Geophysics under stressed: a case study of Tham Luang Nang Non Cave

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Abstract

In the middle of June, 2018, the members of Wild Boar Academy football team consisted of 12 boys and their coach were trapped in a flooded cave complex of Tham Luang Nang Non, Mae Sai District, Chiang Rai Province, Thailand. The plight of the boys and their coach had drawn international attention, with divers, engineers and medics among others flying in from around the world to assist the rescue mission. Initially, there were three maps provided by different sources but none of them were accurate. Therefore, an application of geophysical exploration technique was considered as the alternative method for the determination accurate cave route and geological structure that allowed water flowing through the cave. In addition, electrical resistivity imaging survey and seismic survey were also applied. The results of the resistivity survey indicated that the geological structure of the mountain was useful for drilling operation at D01 and D88. The resistivity survey results at North and South of the mountain indicated the possibility of underground water that flew to the cave. Moreover, the seismic technique used for the earthquake measurement was applied to determine accurate cave route and the position of seismic source along the cave route. The seismic source for this test was from the cooperation with the Royal Thai Navy diving team by hitting their own empty air tank on the ground floor. Unfortunately, the application of the seismic technique was not a success due to the interference of high ambient noise from electrical water pumps, groundwater drilling, and the rescue activities. Later on, the test results revealed that the seismic technique was the effective method for homogeneous strata with sledgehammer source. The larger and stronger seismic source was required for the non-homogeneous strata.

Keywords: Tham Luang, cave rescue, geophysics, Wild Boars, drilling

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Introduction

During the atmosphere of 2018 Russia World Cup which was kicked off in mid of June. The mission of Thailand cave rescue for the members of Moo Paa (Wild Boar) Academy football team was also globally broadcasting and drawing the international attention. This mission was not similar to the San Jose mine incident in 2010 where 33 miners were trapped in a collapsed mine in Atacama region of northern Chile (Rashid, Edmondson, Leonard, 2013; Edmondson, Rashid, & Leonard, 2014). Or other underground rescue mission in the world history (Huggler, 2014; USDL, 2018a & 2018b). Most of the mine rescue was conducted after an explosion, collapse of tunnel, or fire caused by the mining activities. Whereas the rescue in Thailand was the mission for victims trapped in a flooded cave complex. In Thailand, the incident began at 4 PM. of June 24th, 2018, when 12 boys and their coach of the Wild Boar team entered the Tham Luang Nang Non cave, then the 15 mm of downpour caused the flood that trapped all of them inside. Afterwards, for the rescue mission, the key obstacle was the limitation of time spent for searching of accurate route in the cave complex while the heavy downpour had continually filled the water to the cave.

Collaborations with many sectors such as the government and military officers, local and international experts, leading local and international businessmen, and volunteers, had made this rescue the most recognized cave rescue in the world. There were also Thai engineers, geologists, scientists, and special warfare forces, who had been working closely for the rescue purpose.

Due to lacking of an accurate cave map, application of geophysical exploration was necessary to map the cave and to determine the location of Martin's Point. In addition, geophysical survey was aimed to locate the geological structure of underground water that flew to the cave.

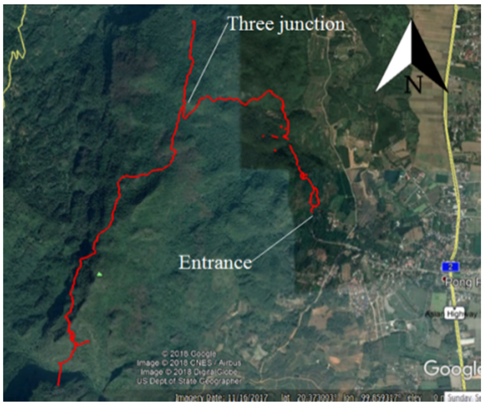


Figure 1 Martin Elli's route map (Elli, 2018b)

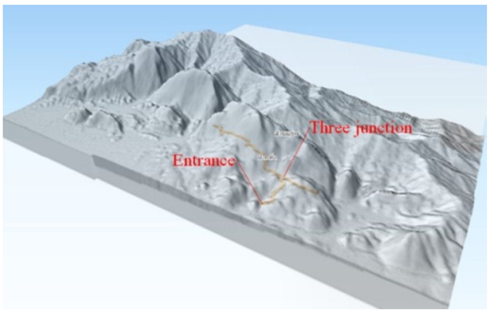


Figure 2 GISDA 3D map (GISDA, 2018).

