GEOLOGICAL OBSERVATIONS IN PYRODUCTS OF JEJU ISLAND (SOUTH KOREA)

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Abstract

Jeju Island, south of Korea, rest on continental rock but is covered by volcanics. About 130 lava caves are known. Several – among them famous Manjang Gul – are protected as World Natural Heritage sites. In August 2015 we investigated Bilemot, Susan and Socheon Caves to be possibly protected in that program as well. Bilemot is not only important because of its length of 11.7 km but also of its unusual braided structure. Susan Cave is special because it derived from a very low shield vent, hitherto not recognized as such, and because its lava contains enormous amounts of continental crust xenoliths, mostly white quartzite, unlike any other cave. Socheon Cave is special because of its pronounced downward erosion and its lower section containing secondary calcite speleothems.

Introduction

Jeju Island (Fig. 1) is entirely composed of volcanic rocks. It is classified as a composite volcano in spite of its shield volcano-like appearance (Yoon et al., 2014) with the Hallasan Volcano at the center. Furthermore, it rests on continental crust. If Jeju volcanism is driven by a hot-spot source or generated by magma, rising from the upper mantel along a tectonic fissure, is still in debate. So far, about 130 lava caves are known on the island. In so far Jeju and the importance of its caves has to be compared not so much with the marine hot spot- or fracture-generated islands like Hawai'i, Iceland, Galapagos, Azores, Tenerife, Reunion, Easter Island and others, but with the intra-continental basalt fields such as those stretching from Jemen, through Saudi Arabia (about 10 caves), Jordan (20 caves) and Syria (2 caves) and the basaltic fields in the western and Northwestern continental US, in the Trans-Mexican Lava fields, along the shoulders of the East-African rift, the Aetna on Sicily, the basaltic lava fields of Eastern Australia (among them the Undara volcanic province)

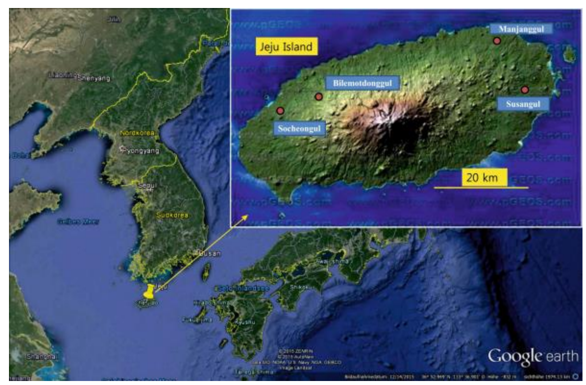

Figure 1: Google Earth view of the situation of Jeju Island at the southern tip of the Korean Peninsula and location of caves discussed.

and a few other basaltic fields in Vietnam, China and Argentina. If compared with these areas then Jeju Island may have the highest lava cave density (possibly with the exception of Mount Aetna) of all of those. This underscores the overall importance of these caves for our understanding of continental basaltic volcanism and their importance for long-range lava transport.

Basics

Lava caves belong to the class of primary caves that form at the same time as the rock containing them. They are much less common than caves that form secondarily in soluble rocks such as limestone, dolomite, gypsum, anhydrite or salt. The first to bring lava caves to the attention of an educated readership was Olafsen (1774-75) who visited Iceland between 1752 and 1757. In the original description of Surtshellir (§ 358, p.130) he stated: „*Der fließende Hraun ist wie ein Strom durch diesen Canal geflossen;…*“ (i.e. “the running lava flowed through this channel like a river…”) (see Kempe, 2008). But even today lava caves are still under-researched and are treated as a mere curiosity in most volcanological textbooks. Exploration and survey of lava caves is mostly carried out by private caving organizations and not by the professional volcanological community.

Apart from a variety of short lava caves, some of them even forming secondarily such as sea caves, fissure caves, talus caves etc. the most important ones are “pyroducts” (for terminology and general volcanology see Lockwood and Hazlet, 2010) commonly also known as “lava tubes” (for review see Kempe, 2002 and 2012a). This cave type is intimately connected to the functioning of shield volcanoes. Pyroducts form during lava-producing volcanic eruptions, petrographically concentrated within the “basalt window”, including picrites, tholeiitic basalts and alkali basalts. They are built forward and downslope and serve to conduct lava gravitationally over long distances. As pāhoehoe (ropy lavas) lava flows advance, they internally form conduits that insulate the lava to such a degree, that it maintains its fluidity for many dozen kilometers. A lava flow with an internal pyroduct displays positively self-enforcing properties and lava is conducted within a flow not visible to the outside observer. Shield volcanoes would not come about without pyroducts, they serve to give this type of volcanoes their very gentle slope that may range from a few tenth to several degrees in inclination.

