THE WORLD'S LONGEST LAVA TUBE CAVES

R. L. Crawford
Burke Memorial Museum
University of Washington

INTRODUCTION

Since lava tube caves began to be mapped in large numbers, numerous claims to possession of the world's longest have been advanced by cavers from various countries. Among the caves for which this distinction has been claimed are Ape Cave, Washington (Halliday, 1962); the Cueva de los Verdes, Canary Islands (Montoriol and de Mier, 1974); Kazumura Cave, Hawaii (Gagne and Howarth, 1975); Leviathan Cave, Kenya (Simons, 1976); Man Jan Gul, South Korea (Anon, 1981); and Bilemot Gul, South Korea (Ogawa, 1982).

Conventionally, the ranking of the above mentioned and other long lava tube caves would be based on their published lengths. Unfortunately, some of the caves involved have conflicting published length figures; even more unfortunately, the mappers have used different standards in defining cave length and cave limits. Uncritical acceptance of the published figures would lead to a list in which the lengths given for different caves would not be truly comparable; thus the ranking would be meaningless. It is evident that a single set of standards and definitions must be adopted for a meaningful ranking of the caves in order of length to be possible.

The Problem of Segmentation

The most important controversy among lava tube mappers is whether intact lava tube segments separated by collapse trench should be counted as the same or different caves. Figure 1 illustrates diagrammatically eight possible caves bearing on this controversy.

Figure 1A shows a single passage cave divided by a typical collapse entrance. Korean, Spanish, or British cavers would almost certainly count this as a single cave. American, Canadian, or French cavers would most likely count it as two. This difference of opinion would lead to two alternative length figures differing by a factor of about two. Moreover, of the mappers who would count this as a single cave, some would include the collapse in the cave's length and some would not.

Figure 1B is a more extreme case of Figure 1A. Some of the mappers who would count 1A as one cave would count 1B as two. Probably some would count even 1B as a single cave. In this case, if the collapse trench were counted, it would nearly double the cave's (or caves') length.

The same mappers who would count 1A as one cave would probably count 1C as one also; others would count it as three. But would anyone count the largely collapsed system in 1D as a single cave for the sake of its four tiny intact segments? Probably not. This is what is known as a reduction ad absurdum. If one is not to count extreme cases like 1D as entire caves, where is the line to be drawn? Standard definitions are the only answer.

The diagrams on the right side of Figure 1 illustrate some cases to be considered in formulating standards on segmentation. Figure 1E illustrates the least controversial possible case. A collapse at one end of a passage obviously leaves the cave intact. The case in Figure 1F is almost equally clear. Everyone, I think, would agree that a collapse which can be bypassed via intact passage does not segment the cave.

Figure 1G illustrates the nub of the problem. Several points of view are possible here. First, one could view the left hand case as a single cave, despite the segmenting collapse. One would then have to decide where to set limits on how much collapse can be part of a cave, or be forced to count extreme cases like 1D as caves. Second, one could adopt some such rule as that a collapse of the full passage width segments the cave. One would then have to count the right hand case of 1G as two caves, something most cavers would be reluctant to do. The best compromise between these two points of view I have seen is the international standard as adopted here; see below for details.

A more difficult problem, and one that has yet to be satisfactorily settled, is illustrated in Figure 1H: a collapse that does not include the full passage width, but leaves an overhang on one or both sides. If the collapse in this example does segment the cave, what then about a much smaller skylight collapse? If it does not segment the cave, what then about a case where the overhang is less than half a meter?