Cave route maps

There were three route maps available at the time of the mission. Those maps were from Mr. Martin Ellis, Department of Mineral Resources (DMR), and Geo-Informatics and Space Technology Development Agency (GISDA). Unfortunately none of them were accurate.

Ellis (2018a & 2018b) mapped the cape route by non-calibrated magnetometer with the IGRF Model software. The positions were accurate to a degree, depending on the measurement location (Figure 1).

DMR mapped by the application of a fundamental part of speleology by geologists. Under collaboration with ESRI Thailand and Royal Thai Survey Department, the extract route was plotted on topographic map scale 1 : 50,000.

A 3D map by GISDA (2018) was complied with Airbus's high resolution satellite images with a resolution of 50 cm/pixel. However, Martin Elli's route map was adopted for the provision of an initial information of the cave (Figure 2). Result of the overlaying of those maps revealed the three routes on a difference location except the entrance.

During the rescue mission, there were several media reports a potential entrance to the area that the group was expected to be found. National media had referred this point as Martin's point or Martin Chimney. The location was discovered by two British cave divers, Dr. Martin Ellis, and Mr. Vernon Unsworth, who saw it under the sunbeam that shone through the cavity at the trailing chamber during their survey to this cave complex in 2014-2015.

Geographical and geological information

Tham Luang Nang Non is the cave complex in Mae Sai District, Chiang Rai Province, Thailand, located beneath a mountain range called Doi Nang Non, which is known as the natural border of Thailand and Myanmar. Elevation of the cave entrance is 446 m MSL and the peak is 1,389 m MSL (GISDA, 2018).

Structure of this cave is consisted of a semi-dry limestone and marble strata, Carboniferous-Permian: CP hard rock with the age of 300 million years. As a result of erosion process, there are many deep recesses, narrow tunnels, boulder chokes, collapses, and sumps inside the complex. Stalactites and stalagmites are found through out the cave (ONEP, 2018).

The rows of granite on west of mountain (at the contact zone between granite and limestone) can be easily found. Since granite are harder than limestone, many crack lines and fractures are found on limestone. This fracture zone allows water to flow through and dissolve mass of limestone to create network of the cave's complex. The flow orientation of underground water is from west to east. The geological model of Tham Luang Nang Non cave is shown in (Figure 3).

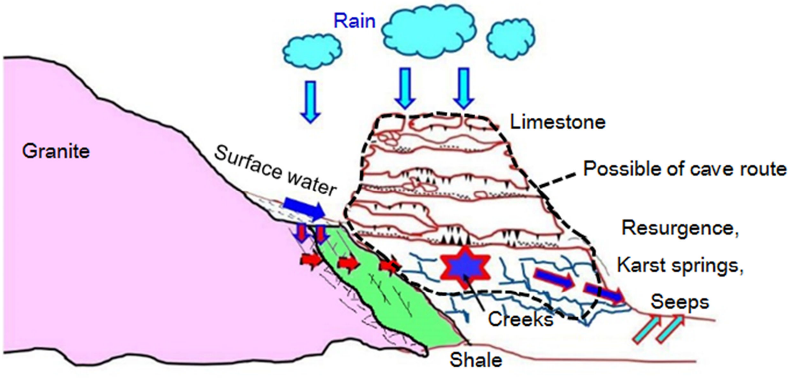


Figure 3 Geological model of the cave (Chaiporn, 2018).

Geophysical survey

Several geophysical methods were discussed in order to investigate the cave route. The Electrical Resistivity was initiatively selected as the primary method since it could be immediately executed and was more accurate than others. Afterwards, the Geophysical survey was also selected to provide useful information for geological modeling, drilling, and dewatering.

The seismic imaging technology from oil and gas industry could not work effectively due to the constraints of time. However, the depth of investigation for resistivity survey was limited by the equipment and environmental condition. Therefore, the application of earthquake scan was suggested instantly for the determination of cave route by detecting seismic signal altogether. As a results, the seismometers were installed on the top and around the mountain.