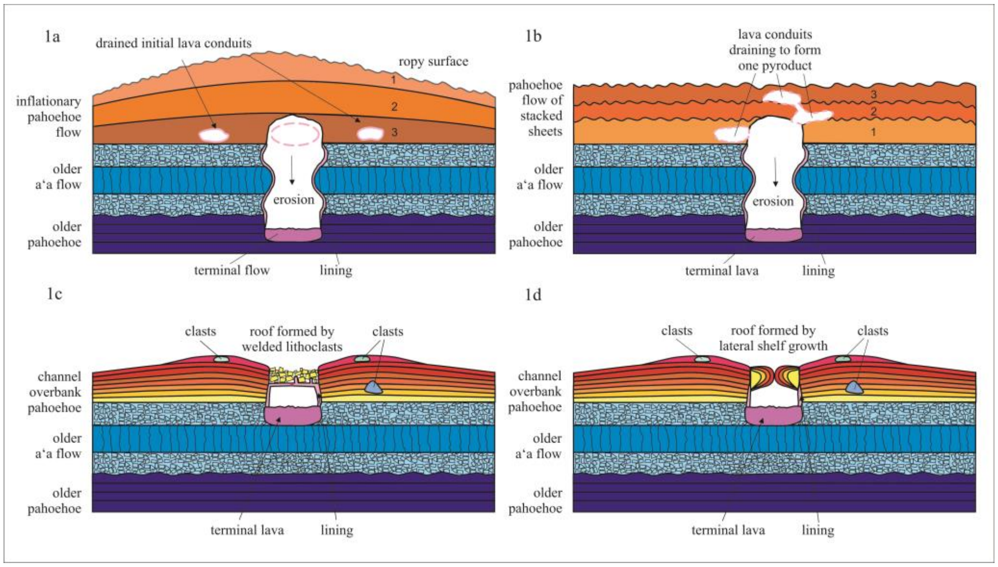

Figure 2: *Within the pyroduct type at least four different formation modes exist: Caves formed by inflation of the lava flow front and later downward erosion (1a), caves formed by coalescence of small ducts and consecutive downward erosion (1b), caves formed by the crusting-over of channels by floating lithoclasts, welded together (1c), and by channels crusted-over by lateral shelf accretion and consecutive closure (1d)*

While the lava flow advances with the help of the pyroduct, many processes can occur that shape the growing cave, so that very unique situations can arrive. Thus, lava caves are a quite diverse natural phenomenon, not adequately described by the term “tube”. So far, we can differentiate between four different “modes” of generation (compare Kempe, 2012b), two involving the crusting over of lava channels and the others by strictly subcrustal processes (Fig. 2). The most widely spread mode in forming long primary lava caves seem to be the “inflationary” mode.

Bilemot Gul

With 11.7 km surveyed length, Bilemot Gul is currently the seventh longest lava cave known. It surpasses Manjang Gul, already part of the UNESCO World Heritage, by several kilometer (Ahn, 2010, quotes a length of 7.9 km, while Loyd, 1999, reports a total length of 8.9 km placing Manjang Gul at either eleventh or tenth on the list of the world’s longest lava caves; Golden, 08/2015 http://www.caverbob.com/lava.htm).

Inspection of the cave on August, 27th, 2015:
The available map of Bilemot Cave based on 3D scanning shows a bundle of passages that split and rejoin, forming a braided pattern. In the upper section (about 600 m) that we inspected all passages followed this basic scheme. Thus, they all belong to one flow event and can be, in spite of its braided property, be

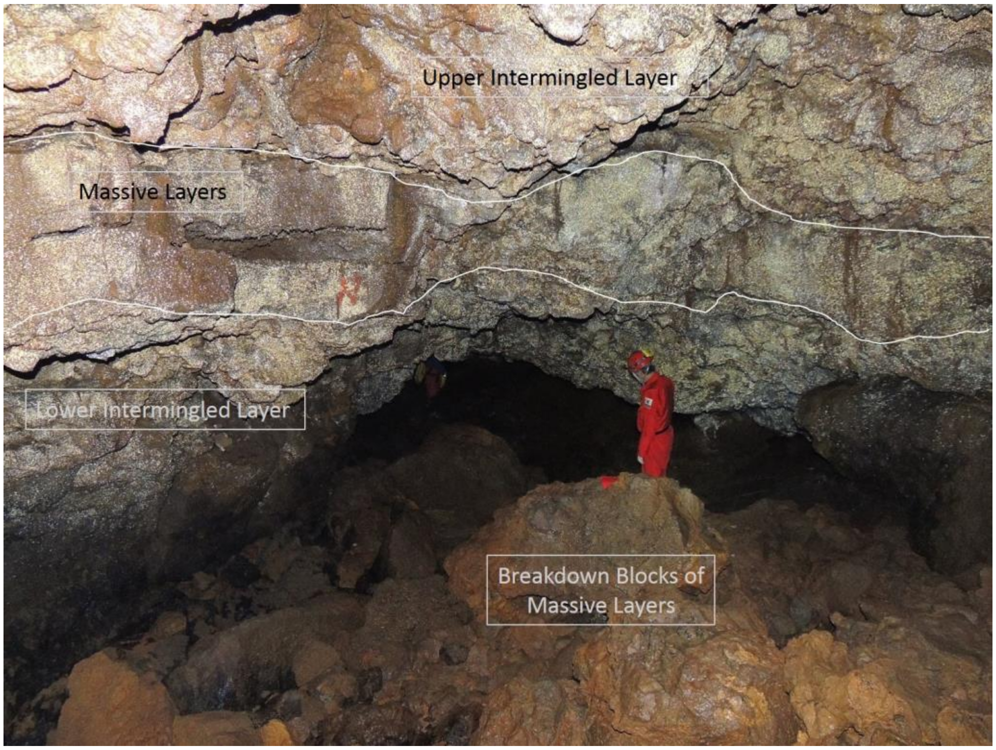

Figure 3: *View downhill in a typical breakdown-dominated passage of Bilemot with stratigraphy indicated.*

classified as a "mono-trunked" system (Kempe 2012a). In such lava conduits, many parallel passages develop initially, and, if activity is longer-lived, one of them will evolve to become the "master" or "trunk" conduit, draining the others one after the other as its collected flow power cuts down into the underlying strata. In Bilemot this downcutting is not very pronounced, it is a meter in places or less. This trunk passage is also followed by the recent water flow that caused noticeable water erosion on the bottom sheet of the cave, partly obliterating its pāhoehoe ropy surface pattern.