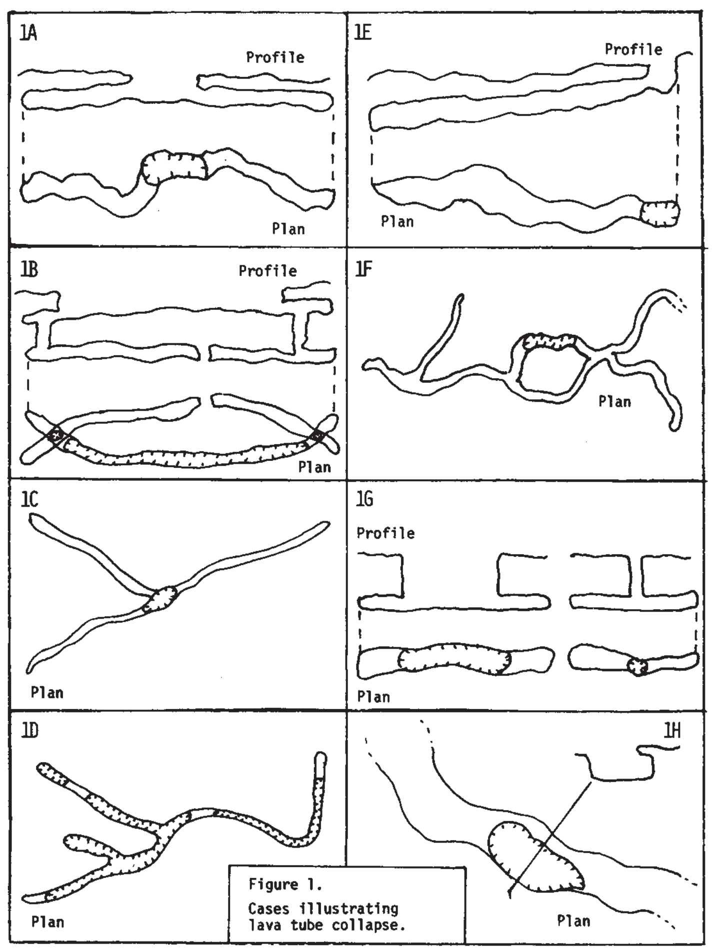

Figure 1.
Cases illustrating lava tube collapse.

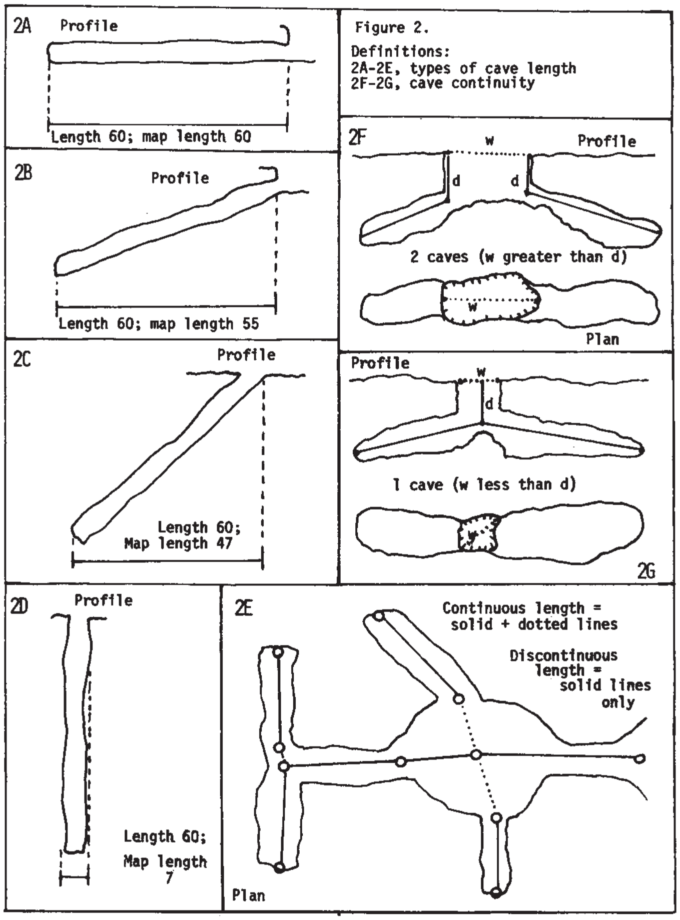

Figure 2.
Definitions:
2A-2E, types of cave length
2F-2G, cave continuity

The Problem of Length Definition

Other controversial aspects of cave length have to do with just how "length" is defined with respect to a cave. To begin with, I think most or all cavers would agree that a cave's length is the total length of all passages, and not just the "main passage" length as some geologists would have it. Another standard that is widely, though not universally accepted is that a cave's length must be determined by mapping, not estimation, to bear comparison with other lengths.

