

The New Survey Result On Lava Cave System In Krongno Volcano Geopark, Dak Nong, Vietnam, In 2017-2018

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1. Introduction: Recently, Vietnam is well-known as an emerging and leading country on lava cave in Southeast Asia and plays an important role not only in Asia but also in the world in the field of volcano geological heritage and volcano geopark as well.

The research on geological heritages, especially volcano geological heritage and lava cave in Krongno area and the vicinity, with the aim to establish Krongno Volcano Geopark (KVG) in Dak Nong province, The Central Highlands of Vietnam, has been started from 2007 by Dr. La The Phuc and his colleagues in the frame of a scientific project funded by UNESCO¹⁾. Lava caves in the area have firstly been discovered during the implementation of this project. The discovery of the lava cave was immediately released to the world by the project's leaflets and Vietnamese news. Catching the news, the NPO Vulcano-Speleological Society (VSS) of Japan independently conducted a preliminary survey in 2012 and then conducted some joint surveys and studies between Vietnam and Japan from 2013 until 2015^{2~8)}. In the first collaborative stage, as a result, 11 lava tube caves have been measured and one of them (C7) was registered as the longest lava tube cave in Southeast Asia of 1066.5m long. Containing a series of typical and marvelous lava interior formations, so in the KVG Dossier prepared by VNMN, the C7 cave is ranged as an international geological heritage.

The total length of the 11 lava caves measured in the first stage is 4832.5m long (Table 1; Fig.1).

In the second stage from 13th February to 25th 2017, as a contract work between Vietnam National Museum of Nature (VNMN) and VSS, in the frame of the project entitled “Study and assessment of geological heritages, construction of the geopark in the Krongno area, Dak Nong province” funded by Dak Nong province, 4 lavacave more have been surveyed and measured including: P8; P11; P20 and P1 + P2 with the length of 1940.7m. In this stage, the P8 and P20 have been measured therefore are considered as two deepest caves in KVG of 26m and 25m deep, respectively (Table 1; Fig.1)⁹⁾.

The third stage conducted by Vietnamese members for 5 lava caves: P3; P5; P10; PT06 and T1 with the length of 948.1m (Table 1; Fig.1)¹⁰⁾.

The discovery of archeologic stone wares etc. in P1/P2 cave and previously measured C61 cave and the biological aspects of the caves are an important human heritage for a volcanic cave Geopark¹⁰⁾. As the biological and archeological aspects of these caves are discussed in the other paper¹⁰⁾. So, in the paper, only the topology and the structure of the lava caves, those surveyed and measured in 2017-2018 (the second and the third stages) will be mentioned.

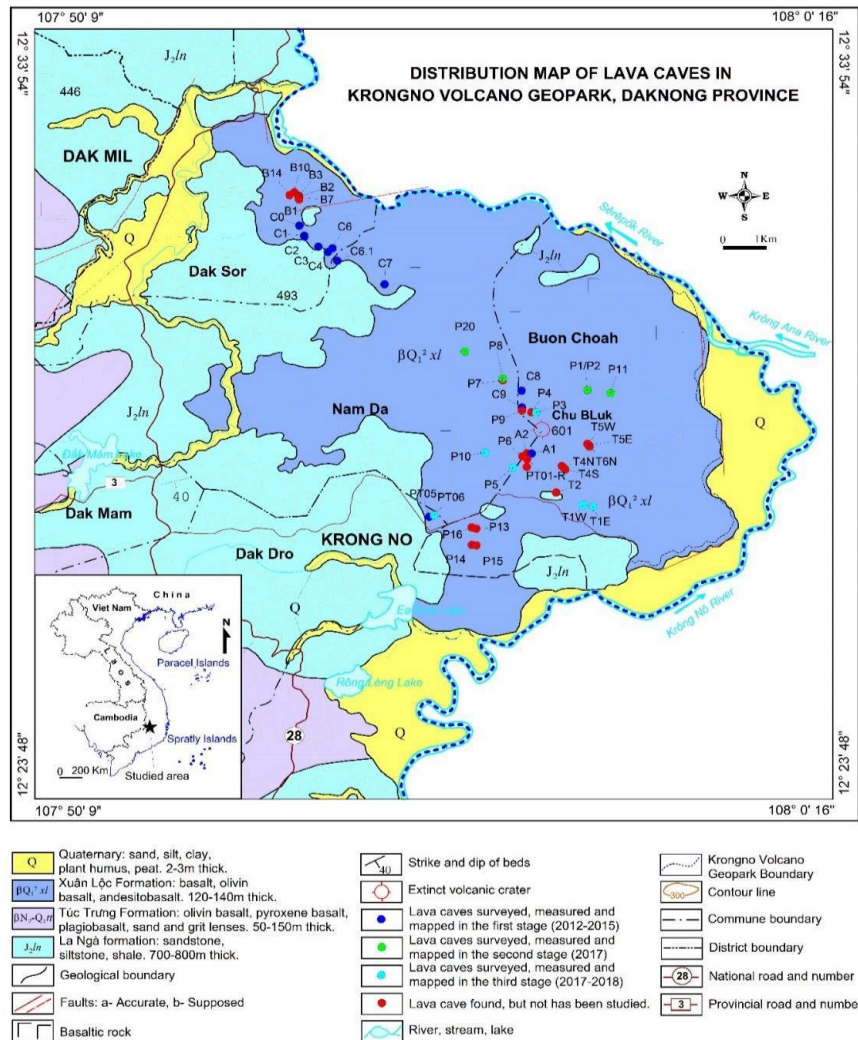


Fig.1. Distribution map of lava caves in Krongno Volcano Geopark, Dak Nong province, Vietnam.

Table 1. List of 20 lava caves surveyed and mapped in Krongno Volcano Geopark, Dak Nong, Vietnam up until March 2018 ^{1~10)}

N ^o	ID	Location	Longitude	Latitude	Length (m)	Depth (m)	Entrance type
The lava caves surveyed, measured and mapped in the first stage (2012 – 2015)							
1	C0	Dak Sor	107° 53' 32.87"	12° 31' 18.69"	475.5	14.9	combined
2	C1	Dak Sor	107° 53' 34.35"	12° 31' 11.00"	402.0	3.5-4.5	secondary
3	C2	Dak Sor	107° 53' 35.39"	12° 31' 10.04"			secondary
4	C3	Dak Sor	107° 53' 47.24"	12° 31' 2.35"	716.3	7.3	secondary
5	C4	Dak Sor	107° 53' 52.28"	12° 30' 57.91"	251.5	9-10	secondary
6	C6	Dak Sor	107° 53' 57.02"	12° 31' 0.91"	180.3	4.3	secondary
7	C6.1	Nam Da	107° 53' 59.76"	12° 30' 51.23"	293.7	4.6	secondary
8	C7	Nam Da	107° 54' 35.12"	12° 30' 32.47"	1066.5	15-20	combined

