

Lava Caves, Lava Formations And Biological And Archaeological Values Firstly Discovered In Krongno Volcano Geopark, Dak Nong, Vietnam

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Abstract: The lava caves or volcanic caves have been discovered in Dak Nong Province since 2007, in the frame of a scientific project sponsored by UNESCO. They now become the key geological heritage of Krongno Volcano Geopark (KVG), Dak Nong, Vietnam. The results of the collaborative surveys and studies between Vietnam geologists and the NPO Vulcano Speleological Society, Japan from 2012 to March 2018 have discovered a total of 45 caves, in which detailed mapping for 20 caves with the length of 7721.3m, including confirmation of endogenous origin for the lava cave system. Up to now, the lava caves in KVG have been studied and recognized heritage values on the three fields: geological, biological and cultural-archaeological as well.

Speleothem/lava cave formations in the lava caves in KVG are considered as valuable and unique geoheritages for geotourism development. They play an important role to interpretate/explain the formation mechanism of the lava cave system there. Therefore, studying speleothem/lava cave formations in lava caves in KVG are considered as important task of the Vietnamese and Japanese scientists. Some initial studying results on the lava tube caves, their typical and unique speleothem/lava cave formations, biological and archaeological values will be presented in the paper.

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1. Introduction¹⁾:

Krongno Volcano Geopark (KVG) is located in the northern part of Dak Nong province, The Central Highlands of Vietnam and based on the main geological heritages related to the volcanic activities in the late Cenozoic stage. Up to now, five volcanoes have been discovered in KVG. However, Chu B’Luk is only one that produced lava cave system in

the eastern part of the geopark. The lava cave system has been known after discovery of La The Phuc and colleagues in the frame of the project “Survey, study of geological heritages with the aim of establishing geopark and protect environment in the Trinh Nu waterfall area, Cu Jut district, Dak Nong province”, (2007-2008) funded by the Vietnam National Commission for UNESCO¹⁾. Since then,

lava caves become object of scientists, especially geologists.

2. Geological setting^{2~5}:

KVG is located in the southern part of The Central Highlands of Vietnam (Fig.1), which is strongly affected by the collision of three major tectonic plates, namely the Eurasia, Indo-Australian, and Pacific. KVG and its adjacent area have a very complicated geological development history. *Before the Cambrian*, this was in the Kon Tum terrane/uplift. This is one of the Precambrian-continental reefs in the Phanerozoic. Geological formations, which are still preserved and exposed on the surface of KVG and its adjacent area, are authentic evidence reflecting the history of KVG development, including (mainly) four stages:



Figure 1. KVG on the map of Asia.

Period 1 - Mountain forming from the Permian to the Triassic period, forming the Truong Son orogenic belt, along with the S-type batholith granitoid whose zircon age (TIMS) was about 260-245 million years.

Period 2 - The passive continental margin in the Early - Middle Jurassic, forming terrigenous sedimentary rocks of Dray Linh (J_1dl), La Nga (J_2ln) and Ea Sup (J_2es) formations.

Period 3 - The active continental margin with the presence of Dinh Quan ($\delta\gamma\delta\gamma J_3dq$), Deo Ca ($\gamma\delta K dc$) and Ca Na (γK_2cn) formations.

Period 4 - Planation and basaltic eruptions of continental diffusion. The stage of Paleogene ((Paleocene-Oligocene) began with the erosion and abrasion which created plain terrains (300-400m, 500-800m, 1,400-1,600m) commonly observed in many places in the Central Highlands, as well as the Indochina. This was followed by the formation of Tertiary basins, the operation of the East Sea, the left sliding in the NW-SE sections. In the Neogene-Quaternary period, the dominant mechanism was mass heat-subsidence, the movement of vicissitudes, where basaltic eruptions occurred strongly throughout the Central Highlands, as well as Indochina. KVG was forcibly raised in block domes and under the influence of west-to-east tension. Those eruptions started from 16.5 mya (where the bottom of the South China Sea stopped its extension) and stopped 199,000 years ago. Two geological units in this period are Tuc Trung ($\beta N_2-Q_1 tt$) and Xuan Loc ($\beta Q_1^2 xl$) formations consist of basaltic rocks. Lava caves in Krongno area were formed in basaltic rock of Xuan Loc formation with the age of 689,000-199,000 years, erupted from Chu B'Luk volcano in the NE of KVG (Fig.2).

