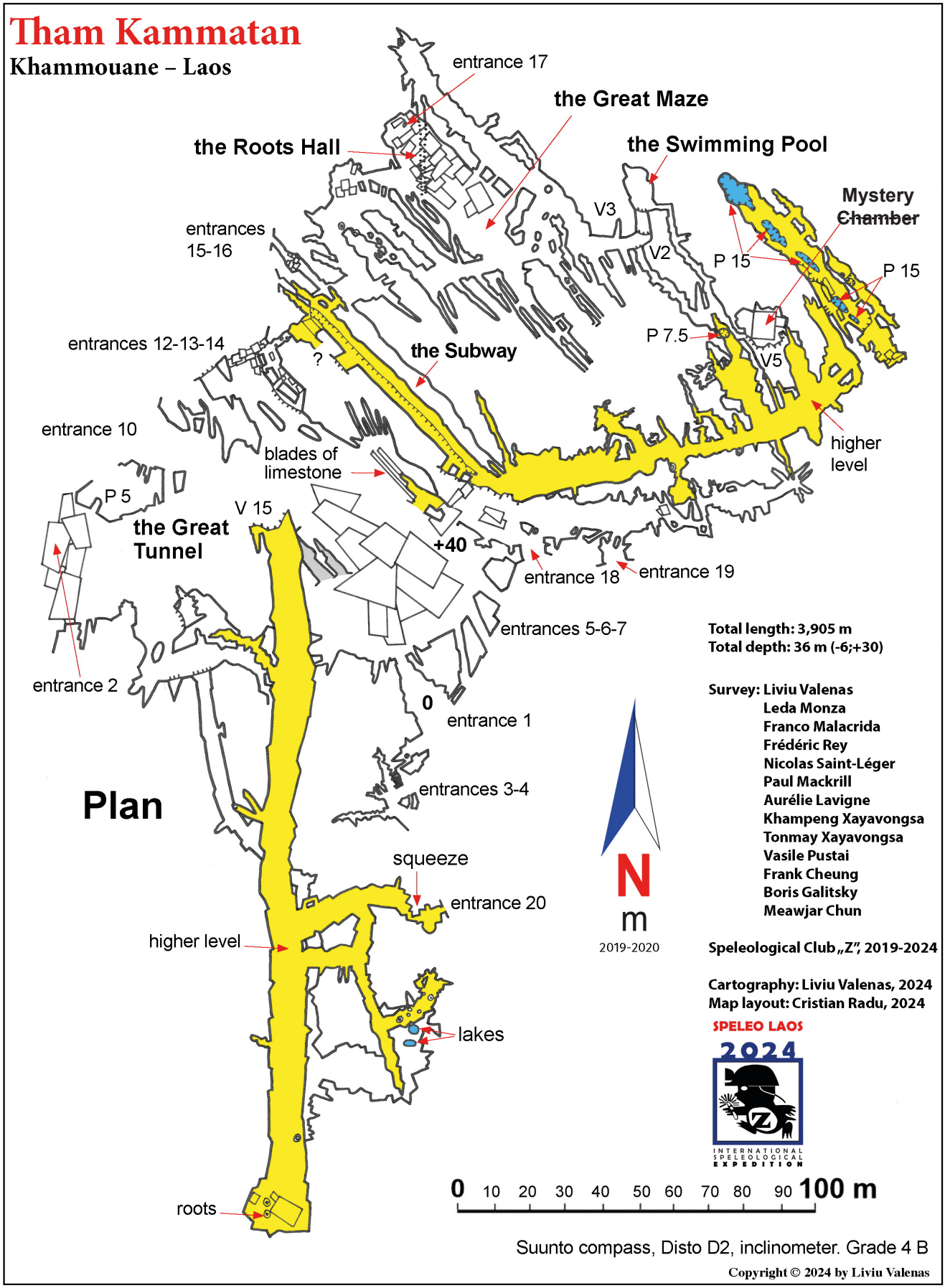

Figure 4. Plan of Tham Kammatan. Cartography by Liviu Valenas

Figure 5. The Great Tunnel of Tham Kammatan.