9	C8	Buon Choa'h	107° 56' 19.20"	12° 29' 8.53"	791.0	23.8	secondary
10	C9	Buon Choa'h	107° 56' 20.03"	12° 28' 55.59"	217.0	22.6	combined
11	A1	Buon Choa'h	107° 56' 28.73"	12° 28' 19.67"	438.7	10	combined
Total length of 11 caves surveyed, measured and mapped in the first stage:					4832.5 (m)		
The lava caves surveyed, measured and mapped in the second stage (2017)							
12	P1, P2	Buon Choa'h	107° 57' 10.14"	12° 29' 8.57"	530.5	15-18	secondary
13	P8	Nam Da	107° 56' 5.74"	12° 29' 18.07"	344.1	26	primary
14	P11	Buon Choa'h	107° 57' 28.24"	12° 29' 5.97"	498.1	7-9	secondary
15	P20	Nam Da	107° 55' 37.67"	12° 29' 39.58"	568.0	25	primary
Total length of 4 caves surveyed, measured and mapped in the second stage:					1940.7 (m)		
The lava caves surveyed, measured and mapped in the third stage (2017 - 2018)							
16	P3	Buon Choa'h	107° 56' 32.87"	12° 28' 51.52"	81.0	5	secondary
17	P5	Buon Choa'h	107° 56' 13.01"	12° 28' 8.86"	204	4.2	secondary
18	P10E P10W	Nam Da	107° 55' 54.22" 107° 55' 52.45"	12° 28' 20.06" 12° 28' 20.82"	160	4.5	secondary
19	PT06	Dak Dro	107° 55' 16.68"	12°27'28.62"	200	5	secondary
20	T1	Buon Choa'h	107° 56' 59.80"	12° 27' 42.69"	303.1	16	combined
Total length of 5 caves surveyed, measured and mapped in the third stage:					948.1 (m)		
Total length of 20 lava caves surveyed and mapped in the 3 stages:					7721.3 (m)		

2. The caves surveyed, measured and mapped in the second stage: They include the following caves: P1/P2, P8, P11 and P20.

[Cave P1/P2] The P1/P2 location is shown in Fig.1, and the structural map and it's features are shown in Fig.2 and photo-1~photo-6. The cave is located 1.450m northeastern of the Chu B'Luk volcano. It is a compound cave in which the caves of P1, P2 overlap each other. This is a close subsurface lava cave with a total extension distance of 530.5m. P1/P2 cave was formed from lava flows originated from Chu B'Luk volcano in the southwest. Lava flows forming the P1/P2 cave occurred in various/episodic phases, in which later lava flows altered, and cause instability to, the previously formed structure of

the cave, even collapsed the ceiling in some place and created the secondary entrance and skylights of this cave system.

P1/P2 cave was formed from lava flows originated from Chu B'Luk volcano in the southwest. Lava flows forming the P1/P2 cave occurred in various/episodic phases, in which later lava flows altered, and cause instability to, the previously formed structure of the cave, even collapsed the ceiling in some place and created the secondary entrance and skylights of this cave system.

P1/P2 cave has thin and unstable ceiling layers, which make it dangerously easy to collapse and the geoheritage to be destroyed.

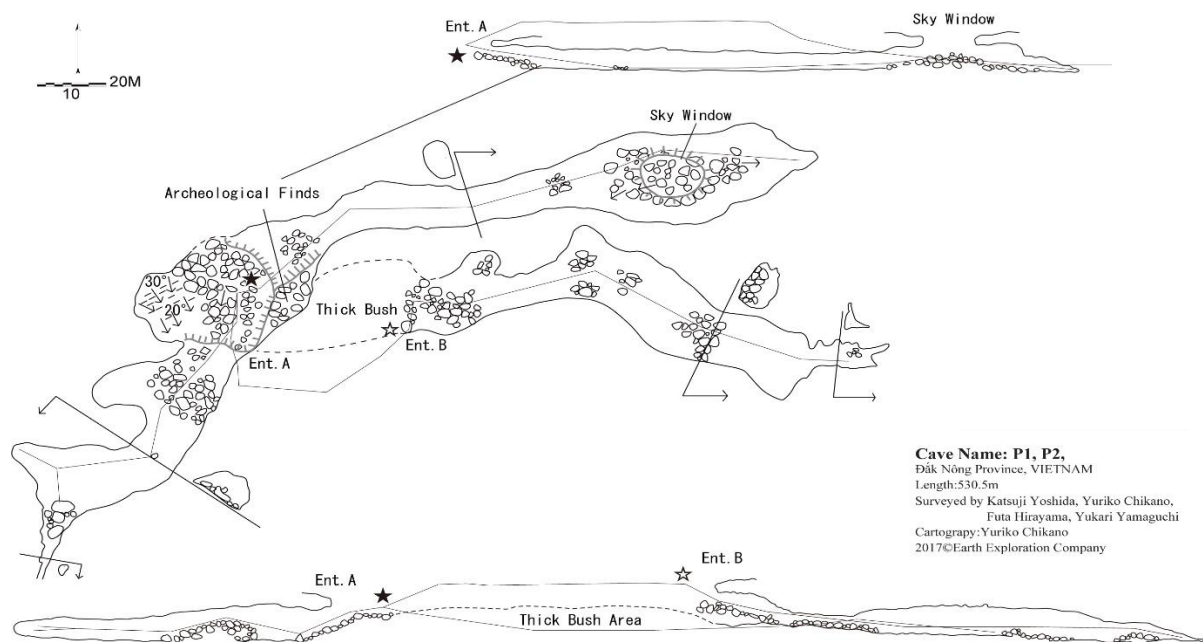
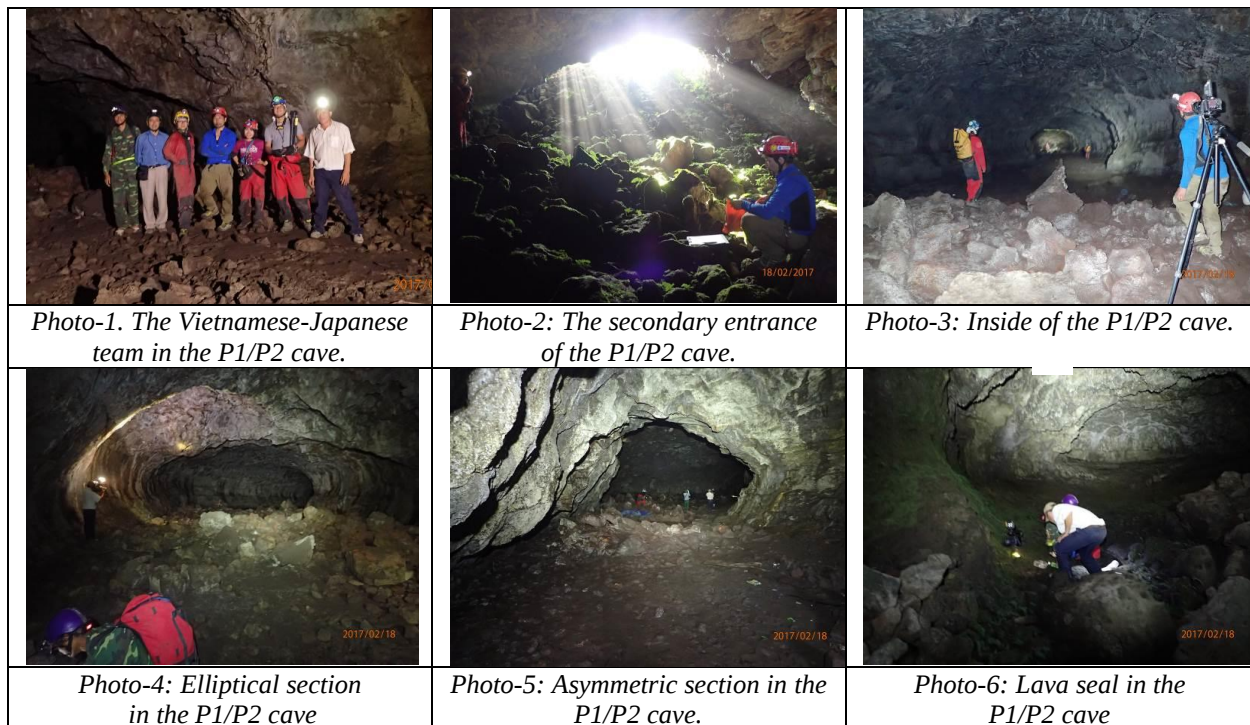


Fig.2. Structural map of the P1/P2 lava cave.



