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A SCIENTIFIC RATIONALE FOR VULCANOSPELEOLOGY

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Vulcanospeleology is the exploration and scientific study of caves in volcanic rocks. It is a recently developed branch of speleology, born from the worldwide eagerness of cavers to search for new caves, even in apparently unlikely places, far from any outcrops of soluble rock. Some volcanic caves have been known and explored for centuries, but only in the last 20 years has there been a serious undertaking to prospect for, explore, and scientifically study caves in the world's major volcanic provinces. This short experience has shown that there is a remarkable assemblage of caves in volcanic rocks, the principal forms being vents and pits, cracks, and lava tube caves. Cavers have also come to learn that it is the basaltic terrains that contain the greatest abundance of large cave forms.

Exploration and mapping activities by specialist caving groups, such as the Cascade and Oregon Grottos of the NSS, the Cave Exploration Group of East Africa, Gruppo Grotte Catania, and others, have contributed to the considerable growth in knowledge regarding the forms and occurrences of volcanic caves. Professional geologists, on the other hand, until very recently, looked upon volcanic caves merely as curiosities. That was until the need arose for terrestrial analogies of the volcanic landforms of the lunar surface, and eventually of the surfaces of the other inner planets of the solar system. Sinuous rills were thought to have probably originated from lava tube collapse, and this stimulated research into the geology of terrestrial lava tube caves, and subsequently, into the processes of lava tube construction and operation as observed for the first time in detail during the 1969-74 Mauna Ulu flank eruption of Kilauea Volcano, Hawaii. Other scientists participating in the program of observations of the Mauna Ulu activity were, in turn, struck by the importance of lava tubes in transporting fluid lava to sites distant from the vent, and by the apparently important role played by lava tubes in the building of Hawaiian-type shield volcanoes. Unfortunately, other volcanic caves have not stimulated as much professional interest. But as time goes by, more and more local geological problems are being solved by exploration and careful study of vents, pits and cracks. Thus, vulcanospeleology has progressed by means of steady amateur study, and by means of a series of coincidental scientific discoveries which have drawn in professional earth scientists.

It is now time to take stock of our position — to ask what has been learnt in 20 years of volcanic cave study, and to point out to cavers the goals to be pursued within a comprehensive scientific framework. The components of this framework are listed below.

1. Basalt, and other cavernous volcanic rocks, cover a larger surface area of this planet than any other rock type, and in these volcanic terrains (including ocean floors), caves are large, abundant, and diverse landforms, worthy of study in their own right.

Outside of caving circles, few realize just how extensive, diverse and abundant volcanic caves are. We need only to cite a few examples here to illustrate this point. There are lava tube caves in Korea and on Hawaii Island that range up to 12 km in length, but these are just isolated segments of caves which may ultimately be found to be 20 or 30 km long (certainly this is probable on Hawaii). On mainland USA, collapsed lava tube caves are known to extend for 40 or 50 km (Green and Short 1971), while a partly cavernous lava tube originating from the Undara Volcano, North Queensland, may have had a length in excess of 100 km (Atkinson, Griffin and Stephenson 1977)! The lava tube cave, Cueva del Viento, Tenerife, is a three-dimensional passage maze, as complex as any limestone cave (Wood and Mills 1977), and Dynamited Cave, Washington, contains significant vertical development (Halliday 1963). The world's largest natural pits are volcanic (for example, Trou au Natron in the Tibesti Mountains, North Africa, has a depth of 1,160 m), while a number of the world's great volcanic rifts (for example, the Great Rift of Idaho, and Hawaiian rifts) may eventually be descended to depths of hundreds of meters. Even exogenetic forces have formed caves of significant length and depth in volcanic rocks, as exemplified by the 214 m cavern complex of Officer's Cave, Oregon (Parker, Shown and Ratzlaff, 1964), while endogenetic caves are known to exist on the ocean floors. Of particular importance, caves are not an isolated phenomenon in volcanic terrains, and in basalts especially, there is a group of cave-related landforms (collapse dolines, natural bridges, gorges, sinks, etc.), forming a distinct non-solutional, karst-like geomorphology.