In order to understand in what "mode" a lava conduit has formed, it is important to study its roof structure. In case of Bilemot Cave this can be easily done as breakdown has occurred almost everywhere in the cave, opening the view into the internal composition of the roof. One can differentiate four units from bottom to top (Fig. 3):

1) The glazing of the lava conduit, consisting of an up to 30 cm thick dense, sometimes sheeted layer of black and shining lava, displaying "shark" tooth stalactites.
2) An "intermingled" unit, consisting of irregularly oriented fragments of pāhoehoe plates, and large "Pele's toes" mostly welded together by lava injected from above in the form of "squeeze balls". This unit is prone to breakdown due to its high degree of macro porosity and sometimes can be disintegrated by hand. Its thickness is variable and may be a meter or more. The general yellow color of this unit is in striking contrast to the black glazing. This color suggests that the unit was exposed to rainwater during its cooling, transforming some of the iron in the basaltic glass to the mineral goethite.
3) A massive unit consisting of a 1 to possibly 3 m thick, solid, dark-colored lava with large vesicles. It is structured by widely-spaced contraction cracks along which large blocks separated forming strikingly different breakdown blocks as compared to the intermingled unit. The massive layer seems to have pāhoehoe ropy texture. This unit is the source of the "squeeze balls" stabilizing the intermingled unit. It also seems to be responsible for the stability of the cave roof.
4) Above the massive unit there seems to be another intermingled unit, exposed only at places where the massive unit has collapsed and thus it is difficult to assess in its structure.

The three last units are best interpreted as representing two thick pāhoehoe flow consisting of fragments of the advancing flow-front buried below the advancing core of the flow.

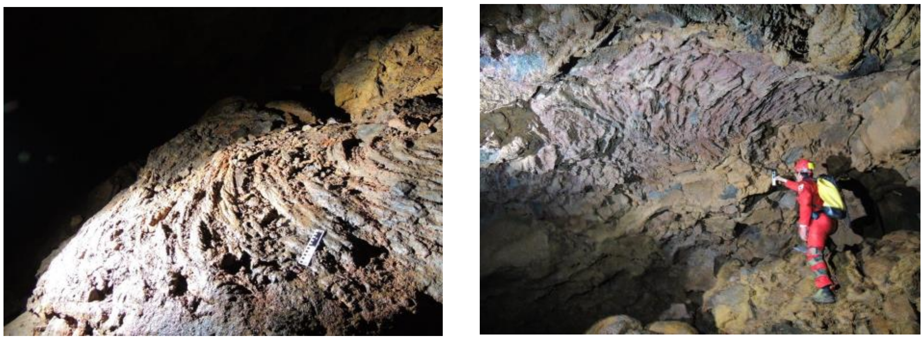

Figure 4: *Bilemot Cave: Pahoehoe ropy texture on top of the Massive Layers and the corresponding imprint of the breakdown block in the Upper Intermingled Unit. Scale-bar: 20 cm.*

This seems possible because the massive layer carries ropy signature on top, and the upper intermingled unit carries the negative imprint of this pattern (Fig. 3). The question remains, how then the conduits were able to develop below such a unit. The suggestion is, that the entire unit was inflated by another solid layer of pāhoehoe. This was easily done due to the high porosity and therefore overall low density of the units above. Within this sheet, the conduits developed initially and then quickly eroded part of the intermingled unit so that the cave developed more upward than downward. Thus, the down-cutting into preexisting subsurface seems to be minimal. For the time being, one has to assume that Bilemot Cave is an inflationary cave, albeit with a rather strange primary roof.

Two further observations are interesting; one is the development of "honey-comb like cupolas" and the other the discovery of an internal ‘a‘ā flow:
Where the roof was formed by the massive unit during activity (i.e. in places were the lower intermingled unit had been removed by the flowing lava in the conduit) the blocks, defined by the contraction cracks, have been subject to intense heat, hollowing them out by partial remelting. The contraction cracks, being cooler and permitting gas exchange, remain as ridges, thus giving the ceiling the appearance of - albeit irregular – honey combs: The center of the blocks displaying cupolas (the chambers of the honey comb) and the contraction cracks protruding as ridges (the chamber walls of the honey comb). The resulting melt often is seen running down in thick, bulbous stalactites, another rare form not described yet from other places in detail (Fig. 4). All in all these forms of remelting must result within an environment of convecting very hot gasses. All this is not physically well understood, nor modelled.

Figure 5: *"Honey-Combing", i.e. remelting of the interior of blocks defined by contraction cracks within the Massive Layers. Note (left) thick cylindrical stalactites caused by the running and dripping down of the created melt.*

According to the published geological map and the personal communication of Dr. Youngwoo Kil, the petrography of the flows in which Bilemot Cave occurs is of basaltic-trachy-andesite composition, i.e. the lava's composition is of higher alkali concentration than normal basalts. If this proves to be true (work is in progress by Dr. Kil), then Bilemot Cave would be the first described having this petrography world-wide.