[Cave P8] The overall cave shape is shown in Fig.3. This is a lava tube cave with a total extension distance of 344.1m and 26m in depth with a vent hole. The cave is 1,556 m northwest to the Chu B'Luk crater (Fig.1) and was created from a high-temperature lava flow, gas rich, low

viscosity, ran along a quite deep valley. Hence, the cave ceiling layer is quite thick and has very large fluctuation: most anticipated thickness can be up to over 20m in upstream area and ultra thin, only about a few dozen centimeters at the cupolar in the downstream of the cave.

The P8 cave entrance is a typical primary type, formed due to the busting lava gas. Therefore, the P8 entrance is quite round and deep vertical to 26m as mentioned above. In fact, it is also a skylight (vertical opening of vent hole) of the P8 cave.

Photo-7 to Photo-15 show some features inside of the P8 lava cave. Stalactites and stalagmites in the cave could be considered probably as calcium carbonate or silicate, so they need to be studied more in details in the future.

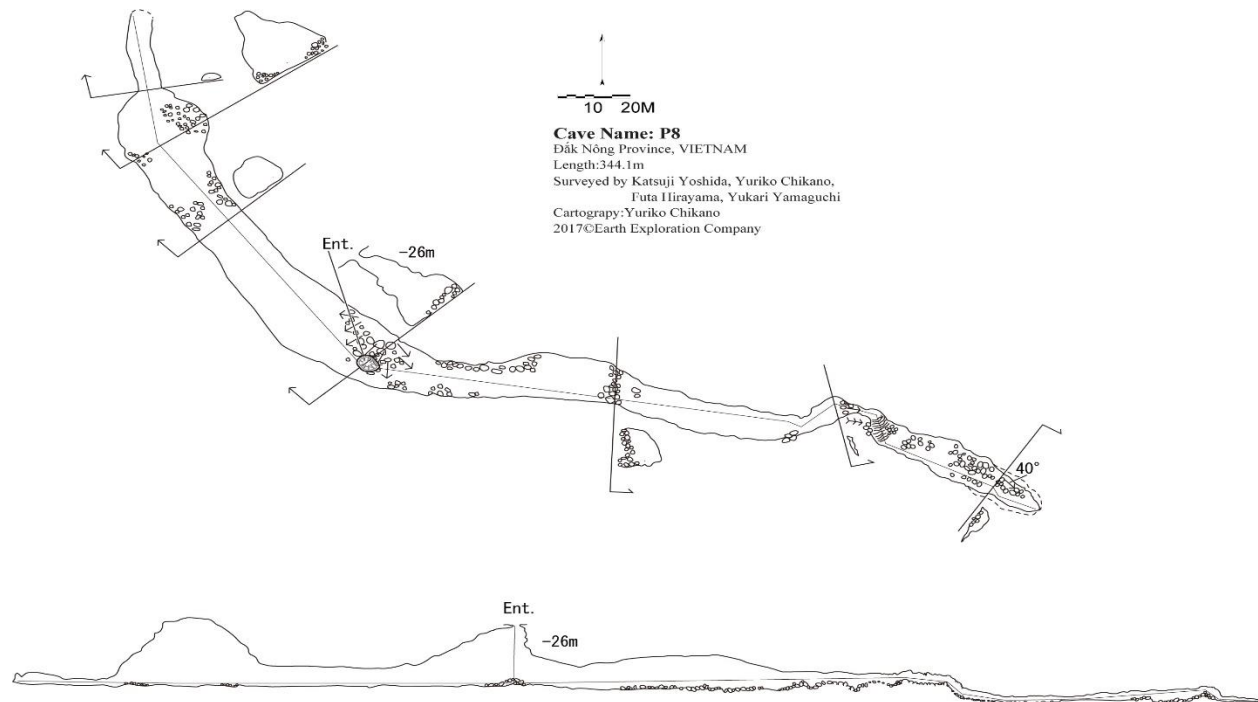


Fig.3. Structural map of the P8 lava cave.

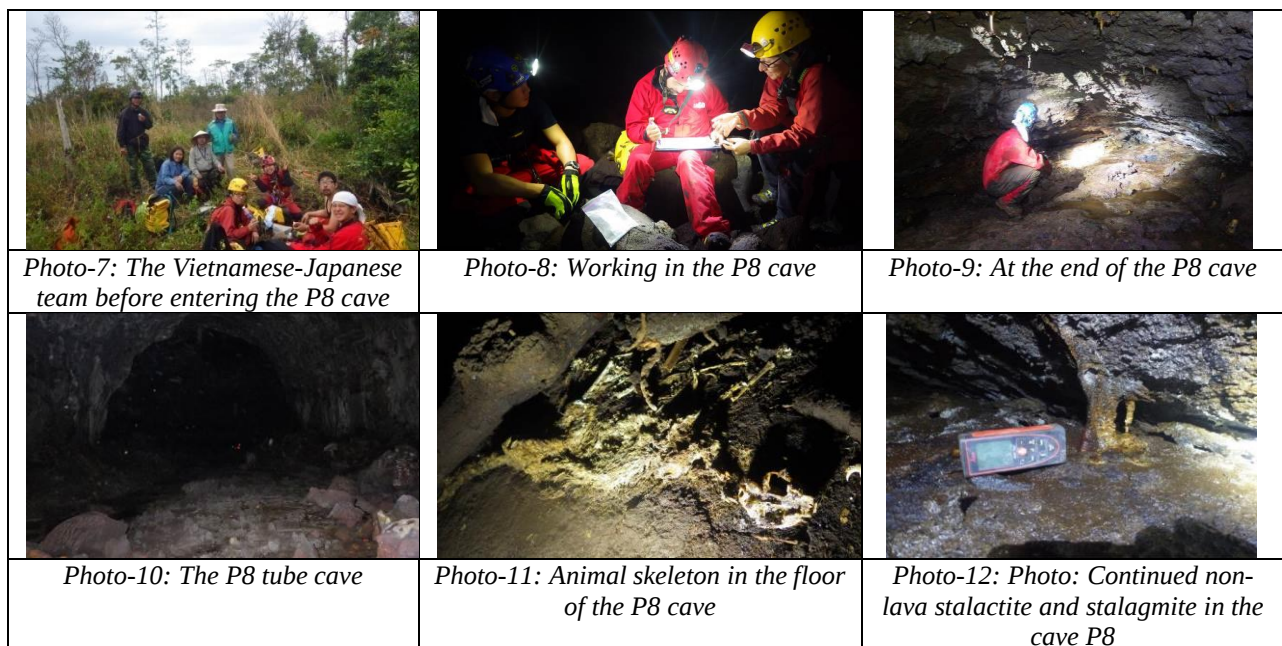




Photo-13: Inside of the P8 cave

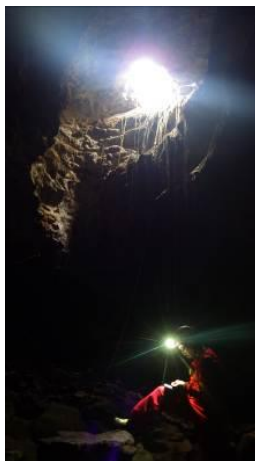


Photo-14: Endogenous entrance in P8 cave



Photo-15: Secondary stalagmite in P8 cave

[Cave P11] The overall cave shape is shown in Fig.4. This is a lava tube cave with a total extension distance of 498.1 m.