What is done with the mapping data to determine cave length? In the case of some mappers, particularly those of the eastern United States, the first step is to reduce the raw length data, as measured in the cave, to horizontal and vertical components and to count only the horizontal components. This is illustrated in Figure 2 (A-D). Length determined in this way is called projected length or map length. In figure 2A, the map length is 60 units, the same as the unreduced length figure, since the cave is perfectly horizontal. In Figure 2B, the map length is 55; in Figure 2C, 47 feet; in Figure 2D, the "length" of the 60-unit pit is 7 units. To my mind, counting map length as the "true" length of a cave is unrealistic to the point of absurdity. A cave passage, like a stick or any other rigid object, does not shrink and expand depending on whether it is horizontal, vertical, or at an angle. The distance from one end to the other is the same in each case. The length of a cave passage is measured along the long axis of the passage. This is also carried slope length or linear development. All the cases in Figures 2A-2D have the same length, 60 units. Slope length is used by cave mappers in most parts of the world. Reduction of slope length to map length is, of course, an essential step in the preparation of a plan view map. However, it must be remembered that it is only a mathematical abstraction useful in cartography, and has no constant relationship with the true length of a cave.

In caves that slope very little, the map length may be only slightly less than the true length. If the cave is very long, however, even a small percentage difference can be important. A case in point: the most recent list of longest caves of the world (NSS News, October 1982), lists Friars Hole, USA, at 66,000 m, in seventh place under Sistema Ojo Guarena, Spain, at 67,000 m, in sixth place. It is not unlikely that the figure for Friars Hole is map length and that for Sistema Ojo Guarena is slope length. In this case, if the slope length of Friars Hole were only 2 percent higher than its map length, it would be 67,320 m and would take sixth place.

Most other variations in length standards have relatively minor effects, but one can be significant at times: continuous vs. discontinuous length. These concepts are illustrated in Figure 2E. The solid lines represent discontinuous length; the solid plus dotted lines represent continuous lines. In the case of large rooms, the difference can be considerable. Either form seems defensible, but a single standard must be adopted nonetheless.

International Standards

Like other cave mappers, I have personal opinions on how cave length should be determined. I could here proceed to codify these, but lacking any authority other than mine, they would stand no more chance of universal acceptance than anyone else's opinions. Fortunately, there exists an International Commission on the Greatest Caves, presently headed by Claude Chabert, whose job it is to set standards for cave mapping. Their preliminary recommendations were published by Chabert (1979) and Chabert and Watson (1981); from this I have extracted the following list of basic standards for lava tube mapping. Some statements have been reworded for clarity or applicability to lava tubes, but the principles are those of Chabert and his colleagues. See the discussion above the definitions of terms.

*1. **An open collapse pit is part of the cave if and only if its greatest horizontal dimension (width, length, or diagonal) is less than its depth.*** See Figures 2F, 2G. By this definition, the collapse in 2F is not part of the cave, but that in 2G, is part of the cave. Depth in this case is considered to be the depth that would be added to the cave if the pit were considered part of the cave; in other words, the vertical difference between the lip of the pit and the first in-cave survey stations.

*2. **A cave is a continuous subterranean cavity; any discontinuity such as a collapse where one must leave and then re-enter a cave, divides that cave into two caves, whose lengths must NOT be counted together.*** This is a corollary of (1) above, and a crucial point which must be accepted in order for a standard list of long caves to be possible. A related point is that caves linked only by artificial tunnels must be treated as separate caves; however, natural passages enlarged or re-excavated by cavers count as part of the cave.

*3. **For ranking purposes, a cave's length is continuous linear development***, or the distance traveled by a caver to explore all parts of the cave. As a corollary, portions of the

TABLE 1 SOME CAVES AND CAVE SYSTEMS OMITTED FROM LIST

Cave/Cave System	Claimed Length, m	Reason Omitted	Location
Ainohou Ranch Cave	7,110	Segmented	Hawaii
Ubuwumo bwa Musanze	4,560	Segmented	Rwanda
Offal Cave	3,400	Unmapped	Hawaii
Kalmanshellir	3,000	Unmapped	Iceland
Catwalk Cave	2,420	Segmented	California
Cueva de Gallardo	2,250	Segmented	Galapagos
Cueva de San Marcos	2,130	Two caves	Canary Is.
Cueva de Felipe Reventon	2,000+	Unmapped	Canary Is.
La Cueva	2,000+	Unmapped	Canary Is.