Drilling

The drilling activities aim to send messages of moral support to the Wild Boar members and to let them know that people outside were trying to help. Moreover, drilling over the projected route in Martin's map at the south of mountain which hopefully that it could reach the big cavity. This borehole was reamed and the divers may use this path to rescue the Wild Boar members. On the other hand, this borehole could be used as the location for the underground water pumping station.

Methodology

Geophysical survey

Since the large scale geological map was not available at that time, the first electrical resistivity survey line was started on June 29, 2018 in order to investigate the dip angle of limestone and location of the cave in the west part of mountain. A Geomative Resistivity meter -72 channels with 10 m of electrode spacing was also applied. Total survey line of 710 m from west to east across the mountain ridge with Wenner-Schlumberger electrode configuration had reached the maximum depth of 135 m (Loke, 2018). One cavity was found near the end of the survey line. It was assumed to be the connection between the cavity and the main chamber, which was lower than 40 m, but it had not touched the floor yet. Thus, the survey team planned to conduct a short electrical survey line to investigate this cavity in the next day.

On June 30, 2018, the using of 32 channels with 10 m of electrode spacing, reached the maximum depth of 60 m. This survey line was intersected with west-east survey line at 140 m and 595 m for south-north line and west-east line respectively (Figure 4).

On June 30-July 2, 2018, the electrical resistivity survey along the north-south creek of the mountain was performed using Syscal Pro resistivity meter - 96 channels with 5 m of electrode spacing. A survey line along the creek at the south of the mountain was crossing the cave route from Martin's map.

The earthquake scan technology was considered as another option for the mapping of the cave route. From the earthquake wave propagation theory, compression wave (P-wave) with higher velocity than shear wave (S-wave) was generated by earthquake activity. The different arrival time of P-wave and S-wave could be used for the determination of the distance between the epicenters of the quake to the record station. The seismic data collected from at least three different locations could be used to determine the epicenter by considering the point of its intersection. (Figure 5) shows the determination of the amplitude in order to derive the magnitude of the earthquake and distance from an earthquake epicenter to the record station.

Drilling

The DTH drilling technique was used for drilling activities. The first plan was to drill from the west of the mountain since the direction of three difference cave route was oriented on the west of the mountain. And this was expected as the nearest path to Pattaya beach where the Wild Boar members were assumed to be trapped. This drilling point was named D01.

At the D01 location, the drilling rig was powered by air electric generator. According to the limitation of accessibility of the location, the helicopter was used for airlifting under the limited load of 3.5 tons. The drill pipes had been mobilized manually. The 4 ½" DTH bit was used throughout the borehole.

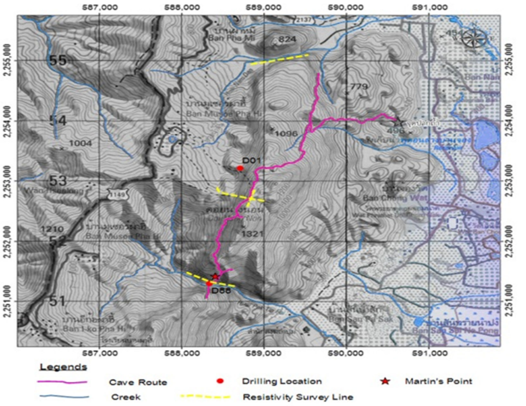


Figure 4 Electrical resistivity survey line and drilling location.

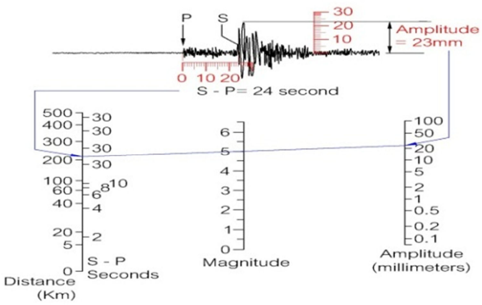


Figure 5 Determination of the magnitude and distance from seismic wave (Bolt, 1978).