P11 Cave is located 1,853m in the northeast of Chu B'Luk volcano, near the east of the P1/P2 cave. The P11 cave mainly developed from northwest to southeast; although its middle section bended towards the sub-latitudinal direction, possibly due to impacts from the paleo-terrains. This part has collapsed and created two entrances facing each other: East and West (Fig.4).

Due to the fact that the P11's cave chamber is fairly wide with appealing dome-shaped ceiling (elliptic cross section), and a flat floor, the name proposed was "Krongno Hall Cave" to allude to its fancy (Figure 5, 6). So the P11 cave has great potential for geo-tourism thanks to its many inherent values. Photo-16 to Photo-24 show some typical features of the P11 lava cave. There are two types of stalactites in this cave: primary and secondary origin with unique drapery (flag) type. Stalactites are considered probably as calcium carbonate or silicate.

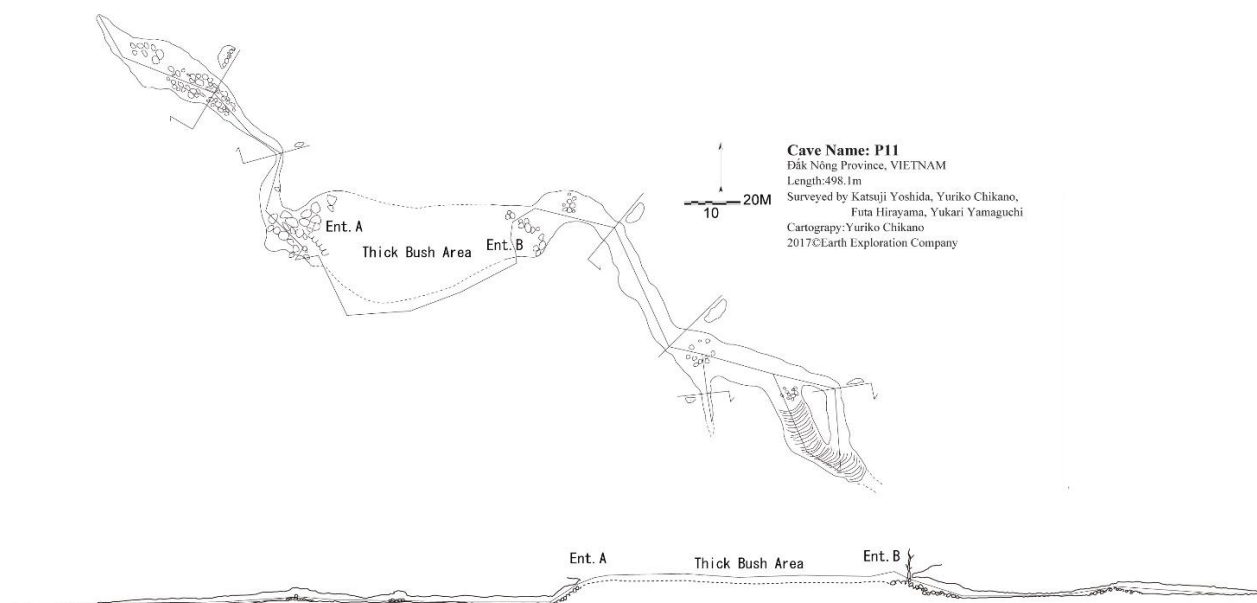


Fig.4. Structural map of the P11 cave.

		
Photo-16. Krongno Hall - The main chamber of the P11 cave	Photo-17. Lava levee in P11 lava cave	Photo-18. Lava flow direction in the floor of the P11 lava cave
		
Photo-19. Semi-rounded lava linings in the P11 lava cave	Photo-20. Lava flows drained at the end of the P11 lava cave	Photo-21. Primary stalactites on the ceiling of the P11 lava cave
		
Photo-22. Upstream of the P11 lava cave	Photo-23. Drapery non-lava stalactites in the P11 lava cave	Photo-24. Primary stalactites on the P11 lava cave's wall

[Cave P20] The overall cave shape is shown in Fig.5. This is a lava tube cave with a total extension distance of 568.0 m. The P20 interior features will be illustrated in photo-25 to photo-31.

The P20 cave is located 2,602m from the Chu B'Luk crater to the northwest, just south of the C7 cave, on the same axis (Fig.1). Due to being formed from a large lava flow, the P20 has a very thick cover and up to > 15m. The ceiling cover is basically thick and relatively stable, although some sections of the cavern are still in the ceiling, leaving the products to collapse on the cave floor.

Similar to the P8 store, the P20 store is also of primary origin as it is formed by the discharge of lava from a chamber of high pressure gas in a lava tube. P20 cave is a volcanic cave formed from a lava flows flowing in the valley of paleo-terrain should have large thickness, with the direction of stable development from the Southeast to the Northwest. The width of the cave from upstream to downstream remained relatively stable, average from 12m-15m. Most of the lava formations in the P20 cave are re-melted and "enameled" by the high temperature of the late lava flows.