3. Methodology:

In term of geology and speleology, in order to discover and survey volcanic caves effectively, a series of methods and techniques are chosen, including: Inheritance data method; Remote Sensing image interpretation method; Sociological investigation method; Investigation, field survey, sample and literature collection method; K/Ar sample analytical method; Statistical classification method; Professional discussion method; Information technology method; Surveying and mapping lava cave and Current methodology.

However, there are four methods considered as most important and decisive, and briefly described as follows:

- Remote Sensing image interpretation method:

Analyzing satellite and aerial images to interpret and discover entrance of lava caves. Furthermore, the drone images are very effective in discovering lava caves, especially in dry season, when the plant cover almost disappear out of the surface. In dry season, entrances of lava cave may be discovered by scattered and outstanding green dots on the yellowish-grey colour background of basaltic rocks in the images.

- Surveying and mapping lava cave method:

Objectives of the cave surveying is to know the lava tube cave distribution, each direction relative to the eruption point (crater) by measuring the lava tube cave position and length in the KVG area and to know the structure of each lava tube cave by measuring the height width, slope angle and observing the inner structure of wall, ceiling and floor. The used instruments are for cave entrance location: GPS, for height, width and length inside the cave: laser distance measuring instrument, for slope angle of cave floor: inclination meter, for cave turning angle: protractor, for observation of the shape of the inner wall surface floor surface measurement by using calipers.

- K/Ar dating isotopic analytical method:

This method is based on measurement of the product of the radioactive decay of an isotope of potassium (K) into argon (Ar). Potassium is a common element found in many rocks, including basaltic rocks. In basalts, the decay product ^{40}Ar is able to escape the liquid (molten) rock, but starts to accumulate when the rock solidifies (recrystallizes). So the K-Ar dating isotopic analytical method is considered as an effective method for basaltic rocks in the studying area.

- Current methodology: Based on the study of

current geological processes, such as volcanic eruptions and the formation of lava caves, those are taking place at present, for example the volcanic processes in Hawaii, to interpret/explain similar processes happened in the geological past. The formation mechanism of many lava formations in lava cave has been interpreted by using the method.

In term of biology and archaeology, speciality methodologies has been used to meet the detailed requirements of those fields. They will be mentioned in another separate academic papers.

4. Lava caves in KVG^{6~14}:

As mentioned above, all lava caves in Krongno area were formed in lava flows closely related to the eruption of Chu B'Luk volcano. Among 45 lava caves have been discovered in KVG, there are 20 caves have been measured, comprehensively surveyed/researched and mapped as of March 2018 (Fig.2; Table 1). Of course, we only mention the caves having entrances large enough for an adult to go through, but not to mention the others having much smaller, inaccessible entrances. Lengths of these caves vary from 81m to 1066.5m, reaching the record length of SE Asian volcanic caves (6). Volcanic caves scatter irregularly in different directions surrounding the Chu B'Luk volcano, reaching the farthest distance of 15km northwest from the volcano (labelled as B), in Dak Sor commune. The volcanic caves normally aggregate as belt-formed, reflecting the lava flow direction of the eruption of Chu B'Luk volcano.

In term of the groundwater level, the volcanic caves are divided into two types, dry and wet caves. The dry caves are above the current groundwater level, while the wet type is below the groundwater level, normally soaked with the water. The study up to date is mostly concentrated on the dry caves having entrances exposed to the surface. Those

underground water level have not yet been explored and studied on all three scientific

fields, including geological, biological diversity, and cultural heritage as well.