The other interesting discovery was a 50 cm thick flow of welded ʻaʻā rubble above the otherwise very smooth pāhoehoe floor of the cave (Fig. 6). Closer inspection showed that this flow originated nearby through a passage within the massive unit and represents a later

Figure 6: *Front of later surface intrusion that turned to a 50 cm high front of welded ʻaʻā at the tip of the flow. The floor below (foreground) is the flat pāhoehoe floor of the conduit.*

Figure 7: *Showing the entrance to Susan Cave on an inconspicuous topographic rise, possible a shield (left Aug.20015, right Sept. 2008). Pāhoehoe lava in foreground left appear tilted by inflation and could be direct outflows from hidden vent.*

intrusion from above, suggesting that the Bilemot flow was not the final lava covering this area. The intrusive flow at first has a platy appearance before is cascaded down into the main passage forming a large pyramidal column the foot of which turned into the observed ʻaʻā flow unit, that flowed for less than 20 m along the floor of the cave.

One more observation should be recorded: Just below the entrance on a shelf (formed by the cave-initiating pāhoehoe ?) there are many potshards with a few metal artifacts, obviously from the 20th century. How much potential for earlier archeological material the cave offers is hard to assess. Due to the water running in the cave, anything originally deposited near the entrance may have been eroded and washed further into the cave; but nowhere lithics (artefacts made of stone) or shards of older age have been noticed during our visit.

In summary, Bilemot cave is of global interest mainly due to three facts:

1) Its sheer length (7th world-wide) of 11.7 km;
2) its unusual braided structure unlike any of the other long lava caves;
3) and its development in a petrographically unusual rock type (basaltic-trachy-andesite) currently not documented for any other lava cave (pyroduct).

Overall, the cave is of world-wide scientific interest geologically and speleologically. Its biological and archeological potential should be evaluated separately. There is no potential to develop the cave for the public due to the overall small sizes of its passages.

Susan Gul

We visited Susan Cave (33°N25´26.1´´/ 126°E50´36.7´´) on August 28th.
Susan Cave is listed with 4.67 km length by Loyd (1999) and appears as the 24th longest lava caves in the world in Bob Gulden's list. The Guidebook (2008) as 4.52 km long and states that it is not entirely explored and surveyed. The map shows a major branch north of the entrance and a long meandering passage with a few oxbows and short blind side passages.

The small entrance is situated on a local high point and surrounded by a fence (Fig. 6). As such, this is not uncommon for lava cave entrances since the pyroducts very often are below the center of a flow ridge. Nevertheless, this observation will play a role in the conclusions to be drawn below.

Figure 8: *Views of the southern main passage towards the entrance (left). It appears as if there is much more breakdown than actually is missing rock mass on the ceiling. View uphill of the main passage below the entrance (pictures 2008).*

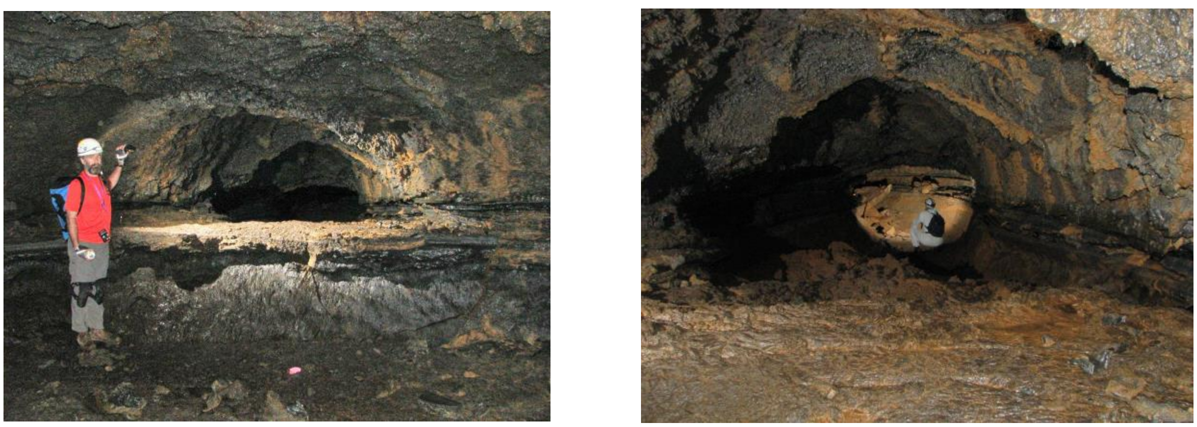

Figure 9: *Entrance to oxbow, that is dammed off by a levee (left) and view across the levee into the oxbow that is today 35 cm deeper than the main passage where caver (to left) stands (pictures 2008).*

The 3 m deep entrance drop leads unto a pile of breakdown blocks rocks (Fig. 8). First, we proceeded south along a meandering main passage that appears to become smaller in cross-section downhill. Since there is hardly any breakdown, there is no way to look for stratigraphic information. The floor is rather smooth and shows deep contraction cracks in places, indicative of a relatively thick bottom layer, such as arises from local ponding of final lava. A few small lava falls and lava cascades occur along the first kilometer, indicative of possible downcutting.

At the point where the cave begins to trend toward the SE a side passage enters, that ends blindly because it was backfilled by lava from the main passage. It starts behind a levee, indicative of a later rise in the lava level in the conduit. Where the passage originally branched from the main passage is not seen and may be hidden by this diagnosed later rise in lava level behind the intact glazing. A little further, there is an oxbow, but again, entrance and exit of it are blocked by 1 m high levees build by flows from the main passage into this cut-around (Fig. 8). It is interesting to note, that the floor of the side passage/oxbow is 35 cm lower than that of the main passage. This can only happen if after the initial downcutting of the main passage below the level of the side passage and its consecutive draining, the level in the main passage rose again, building a levee towards the side passage, incompletely filling it and then failing to drain the main passage completely. That there is a thick level of lava on the floor of the main passage is also indicated by deep contraction cracks in the floor.