At D88 on (Figure 4), the airlifting by helicopter was not possible due to the constraint of narrow valley and dense forest. Therefore, all equipment were transported manually such as portable drilling rig (PAT-Drill, 2018) was disassembled in order to reduce weight for the convenient transportation on a rough terrain. The air compressor was installed near the dirt road which was 1.2 km to the Delta 88. The pilot hole was started with DTH bit size of 6 ½”. Steel surface casing was run to the depth of 1.4 m, then 4 ½” DTH bit was drilled to 26 m depth.

Results

Geophysical survey

The resistivity survey with high and low resistivity zones were identified as cavity-limestone and shale, respectively. The high resistivity zones with possible cavity/chamber were also identified in both two resistivity survey lines. However, the high resistivity zones on both ends of the short survey line (Figure 6) were not identified as cavities, but may be later identified. The limestone and shale were considered to be useful information for geological modeling (Figure 3) and drilling operation.

The resistivity result at the north of the mountain (Figure 7a) also shows low resistivity zones along the survey line at various depth corresponding to the filed geological mapping. This was useful for the bypassing of the creek in order to reduce the water inside the cave.

The resistivity along the creek at the south of the mountain (Figure 7b) show low resistivity zone indicating possibility of flow channel near the Martin’s Point at the depth of 6.0-25.0 m. It may be used as the guideline for the divers’ operation. (Figure 8) shows the use of 400 m tubes to diverse the water in the creek from the north of mountain to the downstream.

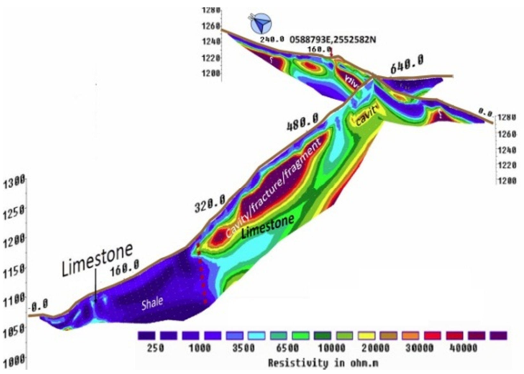
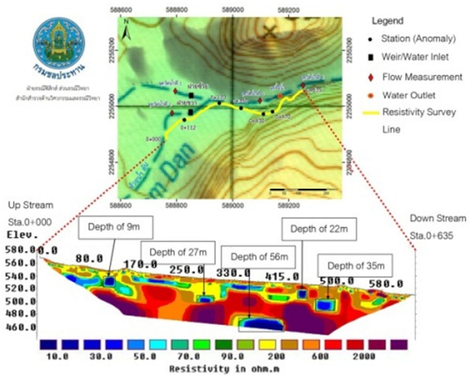


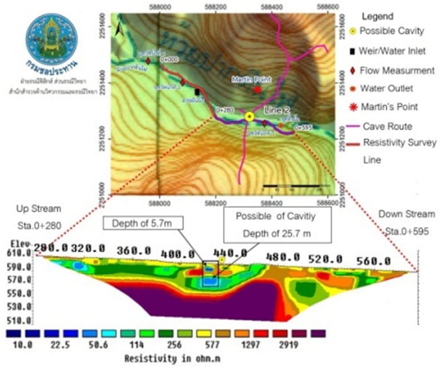
Figure 6 Resistivity survey results over the mountain.

On July 7, 2018 the seismic record was attempted by knocked the air tank on the cave floor. However, the result of this effort was not good enough to interpret due to the interference from a high level of ambient noise signal.

Seismic wave was investigated at the trial location on Tham Pla cave, 4 km. away as shown on (Figure 9). The 9 kg. sledge hammer was used to produce the wave. The P and S waves were not successfully recorded. With the limited time, the stronger sources were not tested.



(a) At the north of mountain.



(b) At the south of mountain.

Figure 7 Resistivity imaging results along the creeks.

Figure 8 Bypassing the creek at the north of mountain.

After 3 Wild Boar members were taken out of the cave, groups of scientists and geologists with their doubts in the potential of the seismogram after the test on July 8-9, 2018 had conducted another test on plain area with no limestone formation (Figure 10). Seismic record of this test was processed and finally could be used for the determination of P-wave and S-wave which also indicated an accurate position of the seismic source, (Figure 11).