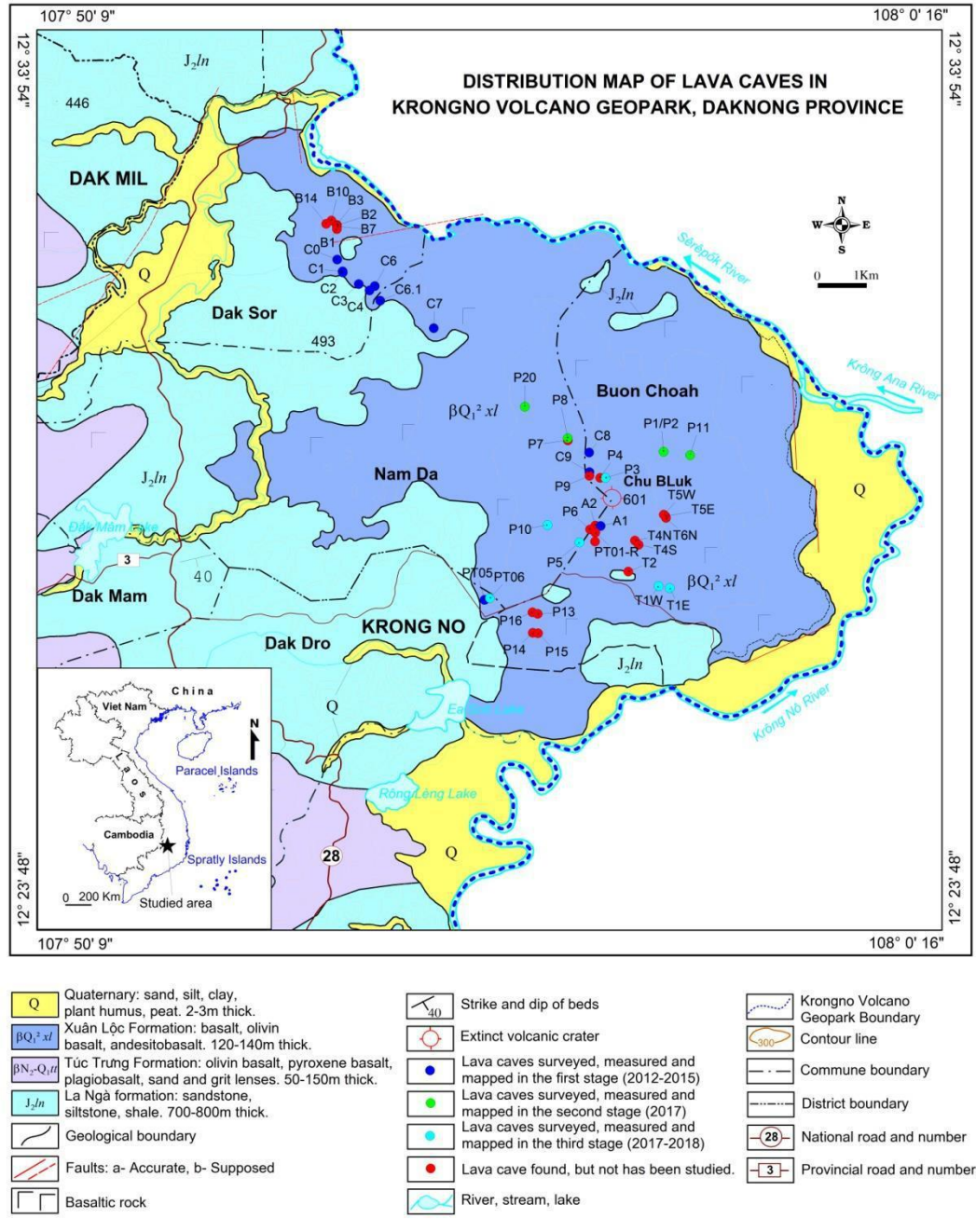


Fig.2. Distribution map of lava caves in Krongno Volcano Geopark, Dak Nong, Vietnam.