At this site a lava fall is found as well (Fig. 9). On its one side (Fig. 9) and uphill of it the lining came off (Fig. 10) revealing an at least 1 m thick loose reddish rubble and coarse sand. This layer, without closer analysis, seems to be tephra; ‘a‘ā rubble would not have a sand-sized component. Thus, the conduit has encountered here tephra from a nearby cinder cone. Its erosion was easy and an undermined notch in the lower wall is well visible. Above the tephra a solid, 1 to 1.2 m thick layer of pāhoehoe lava (probably consisting of two sheets) is protruding from the wall. Its lower face shows tephra that was welded onto it as the hot lava crept over the tephra deposit. These pāhoehoe sheets must have contained the primary conduit that later was enlarged to become the present cave. Above this solid pāhoehoe layer, we encounter a reddish intermingled layer, about 1 m thick. Like the intermingled unit in Bilemot, is consists of lithoclasts welded together by “squeeze balls” injected from above. Further down-passage this intermingled unit collapsed as well, exposing an at least 2.2 m thick massive layer, that guarantees the stability of the cave’s roof. Similar to Bilemot, this sequence probably belongs to a first massive pāhoehoe layer, that was later uplifted by the lower two sheets. Thus, here we have evidence also of an inflationary origin of the cave.

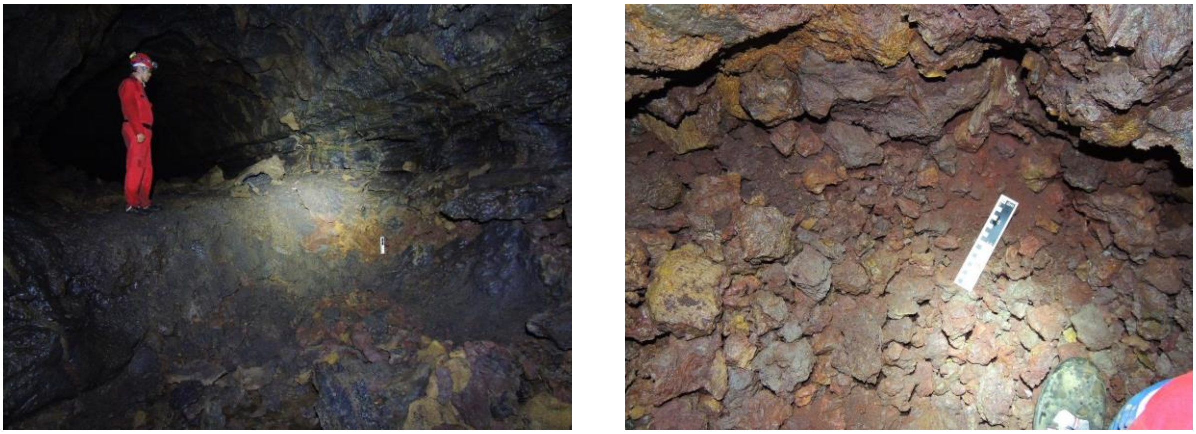

Figure 10: *Lavafall near the entrance to the oxbow (left) that excavated tephra as visible below the lining (right). The tephra is composed of lapilli and coarse ash (right) (scale bar 20 cm).*

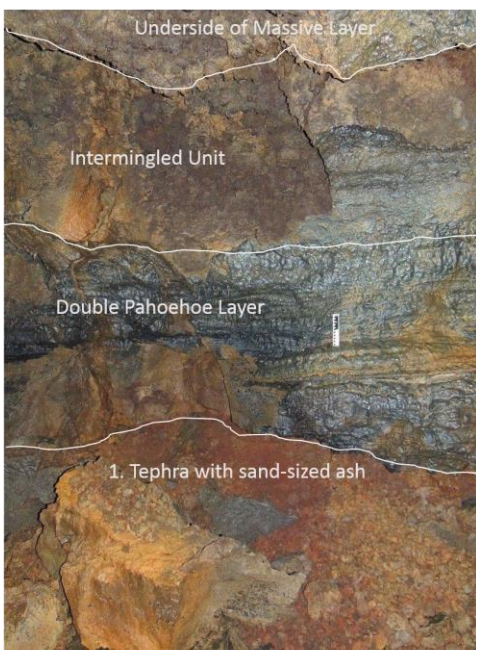

Figure 11: *Stratigraphy of Susan Cave near the first oxbow above the lava fall in Fig. 9, right wall looking uphill (scale bar 20 cm).*

Near the lava fall, the ceiling shows pronounced “honey-combing” (Fig. 12), just as in Bilemot. It developed in the uppermost massive layer. The interior of the blocks are deeply hollowed-out by melting, while the colder contraction cracks form ridges. Some of the blocks have concave cavities, up to 30 cm deep. Remains of the melt cling to the lower lips of the cavities, but different to Bilemot, no thick cylindrical stalactites formed. Honey-combing is also often seen in the ceiling of the passage uphill.