TABLE 2 CAVES LISTED WITH REDUCED LENGTH

Cave/Cave System	Max. Claimed Length, m	Listed Length(s)	Reason
Man Jang Gul	13,268	4,632	Segmented
Leviathan Cave	11,152	9,152 } 2,071 }	Segmented
Cueva del Viento (system)	10,002	7,922	Segmented
Cueva de Los Verdes	6,100	2,565	Segmented
Susan Gul	4,700	4,674	Overestimate
Gruta dos Balcões	3,200	2,650	Overestimate
Socheon Gul	3,074	2,186	Segmented

TABLE 3 WORLD'S LONGEST LAVA TUBE CAVES

	Cave	Length, m	Vertical Range, m	Location
1.	Bilemot Gul	11,749	---	Cheju Do
2.	Kazumura Cave	11,713	261	Hawaii
3.	Upper Leviathan Cave	9,152	408	Kenya
4.	Cueva de las Breveritas	7,922	261	Canary Is.
5	John Martin Cave	6,400 ?	---	Hawaii
6.	Cueva de Don Justo	6,315	143	Canary Is.
7.	Susan Gul	4,674 ?	---	Cheju Do
8.	Man Jang Gul	4,632	---	Cheju Do
9.	Ape Cave	3,904	210	Washington
10.	Duck Creek Lava Tube	3,674	76	Utah
11.	Falls Creek Cave	2,797	126	Washington
12.	Gruta dos Balcoes	2,650	43	Azores
13.	Cueva de Los Verdes	2,565	29	Canary Is.
14.	Kaumana Cave	2,544	---	Hawaii
15.	Dynamited Cave	2,388	108	Washington
16.	Pot o' Gold Cave	2,250	---	Idaho
17.	Socheon Gul	2,186	---	Cheju Do
18}	Mitsuike Ana	2,140	70	Japan
19}	Gypsum Cave	2,140	---	Idaho
20.	Lower Leviathan Cave	2,071	57	Kenya
21.	Catacombs Cave	2,000	---	California

cave no caver has passed through, such as unclimbed domes and undescended pits, cannot be counted.

4. For ranking purposes, a cave's depth is the difference in elevation between the highest and lowest points reached by cavers in the cave.

5. Only accurately surveyed caves can be ranked; where the survey is unfinished, only that part which is surveyed qualifies.

One problem not addressed directly in these standards is that illustrated in Figure 1H, where a collapse sink leaves an overhang. One of the Commission's principles that may apply is that in a horizontal entrance, the cave begins at the innermost point of the drip line. Unfortunately, this does not seem to help much. This problem is one that should be addressed by the Commission at the earliest date possible. In the meantime, this list will count caves like that in Figure 1H, where it is possible to remain under the overhang while passing the collapse without undue contortion, as single caves.

Criteria for Inclusion

The intention of the list given here is to include every continuous lava tube cave with 2,000 m or more of mapped passage. In most cases, it has been possible to determine whether the caves on the list are segmented, although in some cases, the information has been hard to find. Since there are no lava tubes in the eastern United States, I assume that all the lengths given are linear development rather than map length. In some cases, this has been confirmed.

Two caves are listed which may be segmented, but are being given the benefit of the doubt pending confirmation. Favre's map of John Martin Cave does not show collapses clearly, but in a conversation with John Martin, I received the impression that his cave will probably prove to be segmented when detailed information becomes available. No map or photographs of Susan Gul have yet been published, so its nature remains unconfirmed.

A number of lava tube caves with lengths claimed in excess of 2,000 m have been omitted from the list for reasons connected with the standards set above. In most cases, these caves were either segmented or unsurveyed. In one case, the Cueva de San Marcos, the cited length was the total of two caves with entrances near each other on a cliff face, but not even connected by collapse trench. The more important of the omitted cases are given in Table 1.

In segmented systems, all segments more than 2,000 m long have been listed. So far, only one system has proven to have two such segments; the Leviathan System in Kenya. Originally, it was thought that the Leviathan System was segmented in two places, but data kindly supplied by Jim Simons show that only the lower of these two, "Pottery Collapse," actually segments the cave (see Figure 3). Simons' data is admirably thorough and might serve as a model for other cave mappers. A number of the caves on the list are the longest single segments of cave systems which in toto are considerably longer. Some of these are compared in Table 2 below.