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

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 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

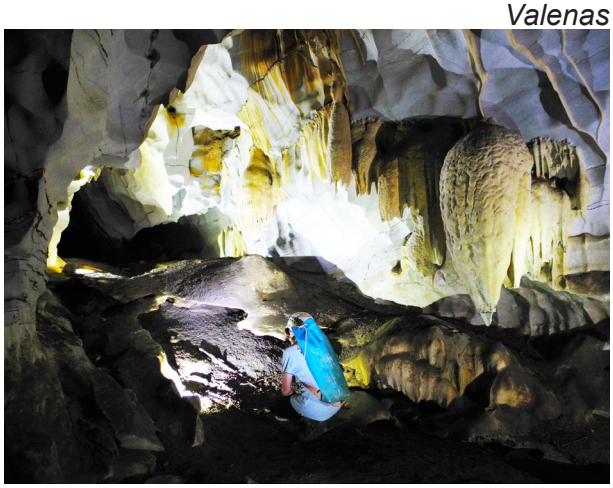

Figure 11. Tham Kammatan; fine speleothems in the Subway Gallery. Photo by Leda Monza.

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.

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).

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

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

Soung Mountain, just above the cave, did not reveal any potholes among the tsingy leading down to Tham Kammatan.

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

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

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.

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

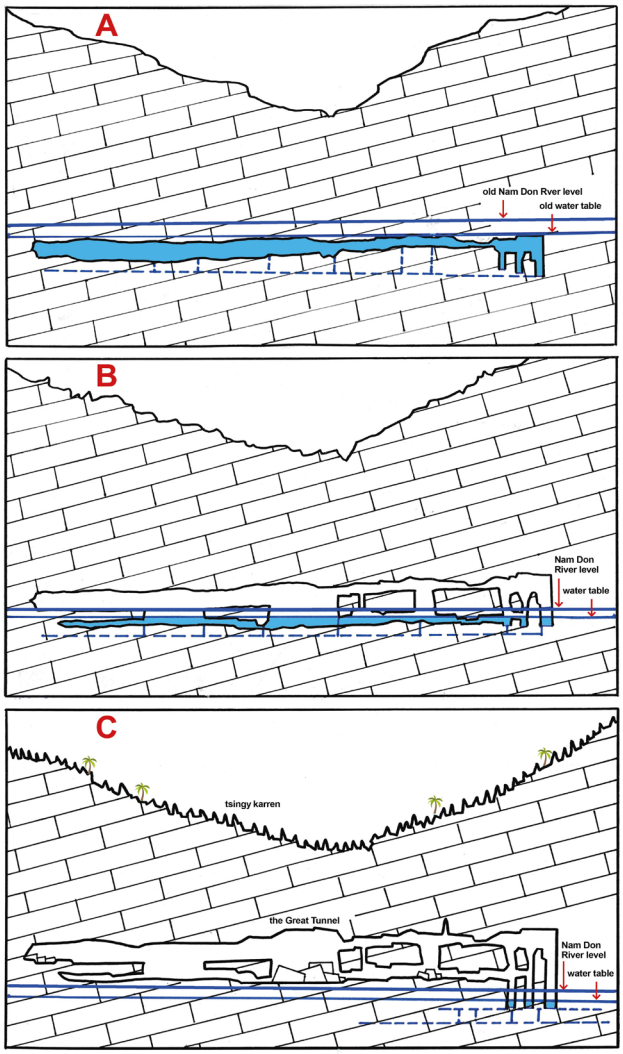

Figure 18. The stages in the formation of the epiphreatic labyrinth and the Great Tunnel of Tham Kammatan. A: Middle Pleistocene, B: Upper Pleistocene, C: Upper Pleistocene-Holocene. Graphic by Liviu Valenas.

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.

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Photographs, unless otherwise attributed, are by Liviu Valenas.

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