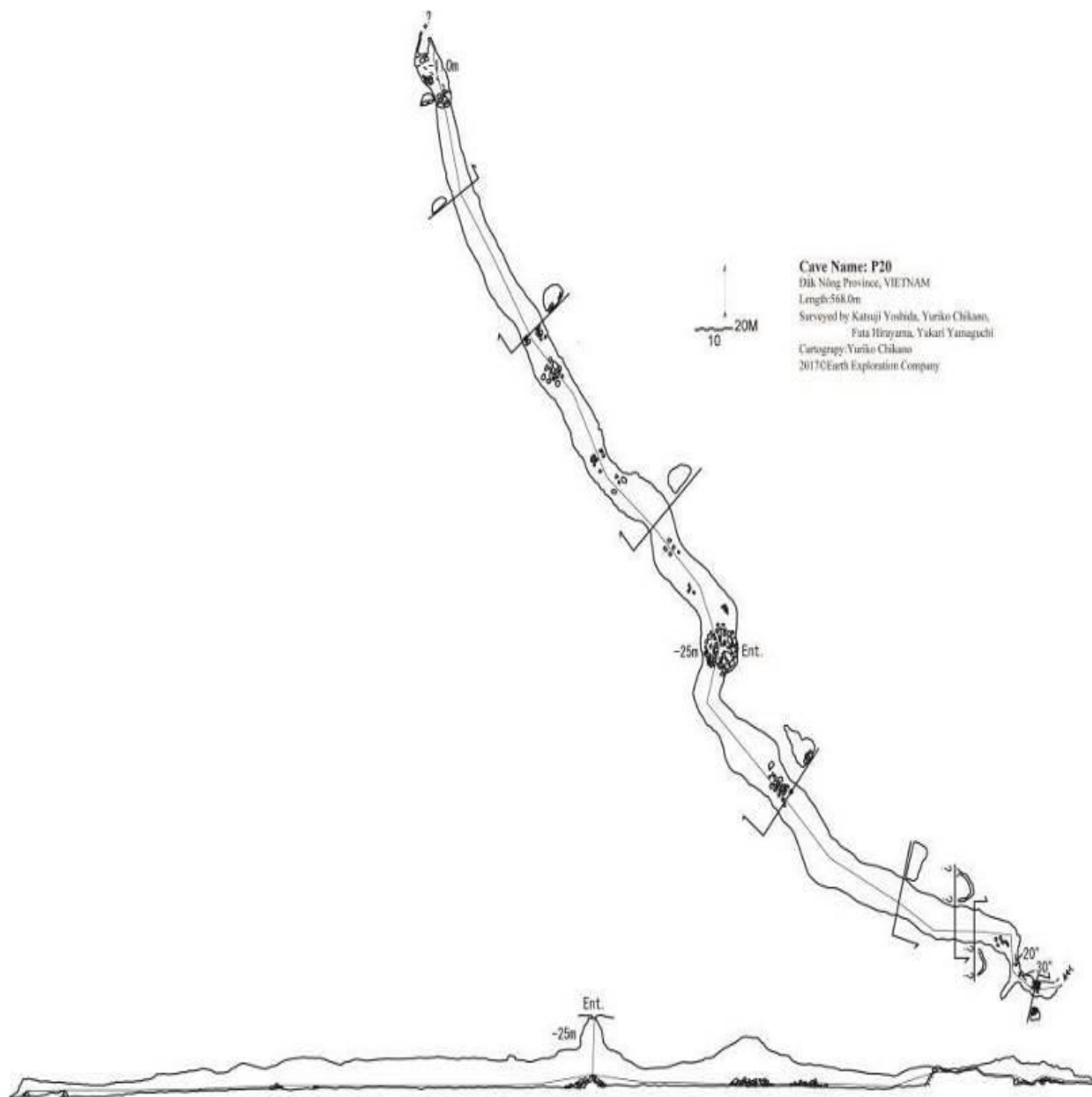
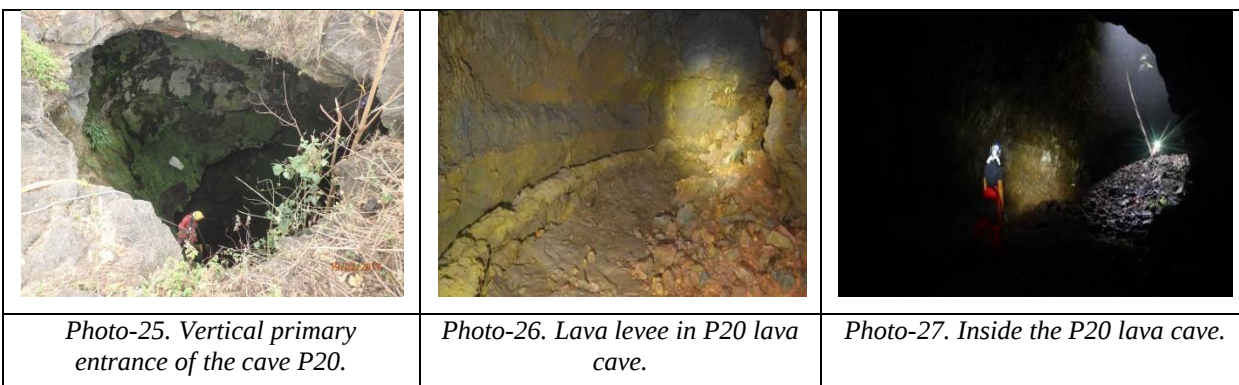
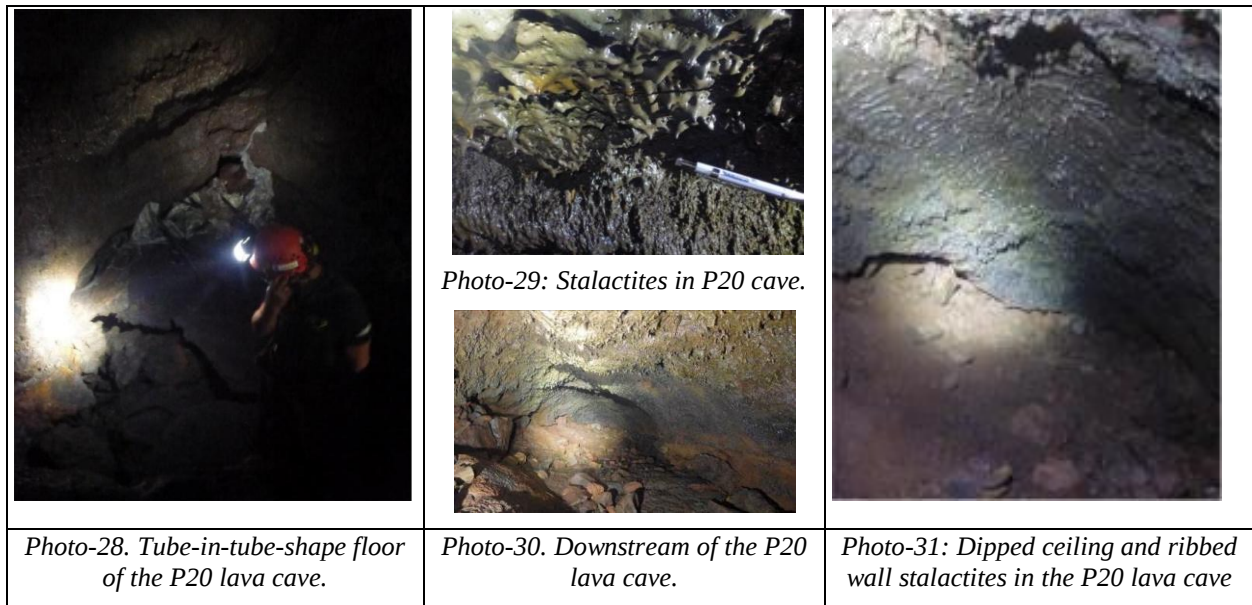


Fig.5. Structural map of the P20 cave.





[Cave P3] P3 lava cave is quite close to Chu B'Luk volcano, just 473 m in the north-northwest (Fig.1). The P3 interior features will be illustrated in photo-32 to photo-37.

This is a cave with a less complex formation and structure than other caves, which reflects the lava flow with large energy, rich in gas. Originally, the lava flow in the straight direction toward the crater, then it changed direction aligning with a trench (NW-SE direction) of the paleo-terrain. P3 has many sections with roof collapse that created breakdowns, which make going in and out rather difficult.

Cave P3 has a single and relatively circular entrance formed by roof collapse.

Overall development direction of P3: Besides the short section of the cave of 5m running in the sub-longitudinal direction; the rest of P3 developed in linear towards the southeast - northwest 310° (Fig.6).

P3 has relatively flat floor that is lower in the upstream in the southeast and gradually higher in the northwest, concave ceiling. These created 2 high level distinctive from each other, where lever 1 is the lower section in the SE (Fig.6).