2. The study of volcanic caves, and the landforms derived from them, help to explain landforms on the surfaces of the other planets.

Extra-terrestrial landforms cannot be studied on the ground, but terrestrial equivalents may provide the necessary insights into the evolution of such landforms. Terrestrial volcanic terrains, such as the Snake River Plain, Idaho, appear to be directly analogous in surface morphology to many volcanic regions on the Moon, Mars, Mercury and Venus (Greeley, 1977), while the Hawaiian shield volcanoes appear to be comparable with the great lava shields of Mars. Mention has already been made to the belief that sinuous rills are collapsed lava tubes (see, for example, Greeley 1972), and rifts and pits are being examined to provide insights into comparable extra-terrestrial landforms (as in Greeley 1977). More important, as will be explained later, tube-fed lava flows may have played a fundamental role in the development of plains and shields on earth, and by implication to have been an important process in the formation of comparable parts of the surfaces of the other inner planets.

3. Exploration of pits and cracks reveals details of the internal "plumbing of volcanoes, and aids an interpretation of their deep stratigraphy.

The exploration of volcanic pits, vents and cracks is exceedingly dangerous because of the fragile nature of the wall rock, but it provides the volcanic caver with the opportunity for vertical exploration, and it can provide solutions to problems of the local geology which cannot be discovered on the ground surface. Much is now known about the geology of the Great Rift, Idaho, partly because it is examinable in all three dimensions (King 1977). This author, amongst others, has descended smaller rifts, vents and hornitos on Mt. Etna, Sicily, in order to solve specific problems relating to the local stratigraphy (Wood 1976). Others have described in this symposium the descent of a pit in the Ka'u Desert, Kilauea Volcano, Hawaii. This pit, and others on Hawaii Island, display a stratigraphy ranging over hundreds of meters in vertical extent, a thorough examination of which would reveal much about the various styles of eruption which have built up this volcano.

4. Detailed mapping of cave groups in specific lava flows enables the eruptive history of the flow to be worked out.

This author has undertaken two very successful studies of this nature. In an investigation of the small, monocyclic lava shield of Gullborg, Iceland, (Wood 1978), analysis of lava structures, and surveyed relationships between the lava tube caves, open lava channels, and major flow units enabled an interpretation of the genetic history of the volcano to be made. Similarly, in a collaborative study of the unusual 1614-24 lava flow, Mt. Etna, with R. Greeley and J.E. Guest (Wood 1978), he surveyed relationships between the lava tube caves and large terraces in the flow, providing details of their relative ages and the order of terrace formation.

5. Equilibrium flow of liquid lava through a lava tube may be a reason for the formation of long lava flows on minimal slopes, and thus for the development of basaltic plains and shields.

Geologists were much enlightened about the construction and operation of lava tubes following observations of the 1969-74 Mauna Ulu flank eruption of Kilauea Volcano, Hawaii. Amongst other things, these observations revealed that the lava tubes developed during this activity were highly efficient transporters of liquid flow, for the original temperature and mobility of the erupted fluid were only slightly reduced, even after flowing through more than 12 km of lava tube (Peterson and Swanson 1974). In a later study of lava tube systems, based upon the morphologies of lava tube caves (Wood 1978), this author also emphasized the efficiency of tube-fed flow, and drew attention to the similarities between the channel forms and activities of lava rivers and water rivers. It was proposed that, although this efficiency may be due in part to the low thermal conductivity of the cooled basalt rock, an important factor might be that, like a water river, a lava river may possess the capacity to adjust its channel, through erosion and deposition, in a direction that minimizes thermal and mechanical energy losses.

As this author has previously pointed out (Wood 1978 and 1981), the proposal implicit in these studies — equilibrium flow through a lava tube system — is far-reaching, for it infers that the tube-fed volcanic process may be a reason for the apparent anomaly of very long flows emplaced down minimal slopes. In theory, accumulations of these flows would form a low-angled lava shield if they were erupted from a single vent, or form an expansive lava plain if erupted from multiple vents. Indeed, it is well known that basaltic plains, such as the Snake River Plain, contain extensive lava tube caves on very low slopes, while studies of the Hawaiian shield volcanoes (Greeley, Wilbur and Storm 1976; Holcomb 1980; Wood 1981) have shown that lava tubes are very abundant, with many developed on slopes of a little as 1-1/2° (for example, this is the mean gradient of Kazumura Cave).