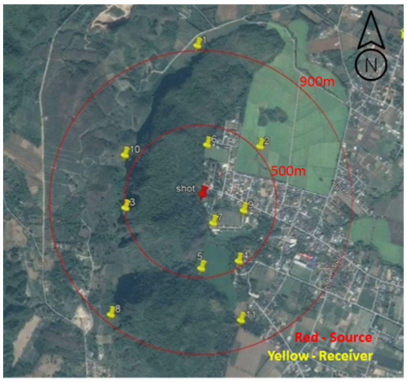
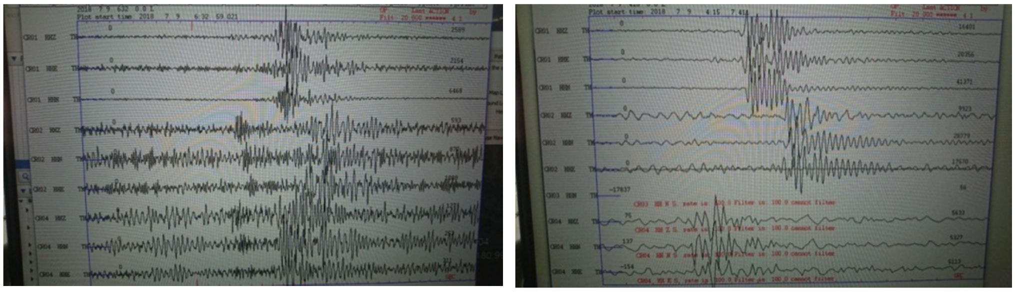


Figure 9 Earthquake scan test map.

Figure 10 Earthquake scan retest map.



(a) Raw data. (b) Processed data.

Figure 11 Results of earthquake scan retest.

Drilling

During the drilling at Delta 01 on July 2, 2018, which reached the depth of 15 m, the drilling team met the cavity. At the depth of 200 m, the drilling string was locked and paused the operation. Afterwards, the drilling was stopped by the command from the special warfare because they finally found all the Wild Boar members. On the next day the drilling team stopped the mission, uninstalled, and transported all the equipment back without any rain.

The drilling location Delta 88, on resistivity survey line (Figure 4 & 7b) at sta. 0+425, was aimed to investigate the cave route in accordance to the expected Martin's point.

Drilling result indicated geological layer corresponding to the resistivity survey result (Figure 7b), shown in (Figure 12). Low resistivity anomaly was located around 5.7 m beneath the ground surface followed by high resistivity zone from the depth of 12.0-25.7 m. Next to this layer was low resistivity zone which was the cavity that filled with water, sediment, or gravel.

The drilling results revealed that the first cavity at the depth of 7.0-8.2 m contained sandy clay mixed with gravel, and the second cavity at the depth of 15.0-16.0 m inside cavity contained difference sizes of loose packed gravels. At the third cavity found at the depth of 25.0-26.0 m, was loosed gravel, and no any water emerged during the drilling in this borehole. Loss circulation water was found in this borehole as well as D01.

The summary of evaluation of exploration methods that used in Tham Luang cave rescue mission is shown in (Table 1).