After clarifying the stratigraphy, we turned around and went back to the entrance to look at the “upstream” section. However, after a few meters we found a small lava fall going down and about 50 m in we encountered a large lava fall, also going down five meters (Fig. 13). We were extremely puzzled, how could the passage go down into both directions? Why did nobody wonder about this during the excursion in 2008 (including the author?). But, there is no doubt, the entrance marks the

Figure 12: *Showing the deep „honey-combing" in Susan Cave in the ceiling, signs of remelting the interior of the still hot blocks of the upper massive layer while the colder contraction cracks form ridges.*

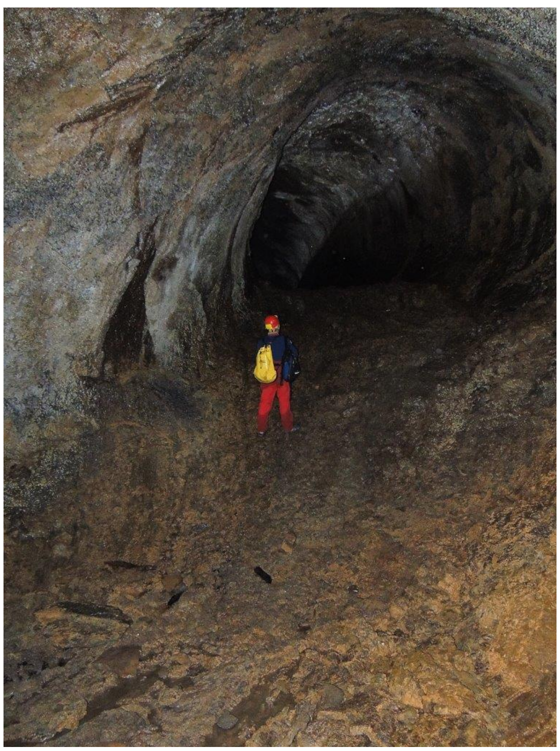

Figure 13: *Ca. 5 m high lava fall below the entrance towards the NE looking uphill.*

highest point in Susan Cave. Therefore, there must have been a vent below the entrance, from which lava was erupting and going downhill into two directions. No other likely explanation can be offered. This is in accordance with the observation that the entrance is on a high point (compare Fig. 7), now to be interpreted as a low shield volcano issuing basaltic lava. So far I know of only one example were the vent of a shield volcano is directly below a cave and that is in a small, unnamed shield on the SW rift of Kilauea, Hawai'i (Kempe, 1999).

Just beyond the lava fall is a large hall (Fig. 13), stretching at right angles right and left. It is filled with huge breakdown blocks from a single massive pāhoehoe layer. The ceiling does not offer any stratigraphic information. At this point we only can speculate what that means. One possibility is that we are below the filling of a lava pond, filling a former depression. This was not the only surprise, even more surprising was the petrography of the lava: it is packed full of xenoliths. Most of them are milky metamorphic quartzite (Fig. 14), just as seen in Manjang Gul, but other components occur as well: gneiss, metamorphic schists and metamorphic sediments and possibly granites, just to name a few that we saw (Fig. 15). To the right, the passage goes on for some time, it becomes very low, and the slightly convex floor suggest a ponding of the terminal lava. Similarly the passage ponds to the left in two short annexes.
One more geological interesting observation was made: along the far wall piles of welded plates are found (Fig. 16). These must have shed off the wall while cooling, suggesting that this part of the cave has been very hot for a long time, even after the flow had subsided. This would be in accordance with the suggestion that the hall is below a very thick unstructured filling of a lava pond.

Last but not least, we found reed torches and remains of reeds (Fig. 17). This could be an interesting archeological finding, worthwhile to try dating by C^{14}. It looks as if someone had explored this part of the cave with very primitive lighting.

Figure 14: *Panorama view into the large hall filled with large breakdown blocks which feature a large number of xenoliths, largely of quartzite.*

Figure 15: *Breakdown blocks with large quartzite xenoliths.*

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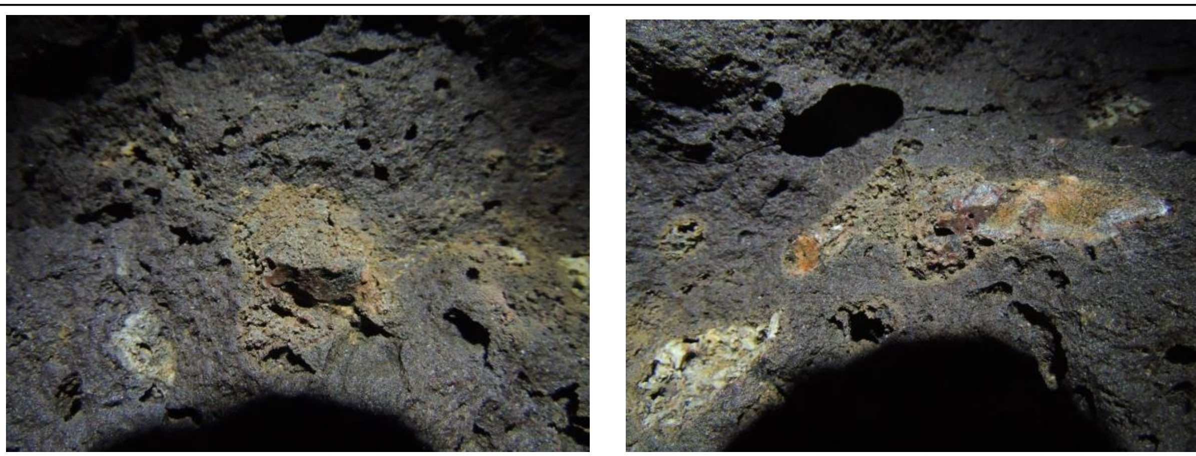

Figure 16: *Various kinds of continental crust xenoliths.*

In summary Susan Cave is of world-wide interest because of two facts:

1.) It is the only cave yet described as deriving from a hidden shield vent.
2.) It displays the richest, yet described in a basaltic lava occurrence of continental crust-derived xenoliths.