6. Studies of the discharge of liquid lava through a lava tube system may enable future calculations of the rate of effusion, or the duration of a dated vent effusion, to be worked out.

This author surmised in his previous paper in this symposium that if it could be established that certain passage forms in lava tube caves formerly transported full-bore flow, and subsequently drained off all the fluid fill, then it should be a relatively simple matter to estimate the mean discharge of the tube. Such a figure for a known tube would be most useful, and together with an estimate of the volume of the lava flow emplaced, a calculation of the duration of the effusive vent activity is possible. Similarly, if the period (duration) of the activity is known, it would be possible to calculate the mean rate of effusion from the vent. These obviously would be tentative figures, but they would be invaluable to a geologist attempting to understand the overall history of a particular effusive period of a volcano.

The biggest problem is the identification with certainty of tubes which carried full-bore flow, and which drained completely. This author believes that circular, or sub-circular, conduit-like passages, with or without conical ceiling stalactites, such as the passages making up parts of Kazumura Cave and Ainahou Ranch Cave, Hawaii (Wood 1981), are of the type necessary for this calculation.

*7. **Future knowledge of the formation and operation of lava tube systems may be a key to predicting the behavior of dangerously active lava flows.***

There have been attempts in the past to divert dangerously active lava flows by aerial bombardment, or through the construction of barriers in advance of the flow front. Wentworth (1954) considered why such attempts were not a great success, and modern knowledge of the morphology of active lava tube systems, gained principally from cave evidence, adds further insights into the behavior of active tube-fed lava flows.

On the basis of his own researches into lava tube caves, this author has proposed (Wood 1978) that an ideal lava tube system, feeding a simple tongue-shaped lava flow, or flow unit, comprises four morphological elements: (1) a long, sinuous, partly braided main feeder tube lying along the axis of the flow; (2) lateral complexes of smaller tubes, which transport liquid flow only when surges from the vent cause the axial feeder to overflow; (3) tube complexes overlying the axial feeder, left vacant because their flow has been captured by the underlying tube; (4) a delta-like region of smaller distributary tubes at the flow front. Elements 1 and 4 are common to all systems, while elements 2 and 3 may or may not be present.

This author proposes that this system behaves as follows: the axial feeder tube is an "adjusted" or equilibrium form, through which fluid lava is conveyed between the vent and the flow front without significant loss of heat energy or mechanical energy. At the flow front, where the velocity of the fluid passing out of the axial tube is checked, as a result of rapidly increasing energy losses, the stream rapidly agrades, dividing and subdividing into a myriad of smaller distributary tubes and channels, feeding lava to a broad delta-like front. It appears that as the lava front advances, the axial feeder tube elongates across earlier formed frontal deltas. The mechanism for this elongation is not known, though it is clear that very few of the vast number of distributaries of the older deltas are utilized, for competition between routes must cause most to clog, and the mobile fluid to be concentrated along the flow axis.

A more detailed description of this model is provided by this author elsewhere (Wood 1978), but this synopsis points to two important implications.

A. The model now shows that there is little benefit in attempting to divert dangerously active tube-fed flows, unless fluid can be drained away from the axial feeder.

B. Comparison with the work by Bates (1956) on water river deltas, suggests that the lava emerging from the end of an axial tube, at the front of an active pahoehoe flow, may be likened to a jet flow. Thus, the development of pahoehoe lava flows may be predictable and amenable to future quantification through the application of jet theory.

*8. **Studies of wildlife in lava tube caves aid the development of models of cave life evolution.***

Although the author is not a cave biologist, he recognizes that there are certain advantages to studying wildlife in lava tube caves, particularly caves situated on isolated oceanic islands. Howarth, for example, has shown that the rapid speciation of faunas in the Hawaiian caves holds important clues to the interpretation of the evolutionary process.

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