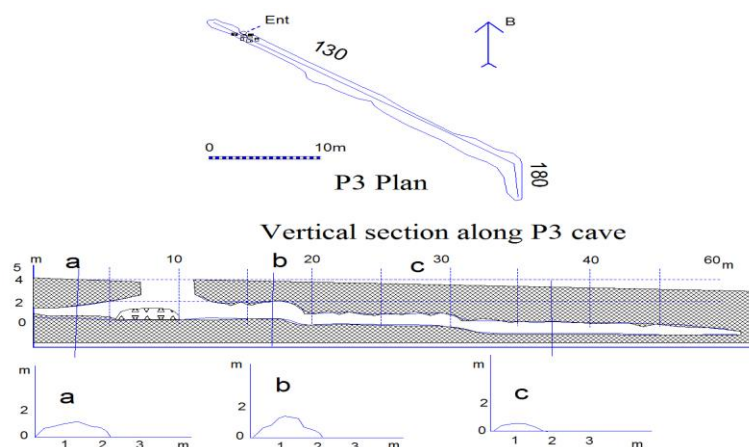
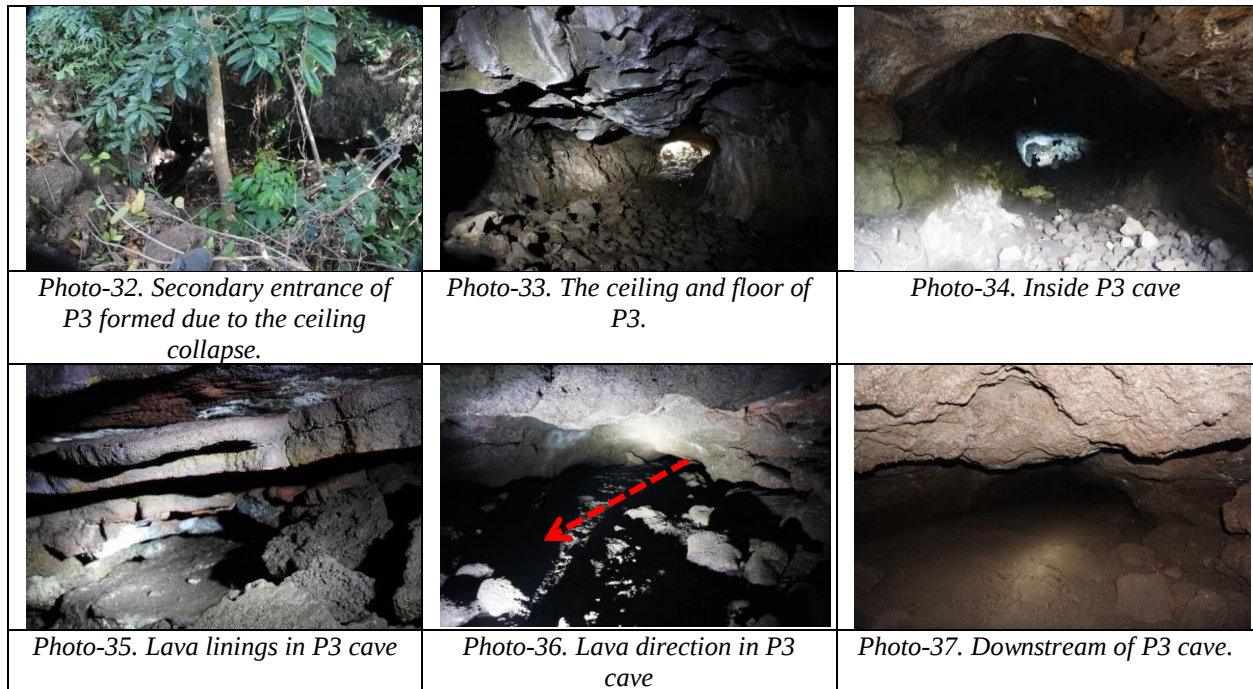


Fig.6. Structural map of P3 lava cave.



[Cave P5] Cave P5 is located about 1.080m to the southwest of Chu B'Luk crater (Fig.1). It developed quite zigzag due to the paleo-terrain, where the lava flows were controlled (Fig.7).

There are many seals developed in the cave, where late lava flows run into the main tube through lava skylights, then those windows were

sealed. The only sole mixed entrance is in the Southwest downstream of P5 lava cave.

The P5 interior features will be illustrated in photo-38 to photo-47.

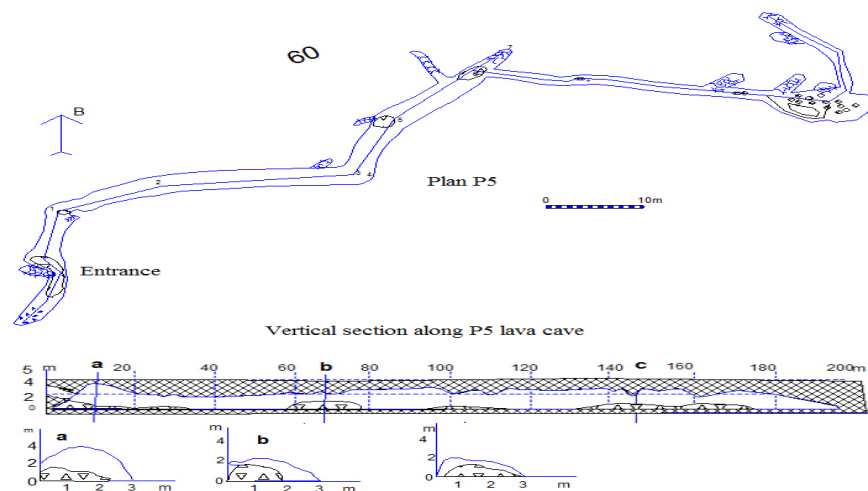
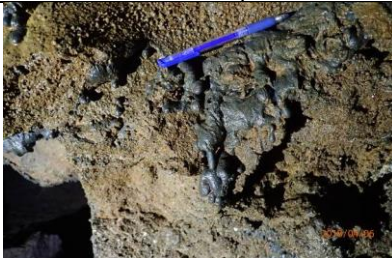


Fig.7. Structural map of the P5 cave.

		
<i>Photo-38: It's difficult to go through the narrow entrance of the P5 cave.</i>	<i>Photo-39: One of lava seals in the P5 lava cave.</i>	<i>Photo-40: Cupular in the P5 lava cave</i>
		
<i>Photo-41: Primary stalactites</i>	<i>Photo-42: Grape-like stalactites in the P5 lava cave</i>	<i>Photo-43: Glaze-stalactites in the P5 lava cave</i>
		
<i>Photo-44: Running stalactites in P5</i>	<i>Photo-45 (left); Photo-46 (right): Secondary stalactites in the P5 lava cave</i>	<i>Photo-47: Drainage exit of the P5 lava cave</i>

[Cave P10] P10 is located 1,310m northwest of Chu B'Luk volcano (Fig.1). Cave P10 is a subcrustal, shallow, extend in sub-latitudinal linear, and non-stratified (Fig.8). The P10 interior features will be illustrated in photo-48 to photo-57.

The cave has two entrances of secondary origin, as they are formed from roof collapse in the middle of the cave: East entrance facing west and West entrance facing east. These two entrances are formed from a cave ceiling collapse about 10m wide near the upstream of the cave, dividing

the cave into two branches: east branch and west branch.

Cave P10 is the only surveyed cave in KVG that turns out to be subcrustal lava cave, with a different mechanism of formation from other caves.

P10 is a shallow, semi-submerged cave with a roof cover from 1m to 1.5m.

The P10 is subcrustal lava cave, small in size, formed by the gas pressure in the lava flow that pushes the hard shell above it. Some authors

(Stevenson, 1999; Ken G. Grimes, 2002; Gadányi, 2010) explained that the mechanism of this cave formation was due to the high pressure in the

lava tube which raised the hard shell up to form a cave, (blister or inflation).