Table 1. List of KVG lava caves

List of 20 volcanic caves surveyed and mapped							
N ^o	ID	Location	Longitude	Latitude	Length (m)	Depth(m)	Entrance type
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"			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	P1, P2	Buon Choa'h	107° 57' 10.14"	12° 29' 8.57"	530.5	15-18	secondary
12	P8	Nam Da	107° 56' 5.74"	12° 29' 18.07"	344.1	26	primary
13	P11	Buon Choa'h	107° 57' 28.24"	12° 29' 5.97"	498.1	7-9	secondary
14	P20	Nam Da	107° 55' 37.67"	12° 29' 39.58"	568.0	25	primary
15	A1	Buon Choa'h	107° 56' 28.73"	12° 28' 19.67"	438.7	10	combined
16	P3	Buon Choa'h	107° 56' 32.87"	12° 28' 51.52"	81.0	5	secondary
17	P5 (PT07)	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	T1W	Buon Choa'h	107° 57' 6.264"	12° 27' 39.02"	303.1	16	combined
Total length of 20 volcanic caves surveyed and mapped					7721.3		
List of 25 volcanic caves discovered, not detailed surveyed and mapped							
21	A2	Buon Choa'h	107° 56' 24.22"	12° 28' 19.96"			
22	PT01-R	Buon Choa'h	107° 56' 23.52"	12° 28' 15.38"			
23	PT05	Dak Dro	107° 55' 7.99"	12° 27' 31.50"			
24	T1E	Buon Choa'h	107° 57' 7.44"	12° 27' 41.51"			
25	B1	Dak Sor	107° 53' 32.72"	12° 31' 35.34"			
26	B7	Dak Sor	107° 53' 32.82"	12° 31' 40.68"			
27	B2	Dak Sor	107° 53' 32.30"	12° 31' 41.65"			
28	B3	Dak Sor	107° 53' 30.32"	12° 31' 41.71"			
29	B10	Dak Sor	107° 53' 28.05"	12° 31' 44.91"			
30	B14	Dak Sor	107° 53' 22.64"	12° 31' 42.49"			
31	P4	Buon Choa'h	107° 56' 26.64"	12° 28' 51.57"			
32	P6	Buon Choa'h	107° 56' 27.20"	12° 28' 17.57"			
33	P7	Nam Da	107° 56' 5.84"	12° 29' 16.87"			
34	P9	Buon Choa'h	107° 56' 21.40"	12° 28' 53.09"			
35	P13	Buon Choa'h	107° 55' 42.94"	12° 27' 21.57"			
36	P14	Buon Choa'h	107° 55' 42.54"	12° 27' 8.97"			
37	P15	Buon Choa'h	107° 55' 46.04"	12° 27' 8.67"			
38	P16	Buon Choa'h	107° 55' 42.44"	12° 27' 22.77"			
39	T2	Buon Choa'h	107° 56' 39.54"	12° 27' 52.67"			
40	T3	Buon Choa'h	107° 56' 17.24"	12° 28' 12.97"			
41	T4N	Buon Choa'h	107° 56' 44.24"	12° 28' 13.27"			
42	T4S	Buon Choa'h	107° 56' 46.55"	12° 28' 10.47"			
43	T5W	Buon Choa'h	107° 57' 4.14"	12° 28' 30.37"			
44	T5E	Buon Choa'h	107° 57' 5.04"	12° 28' 29.27"			
45	T6N	Buon Choa'h	107° 57' 5.54"	12° 28' 28.17"			

interpretation of topographic map, Flycam images in combination with the field survey documentation reveal a number of negative topographic relieves (tunnel-shaped), having

diameters varying between 10m and 15m and depths ranging from 3m to 20m, aligned linearly. Subsided holes are filled with disorderly aligned basaltic boulders, indicating wall or ceiling collapse. Other

holes contain elastically deformed basalt fragments, produced by initial volcanic eruption. Whether the holes are collapsed cave roofs, forming secondary cave entrances now being buried, or small-scaled volcanic craters of the Chu B'Luk volcanic system. needed further detailed investigation.

5. Lava formations in lava caves in KVG^{13~14}:

Many lava formations have been identified in KVG lava caves. They are reliable evidences for the endogenous origin of lava cave system in the area, reflect the

properties of the lava flows, the cave formation process as well as their origin. A variety of lava formations have been mentioned, such as: primary and secondary entrances, flooring and branching features of the cave, lava levee, lava shelves, traces of lava on the cave floor and cave wall, lining, lava ball, lava window and seals, lava waterfall, skylight, lava lakes, lava pillows, pahoehoe and clinker floors, primary and secondary stalactites, lava glaze, lava tree molds, ect.(Fig.3~Fig.34).



Fig.3 Multi-generations stalactites in C6.1.
Photo: Luong Thi Tuat.



Fig.4 Saw-blade stalactites in C0 cave. Photo: Luong Thi Tuat.



Fig.5 Shark teeth stalactites in C0 cave. Photo: La The Phuc.



Fig.6 Primary stalactites in C0. Photo: Nguyen Thanh Tung.



Fig.7 Parallel tube structure of A1 cave.
Photo: Luong Thi Tuat.



Fig.8 Linga-shape lava in C6'. Photo: Luong Thi Tuat.



Fig.9 Lava seal in C2 cave. Photo: La The Phuc.



Fig.10 Level marks in C7 cave. Photo: Luong Thi Tuat.



Fig.11 Thin lava linings in C8 cave. Photo: Luong Thi Tuat.



Fig.12 Thick lava linings in C9 cave. Photo: Bui Van Thom.