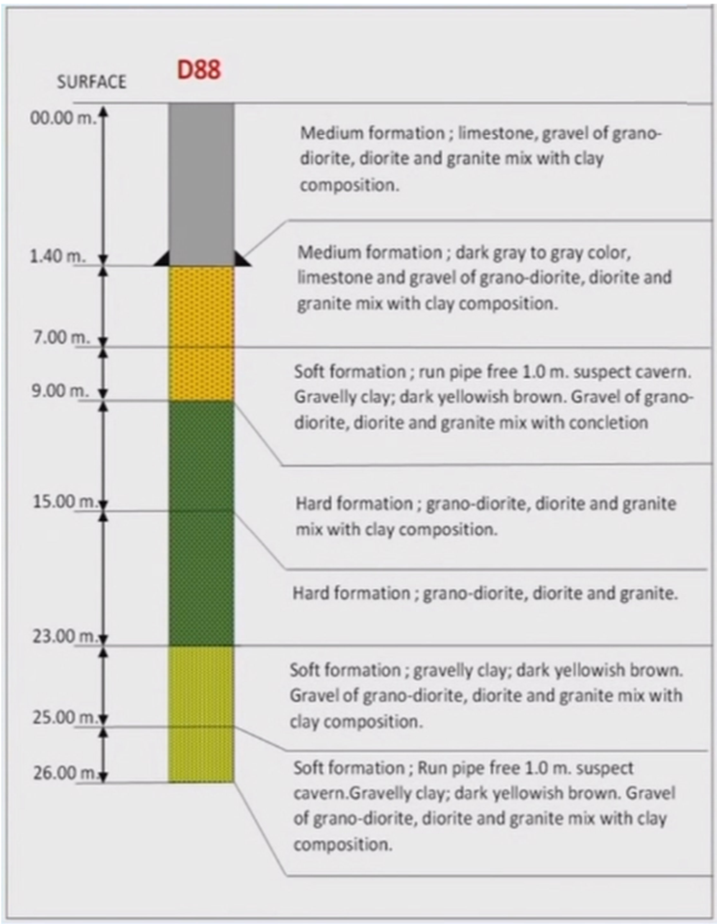


Figure 12 Drilling results of Delta 88.

Table 1 Summary of evaluation of exploration techniques used in Tham Luang cave rescue mission.

methods	physical property model	advantage	disadvantage	problem-solving
reflection seismic	depth/velocity models	high precision, deep penetration	time-consuming, relatively large energy was required with depth	none
resistivity Imaging	electrical resistivity model	fast to operate and get the result	requires good ground contact, less depth of investigation	improve ground contact, using long electrode array
earthquake scan	distance from the source model	fast to operate and get the result	sensitive to ambient noise, requires relatively large source	reduction of ambient noise
drilling	lithology model	most accurate method. Drill performance depends on weight and its capacity	relatively expensive, difficult to perform on a steep slope, the precision of target was required	site preparation, prepare precise target information

Discussion

Due to the constrains of accessibility of location and limitation of time, the resistivity survey was applied to locate the cave at possible exit point (Martin's Point) and inflow point of water into the cave.

The earthquake scan technology with sledgehammer source can be successfully applied over the uniform strata. However, the limestone formation without a uniformed layer, fracture, caves, chamber, had affected the wave attenuation. Therefore, the strong seismic source was necessary to improve seismic record of limestone formation.

Delta 01 was located on shale at elevation of 1,040 m MSL. From an assumption, if the cave was located at 500 m MSL, the depth of drilling at 540 m TVD was possible by the machine afforded on that day. But the transportation of the drilling rig and it components to the drilling location was very difficult due to the condition of the forest. Only alternative was an air lifting by helicopter.

At the late of July 8, 2008, the drilling to Delta 88 pass through the low resistivity zone and stopped at the depth of 26 m which was a hard granite layer. The low resistivity zone at this location had no water as expected, which might be due to the bypassing of the creek and dewatering. The high resistivity zone at this location, that was expected as a cavity, were not suitable for rescue mission and dewatering since the area was filled with a large quantity of sediments. By that night, the governor had officially announced that the first group of Wild Boar members had been rescued.

Conclusion

The heavy downpour over the mountain was considered as the key obstacle to the rescue mission since it caused a rapidly risen of the water level inside the cave. To overcome all of the problems and obstacles of the mission, the collaboration of concerned persons from domestic and international sectors and the application of their expertise had made this mission possible and success.

Geophysical exploration program was applied in order to provide useful information for mapping, drilling, and water management teams. The resistivity survey method was selected since it allowed the mission teams to create an accurate mapping of the geological structure of Tham Luang and underground water flow channels. The resistivity results assisted the creek to bypass over the cave that caused the dewatering performance. However, the result of the application of earthquake scan technology had not met the mission team's expectation due to the interference of a high level ambient noise and low seismic source energy. The proper cave route survey will be performed in the coming dry season to verify the resistivity imaging results.

The water management was successful by the methods of groundwater pumping, drainage inside the cave, and the bypassing of the creeks at north and south of the mountain. These caused the reduction of water level that the diver team can walk through chamber 2 and chamber 3 which are located from the entrance of around 300 and 1500 m, respectively, and the rescue mission began after that. However, the divers still needed to dive from chamber 3 to chamber 4, where the boys and their coach were found at around 2400 m from the entrance.

The Joint geophysical surveys and dewatering had successfully reduced water levels, making the rescue mission possible.

Acknowledgement

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