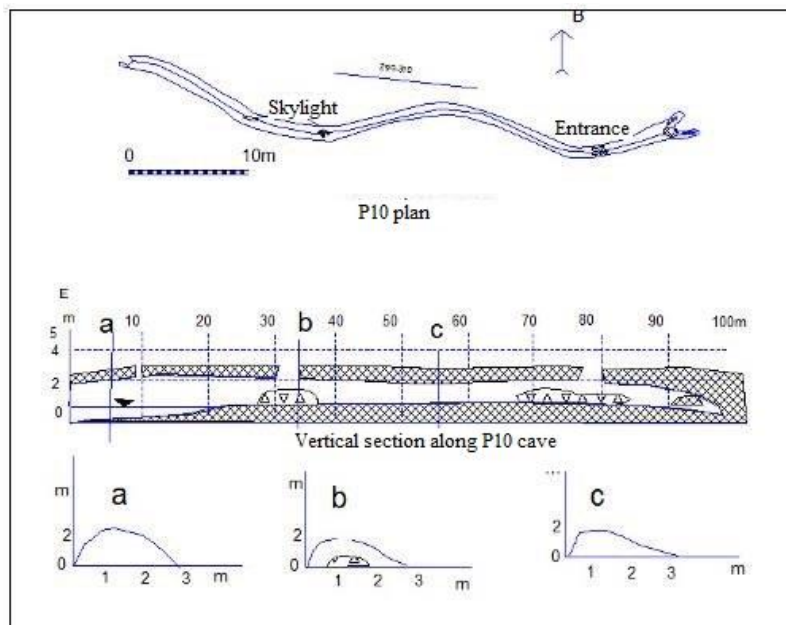
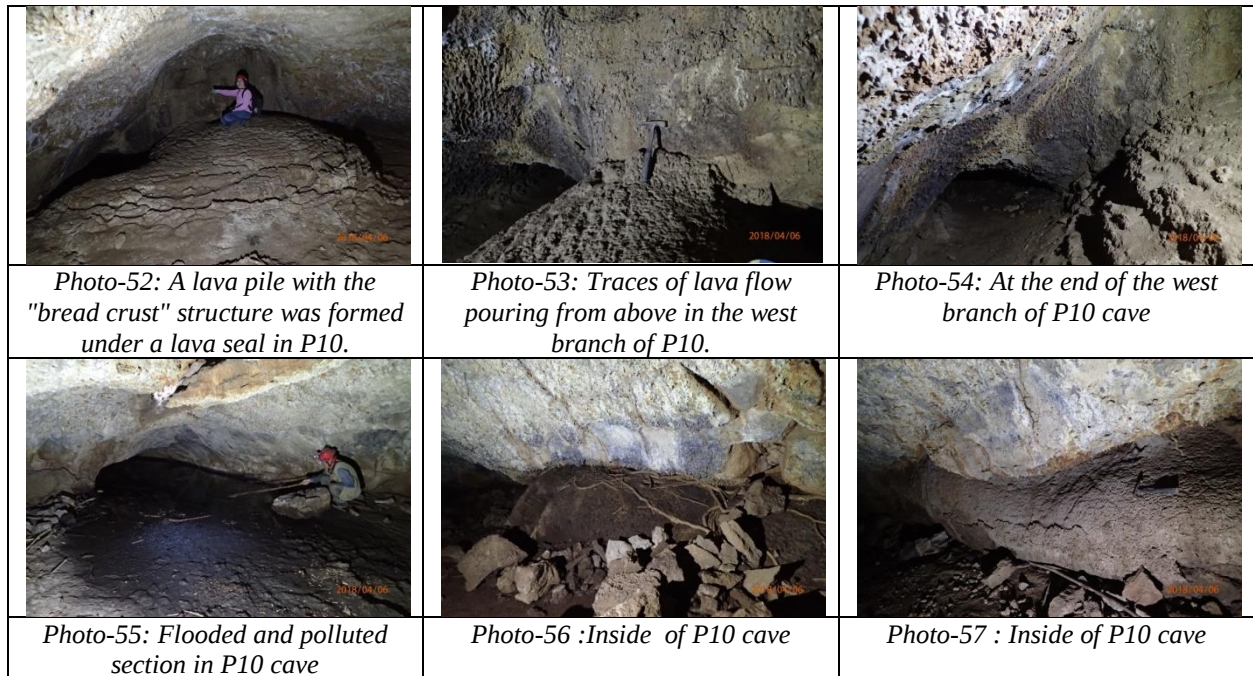


Fig.8. Structural map of P10 cave.





[Cave PT06]: The PT06 is located 3,240m northwest of Chu B'Luk volcano (Fig.1). The cave is formed from lava flowing from the Chu B'Luk volcano in the northeast to the southwest with a fairly flat trough on the paleo terrain. This

cave has a mechanism of formation as well as a simple cave structure with traces of overflow on the surface of paleo terrain. PT06 floor is composed of products that are very messy, rugged and difficult to go.

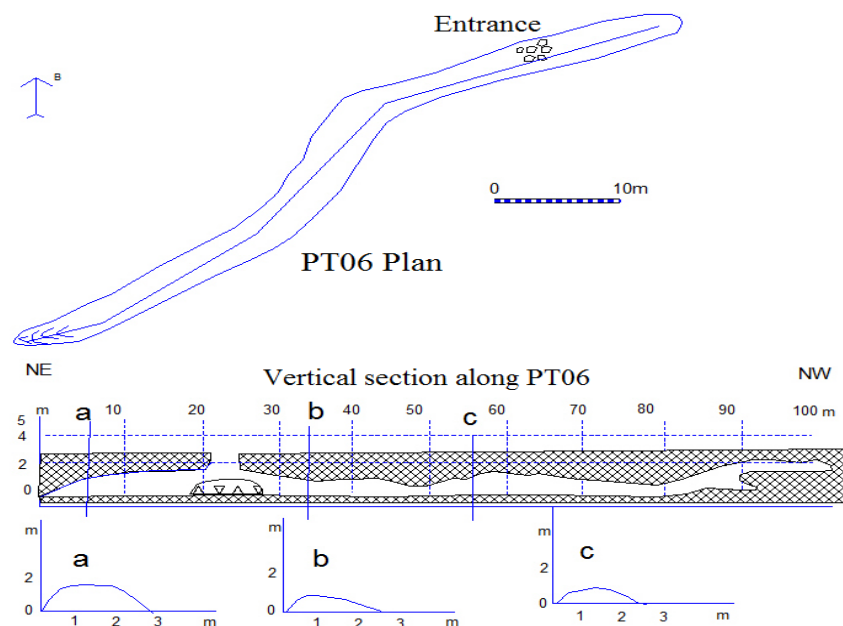


Fig.9. Structural map of PT06.

With the length of 193,0m, PT06 has only one entrance located northeast of the cave. PT06's entrance is a secondary entrance, formed by the process of cave ceiling, narrow entrance cave entrance.

Lava flows originating from Chu B'Luk volcano in the northeast flowing to the southwest, and clinging to the valley of paleo-terrain (NW-TN direction) on the basis of simple terrain, creating a simple lava cave (Fig.9).

Lava flows of the next eruption phase also have low viscosity flowing into the cave area, creeping into the cracks as well as various layers of lava that make up the pahoehoe structure. On the ceiling of PT06 developed some oval shaped cupolars. These cupolars are the result of the gas accumulation of the lava flow during cave formation.

The PT06 interior features will be illustrated in photo-58 to photo-63.