Fig.13 Skylight in C7 cave. Photo: Ngo Thanh.



Fig.14 Skylight in C8 cave. Photo: Luong Thi Tuat.



Fig.15 Exiguous tube in the upper C7 lava cave.
Photo: Luong Thi Tuat.



Fig.16 Lava glaze in the C7 cave wall.
Photo: Luong Thi Tuat.



Fig.17 Smooth surface & lava ball in C7.
Photo: Suzuki Kazutoshi.



Fig.18 Scallope ceiling and charcoal in C8 cave.
Photo: Luong Thi Tuat.



Fig.19 Lava window in A1 cave.
Photo: Luong Thi Tuat.



Fig.20 Lava window in C2 cave.
Photo: La The Phuc.



Fig.21 Ship-bow structure in C2 cave. Photo: Luong Thi Tuat.



Fig.22 Grape stalactites in P5 lava cave. Photo: Luong Thi Tuat.



Fig.23 Lava lake in T1 cave.
Photo: Luong Thi Tuat.



Fig.27 Lava shelf in C7 cave.
Photo: Suzuki Kazutoshi.



Fig.24 Pillow-shape lava in T1 cave. Photo: Luong Thi Tuat.



Fig.28 Lava tree mold in C2 cave.
Photo: Luong Thi Tuat.



Fig.25 Tube-in-tube in C7 cave.
Photo: Luong Thi Tuat.



Fig.29 Lava tree mold in C3 cave.
Photo: Tsutomu. Honda



Fig.26 Primary stalactites in C3.
Photo: Tsutomu. Honda.



Fig.30 Lava tree mold in C4 cave
(at least 4.9m). Photo: Luong Thi Tuat.



Fig.31 Ropy lava in C7(left).
Photo: Nguyen Thanh Tung);
Lava levee in C6' (right);
Photo: Luong Thi Tuat.



Fig.32 Lava fall in P5 cave (left)
Photo: Luong Thi Tuat.
Secondary stalactite (right)
Photo: Yuriko Chikano.



Fig.33 Ropy and levee lava in the
C7 upper-stream.
Photo: Luong Thi Tuat



Fig.34 Scroll-shape linings and
pillow-shape lava in T1 cave.
Photo: La The Phuc.

Fig.3~Fig.34. Illustration images for lava cave formations in KVG lava caves.

Source: VNMN and VSS.

6. Biodiversity in KVG's lava caves^{8~13};

Some unique cavern animal species have been seen in KVG lava caves, consist of bat, snake, scorpion, snail, frog, ect. (Fig.35~

Fig.42). Also, several species are expecting to be endemic and new species for science. Of course, they all need to be studied more detailed in the future (Fig.43~Fig.57).



Fig.35 Bat in C6.1 lava cave.
Photo: Luong Thi Tuat.



Fig.36 Bat in C4 lava cave.
Photo: La The Phuc.



Fig.37 Snake (*Bungarus candidus*) in C7 cave. Photo: Yoshida Katsuji.



Fig.38 Black scorpion
(*Heterometrus laoticus*?) in C7
cave.
Photo: Luong Thi Tuat.



Fig.39 Snail in C7 cave.
Photo: Yoshida Katsuji.



Fig.40 Other snail species in C7
cave. Photo: Yoshida Katsuji.



Fig.41 Frog in C9 lava cave.
Photo: Luong Thi Tuat.



Fig.42 Frog in C7 cave.
Photo: Yoshida Katsuji.

Fig.35÷Fig.42: Some different animals have been found in KVG lava caves.



Fig.43 *Laponia* sp.



Fig.44: *Thelcticopis* sp.



Fig.45: *Coelotes* sp.



Fig.46: *Gnaphosa* sp.



Fig.47: *Trombidioidea* sp.



Fig.48: *Pholcus* sp.



Fig.49: *Belisanna* sp.



Fig.50: *Khorata* sp.

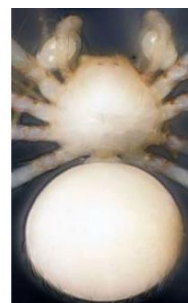


Fig.51: *Leptoneta* sp.



Fig.52: *Tyrannochthonius* sp.



Fig.53: *Anapistula* sp.



Fig.54: *Telema* sp.



Fig.55: *Tetrablemma* sp.



Fig.56: *Opilionida* sp.