Figure 17: *Welded plates that fell off the wall while the cave was still very hot. Note drip stalagmite left of scale bar (20 cm).*

Figure 18: *Remain of a reed torch of unknown antiquity. Scale bar 20 cm.*

Susan Cave is furthermore in an amazingly pristine state of preservation, featuring no garbage nor any other alteration by man (save the survey bolts).

Socheon Gul

The visit to Socheon Cave (33°N21´53´´/126°15´37´´) on August 29th was relatively short. Socheon is listed as 3,074 m (Loyd, 1999) or 3,100 m (Guidebook, 2008), but these numbers are referring to its state before the newly opened section. We therefore first visited the

Figure 19: *Newly dug and secured Opening 3 of Socheon Cave. Note fence and retaining wall around perimeter. At the bottom cave opening leading into newly opened section.*

newly dug entrance (Opening 3) and then went into Opening 1 (the main entrance to the cave) and proceeded underground to shortly beyond Opening 2.Opening 3 is about 10 m deep and was recently dug out and consolidated by civil engineering measures (Fig. 19). It features a metal fence around its perimeter, topped by barbed wire coils. Inside this about 25 m wide enclosure and leaving an about 2 m wide terrace a retaining wall build of large lava blocks rests on the bed rock of the cave's roof. It forms another about 1.5m wide irregular terrace, not actually wide enough for safe navigation. No specific anchor points for cable ladders or rope descent were constructed. Therefore, the fence posts serve as anchors if needed. The cave's roof itself was punctured by an about 7 m wide collapse hole. The walls of it are overhanging on all sides for about 5 m. Cave passages lead off to both downhill and uphill. Both seem to be wide open.

This amazingly affluent construction, however, does alter the entire cave climate fundamentally, possibly with highly unwanted consequences (see below).

We then proceeded to Opening 1, next to the street. It is also gated. The entrance is a typical "cold collapse", i.e. a collapse the happened after the cooling of the conduit.

It occurred because at this site the roof was relatively thin. Figure 19 shows its structure: The roof consists of a series of pāhoehoe sheets, with the top sheet being the thickest. This is typical for "inflation"-type roofs (see Fig. 1), whereby the top layer was emplaced first and the consecutively thinning (and hotter) layers were injected below, thus "inflating" (or lifting) the first sheet. Within the last injected sheet, which is the hottest, the proto-cave was initiated, providing for rapid transport of the hot lava to the tip of the flow. This is seen at the lower entrance opening where the lining of the pyroduct is still intact just below the primary roof. After having climbed down the entrance breakdown pile, one stand in an irregularly shaped canyon (Fig. 21), suggesting that the cave has cut down into older layers. The slope is relatively high, certainly higher than in Manjang Gul. Other than in Manjang Gul and Susan Cave, there are several, short side passages branching off at a high level about 3 m above the floor. Below two of them are artificial rock piles, as if made to support short ladder to reach theses passage. These short passages, ending blindly according to the cave map, are typical for the level of the primary conduit, when several ducts developed in the beginning of activity (such as also seen in Bilemot) in parallel. As the main conduit started to cut down, they drained and were often filled at their upper ends.

Figure 20: *Panorama view of Socheon's cave roof, view downhill at Opening 1. Note the continuous thick primary sheet and the much thinner layers injected below, constituting the inflation of the lava flow.*

Figure 21: *View into the canyon of Socheon Cave below Opening 1. Note prominent ledges, most probably remains of the core of an ʻaʻā layer eroded through, note also deeply undercut walls where ʻaʻā rubble was removed.*

Figure 22: *View uphill into the Opening 2 of Socheon Cave, created by a "cold breakdown". Note Prof. Woo for scale.*

The canyon-shaped passage continues downward including a few not-too-steep lava falls or lava cascades, again suggesting active downcutting. After passing the big rock-fall that created the second opening (Fig. 22), the right wall is well accessible to stratigraphic studies because of substantial rock-fall off ceiling and walls.

At the ceiling, a layer with an imprint of pāhoehoe ropes is seen. Since (compare Fig. 2) in an inflation roof, only the top layer has ropy surfaces, this means that the primary ceiling at this site was superseded by another (or several) further pāhoehoe sheets by later flows. These flows could be generated by a breakout of the pyroduct uphill, by neighboring flows of the same eruption or even by much later, independent eruptions. It all depends if the breakdown occurred during activity ("hot breakdown"), then the superseding flow was of the same eruption or after the conduit cooled ("cold breakdown"), then the superseding flow could be of the same or a later eruption. Due to the presence of a large amount of breakdown, it must be assumed that this is a cold breakdown (otherwise it would have been removed by the active flow) and that it cannot be decided if the superseding was of the same or a later eruption.