		
<i>Photo-58: The ceiling is curved, asymmetrical in PT06</i>	<i>Photo-59: Small cupolar and oriented stalactites in PT06 cave</i>	<i>Photo-60: Tongue-shape lavafall in PT06 lava cave.</i>
		
<i>Photo-61: Traces of lava flow direction on the PT06 cave floor.</i>	<i>Photo-62: Primary stalactites in the PT06 cave</i>	<i>Photo-63: Narrowed drainage exit in the downstream of the PT06 cave</i>

[Cave T1]: T1 cave is located 1,830m south-east of Chu B'Luk volcano (Fig.1). The cave direction develops from northwest to southeast. With the length of 303.1m and two secondary entrances, T1 cave is one of the very complex structure caves bearing many unique interior lava formations. The T1 interior features will be illustrated in photo-64 to photo-72.

The mechanism of formation of the T1 cave is very complex, as the basalt lava flows of Chu

B'Luk volcano from the northwest run to the southeast and cling to a valley of paleo terrains with an undirected direction. The T1 cave with thick cover. Interior formation in the cave has many unique formations on the regional level, such as: pahoehoe and A'a lava, lava flow, lava waterfall, lava window, lava seal, lava lake, pipe-shape linings, primary and secondary stalactites, pillow-shape lava considered unique geological heritages in the region as well as in the world.

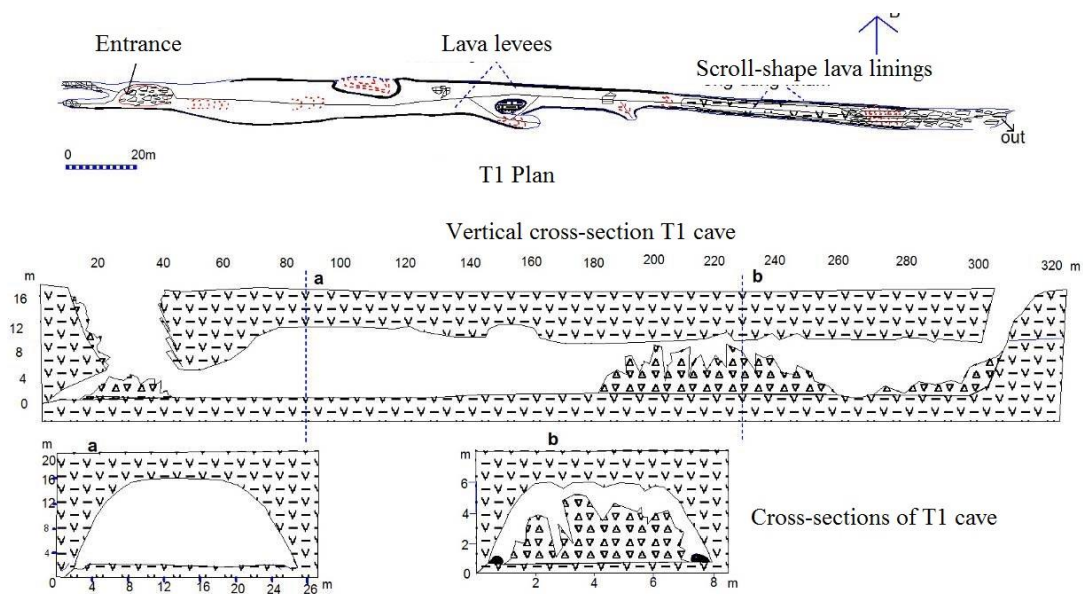


Fig.10. Structural map of the T1 lava cave.

		
Photo-64: Western entrance of Cave T1, viewed from inside	Photo-65: The gas holes with some cm deep in T1 lava cave linings	Photo-66: A big cupular in T1 cave
		
Photo-67: Seal-shape lava pile in the foot of a lava seal in T1 cave	Photo-68: Secondary stalactite in the T1 lava cave.	Photo-69: Lava lake in T1 cave
		
Photo-70: Pipe-shape lava linings in T1 cave	Photo-71: Pillow-shape lava in the T1 cave	Photo-72: Secondary stalactite in T1 cave

3. Concluding remarks and future work:

According to results of the 2017-2018 surveys, there are many new discoveries on the KVG lava caves:

- Besides lava formations with their endogenous genesis such as dipped and ribbed lava, tube-in-tube shape structure, pipe-shape linings, pillow-shape lava, etc., of molten lava on the ceiling, wall and floor, we have also discovered other non-lava formations (secondary genesis): secondary stalactite/stalagmite; drapery-shape stalactite, rose-shape stalactite etc.
- Besides almost ordinary lava tube caves those are lower than topography surface, we have surveyed, measured and mapped P10 lava cave as an only subcrustal lava cave of KVG.
- Many archaeological relics have been found in some KVG lava caves opening a new chapter for prehistoric archaeology and Anthropology in Vietnam and Southeast Asia as well.
- Further observation and analysis will be required by experts or specialists. Further investigation and exploration will be continued and planned without artificial environmental destruction damage, even though research excavation will be required for archaeology.
- Both natural and cultural values in the KVG lava caves contributed the most important content in the KVG's Dossier, that planned will be submitted UNESCO in November 2018.

References:

- 1) La The Phuc(2008): Report on "*Study on geological and environmental protection in Trinh Nu waterfall, Cu Jut district, Dak Nong province, Vietnam*". Archives of Geological Museum, Hanoi.
- 2) Hiroshi Tachihara, Edition, NPO Vulcano-Speleological Society(2012): Vietnam Volcanic Cave Project Preliminary Report 17~23 April 2012, Sakae Print Company
- 3) Hiroshi Tachihara, Edition, NPO Vulcano-Speleological Society(2014): Vietnam Volcanic Cave Project Intermediate Report 28 December 2013~4 January 2014, Sakae Print Company
- 4) Hiroshi Tachihara, Edition, NPO Vulcano-Speleological Society(2015): Vietnam Volcanic Cave Project Third Report 26 December 2014~3 January 2015, Sakae Print Company

5) La The Phuc, Hiroshi Tachihara, Tsutomu Honda, Truong Quang Quy, Luong Thi Tuat(2015): The geological heritage of unique volcanic cave in Dak Nong has been discovered and established the record. *Journal of Geology, Series A*, 349, 1 - 2/2015, 28-38

6) Tsutomu Honda and Hiroshi Tachihara(2015): Vietnam Volcanic Cave Survey, UIS Commission on Volcanic Caves, e-NEWSLETTER, p11, No. 69 April 2015

7) Tsutomu Honda, Hiroshi Tachihara, La The Phuc, Luong Thi Tuat, Truong Quang Quy(2015): P87 Lava tube caves and tree molds of Chu B' luk volcano in the central highlands of Vietnam, 2015 Fall meeting of the Volcanological Society of Japan.

8) Tsutomu Honda, Hiroshi Tachihara, La The Phuc, Luong Thi Tuat, Truong Quang Quy(2016): Vietnam Volcanic Cave Survey Project Report, 17th Internat. Vulcanospeleology Symposium, Hawaii, 2016

9) Hiroshi Tachihara, Yuriko Chikano, 2018. *Vietnam volcanic cave 2017 survey report*. NPO Vulcano Speleological Society, Japan

10) La The Phuc, et al (2018): Lava Caves, Lava Formations And Biological And Archaeological Values Firstly Discovered In Krongno Volcano Geopark, Dak Nong, Vietnam, 18th Internat. Vulcanospeleology Symposium, Lava Beds

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