Fig.57: *Lagynochthonius* sp.

Fig.43~Fig.57 : Some different animals have been found in KVK lava caves and are expecting to be endemic and new species for science (source: the VNMN's biologists group).

7. Archaeological value in KVG lava cave^{15~17)}

- Before 2017, many archaeological relics have been found in KVG area. They all are open-air ones, none of cave relics has been found.

- In 2017, the first lava cave relics have been discovered in a series of lava caves in KVG. - According to the decision 52/QĐ-BVHTTDL dated 09/01/2018 of the Ministry of Culture, Sports and Tourism, Vietnam National Museum of Nature and Department

of Culture, Sports and Tourism of Dak Nong province in collaboration with Vietnamese archaeologist have finished the first excavation stage in C6' and C6.1 lava caves. Results of the excavation has found many important evidences of prehistoric people living in lava cave in the Middle Neolithic (7,000-5,000 years BP) to the Late Neolithic and Early Metal Age (5,000-4,000 years BP) (Fig.60). Besides tens of thousands relics of stone tools, animal bones, snail shells, mussel shells, ceramic broken pieces, brass arrow, (Fig.58;64;65;66;68;69), ect., archaeologists have identified 3 three prehistoric human skeletons (Fig.59;61;62;63) in 3 separate tombs (Fig.58) and many bone pieces of at

least ten other human individuals (Fig.67) in the excavation pit in C6.1 cave. Obtaining the studying results in the C6.1 excavation pit, first time in Southeast Asia and over the world, archaeological relics and prehistoric human skeletons have been found in lava cave. On September 18th, VNMN have released

preliminary results of the excavation in the C6.1 cave, marked a huge milestones in Anthropology, Archaeology in Vietnam, Southeast Asia and the world as well: Prehistoric Archaeology in lava cave.



Fig.58. Archaeological excavation pit in the C6.1 cave.



Fig.59. The skull of a little girl in the C6.1 cave excavation pit (M2).



Fig.60. Results of the 14C dating in the C6.1 excavation pit.



Fig.61. The human skeleton M2 revealed in the C6.1 excavation pit.



Fig.62. The human skeleton M2 revealed in the C6.1 excavation



Fig.63. The human skeleton M3 revealed in the C6.1 excavation



Fig.64. Stone axes tools in the C6.1 lava cave



Fig.65. Sea snail shell jewelry in the C6.1 pit

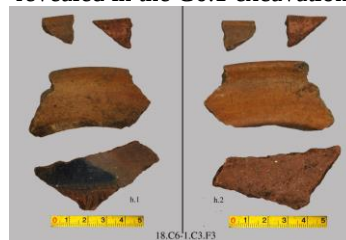


Fig.66. Broken ceramic relics in the C6.1 excavation pit

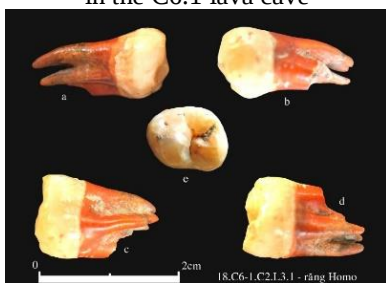


Fig.67. Teeth of prehistoric man in the C6.1 excavation pit

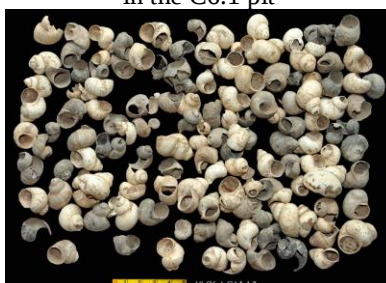


Fig.68. Snail shells in the C6.1 excavation pit



Fig.69. Mussel shells in the C6.1 excavation pit

Fig.58~Fig.69. Archaeological relics in the C6.1 cave archaeological pit, in KVG, Dak Nong, Vietnam
Source: VNMN.

8. Conclusions:

Three lava caves C7, T1 and C6.1 in KVG's lava cave system have proposed ranking as international heritages in KVG Dossier. Lava caves in KVG have been studied and recognized on both natural heritage (geological and biological) and cultural (archaeological) values. Thanks to the unique scientific multi-values, lava caves have become the most important heritage of the geopark. Therefore, they play important role as pillar heritage in the KVG Dossier, that plan to be submitted to UNESCO in November 2018¹³⁾.

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