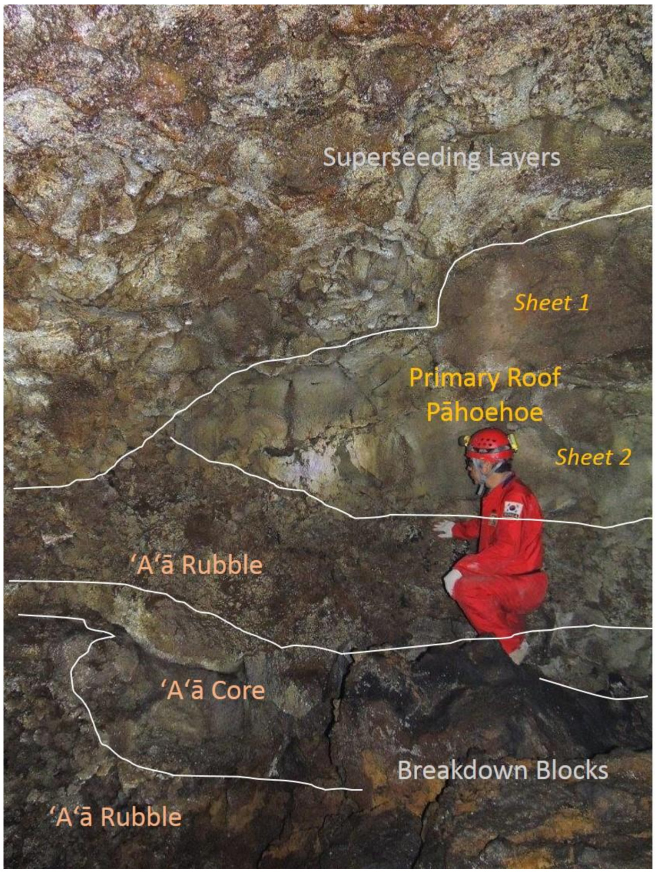

Figure 23: *View of right wall below Opening 2. Due to pronounced breakdown of the walls, the layers composing the side of the cave are exposed. It appears as if the primary pāhoehoe sheets superseded an 'a'ā flow and pinched out laterally. Later a pāhoehoe surface flow superseded the primary roof replacing it as roof material due to cold breakdown.*

Along the walls another interesting observations can be made: Here layers of 'a'ā are seen, consisting of typical, fist-size rough clasts, mostly not fused (Fig. 23). Between these rubble layers the about 1 m thick core of the 'a'ā flow is noticed. Since pyroducts do not develop in 'a'ā flows at low slope (at least none are known), the discovery of these layers in the wall of the cave suggest substantial downcutting, substantiating the observations stated above about the canyon-type passage. It is logical that the erosion of 'a'ā rubble is easier than the erosion of massive 'a'ā-cores or pāhoehoe sheets. Thus, the passage shape depends very much on what substrate the pyroduct encounters: Where 'a'ā rubble is encountered the passage can become wider and deeper, where other layers are encountered, the passage shows protruding ledges and may be less wide and deep. These observations show, that Socheon Cave was substantially enlarged by downward erosion, much more than in the case of Bilemot and Susan caves.

The map of Socheon cave shows a mono-trunked patter with a few oxbows and early, high level, partly filled side passages and one larger side passage. Such pattern arise if the lava flow splits and progresses into two adjacent depressions. Normally one of them will stop to be delivered with hot lava as the other one erodes down more quickly.

Socheon, of the three caves visited, has the largest bat colony. We noticed possibly several hundred bats, hanging and flying, while only one flying bat was seen each in Bilemot and Susan Caves. In Socheon, the bats have colored ceiling cupolas, used as roosts, pitch black and bat guano covers the floor with black smear. One bat skeleton was found on the floor (Fig. 24). Flies were abundant in the section between the entrances. The cave also offers archeological potential. The two cairns were mentioned already. Near the first entrance several stone rings are present, used for fires.

Figure 24: *Bat skeleton found near the entrance in Socheon Cave.*

When judging the importance of Socheon (for example as an eminent example of lava erosion) one must critically evaluate the new, third opening. Cave air flow in general is governed by the temperature difference between the cave (hoovering at around average annual temperatures of the respective latitude and altitude) and the size and altitude differences of the entrances. In case of Socheon, the third entrance altered the existing pattern of air flow fundamentally. Before its opening the section below Opening 2 was, meteorological speaking, a cold air trap. Because the altitude difference between the upper two entrances is small, the air flow there must have been minimal also. With the opening of the lower entrance, cold air rapidly flows out of the system, being replaced by warm air in summer. In winter, the opposite occurs with warm air rising from the upper two entrances and colder air being drawn in at the bottom. Thus, the area where the bats roost experiences much a higher annul temperature variation than before. Furthermore, the fast air exchange will cause a quicker drying out of the cave. Bats that are relying on constantly deep temperatures and a high humidity for their hibernation, may either be in danger of dying or they may decide to look for more constant conditions. These constant conditions they may now find in the section below the third entrance, Opening 3 that is now playing the role of cold air trap. Thus, it is possible that the bats move there. With their urine and guano, they will destroy the very features to be protected: the beginning of a brightly white calcitic secondary speleothem growth.

What this climatic change means to the other cave fauna will need to be explored as well. One more change is provoked by the third entrance: as the air in this section will be exchanged during cold nights in winter, the CO_2- pressure of the air will be lowered on average; compared to the conditions when this cave section was without a rapid air-exchange. This should enhance degassing and speed flowstone growth; but is that what is wanted? These are not the natural conditions that should be protected.

Note added in proof: It was recently decided to reinstall the original meteorological conditions at the new opening.

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