List of the World's Longest Lava Tube Caves

The list which follows is only as good as the data which I received from all over the world. Numerous changes have been made from past lists, and future editions will undoubtedly reflect more additions, changes, and corrections. Kazumura and Upper Leviathan caves are both incompletely mapped, so changes in the ranking of the "top three" may be expected. It is likely, however, that Upper Leviathan Cave will retain its position as deepest known lava tube cave for some time. The position of Catacombs Cave at the bottom of the list is probably permanent, unless new passage is discovered.

Sources of length data and published maps:

1. Ogawa, 1982 (length); map.
2. Wood, 1981 (map, length, and depth).
3. Simons, personal communication, 1982; map not yet available.

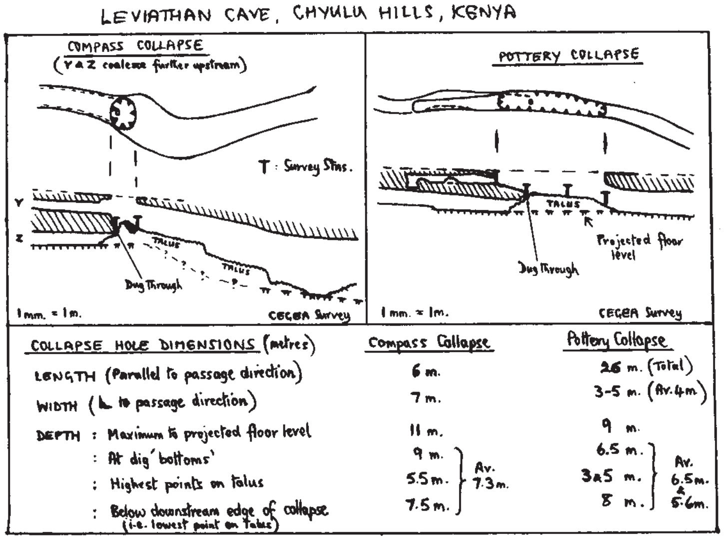

Figure 3. Leviathan Cave collapse dimensions (drawn by Jim Simons).

4. Wood and Mils, 1977 (map, length, and depth).
5. Favre, personal communication, 1982. Map on file, unpublished.
6. Montoriol, Romero, and Montserrat, 1980 (map, length, and depth).
7. Ogawa, personal communication, 1982; map not yet available.
8. Crawford, 1980 (recalculation of length); map.
9. Halliday, 1978 (length, depth); map.
10. Green, 1976 (map, length); 1978 (depth).
11. Nieland, 1975 (map, length, and depth).
12. Montserrat, personal communication, 1981; map on file, unpublished.
13. Montoriol and de Mier, 1969 (map, length, depth of system). Only longest segment listed here.
14. Wood, 1986 (map only). Length given here is estimated from map; when known, true length will be greater.
15. Crawford, 1975 (composite length and depth); only partial maps are available.
16. Ireton, personal communication, 1978.
17. Crawford, 1982 (re-calculation of length, map).
18. Ogawa, personal communication, 1982. Map on file, unpublished.
19. Vance, 1978 (map, length).
20. Simons, personal communication, 1982. Map not yet available. This is the section of cave below Pottery Collapse.
21. Peck, 1976 (map, length).

Concluding remarks:

The study of the world's lava tube caves has hardly well begun. Most volcanic areas have not even been checked by cavers. Even the best-studied areas will, undoubtedly, yield additional caves that qualify for this list. Several of the caves listed here are certain to be extended by further exploration. I encourage all cavers living in or near volcanic areas to explore and map their lava tubes, to adhere to the international standards, and to communicate the results to me for inclusion in future editions of this list.

Simons (1978 and in litt.) has suggested the formation of a separate list of longest lava tube cave systems, where caves divided by collapse would be added together. I am unable to undertake such a list myself, but offer my support and encouragement to anyone who feels sufficiently energetic and meticulous to do so. Much presently unpublished data would have to be gathered to even make a start. Such a listing would have to set standards of its own, answering questions such as: Would collapse trench be counted in the length, or only intact passage? If the former, it would be hard to beat the 28,500 m Bandera Crater Lava Tubes in New Mexico (Hatheway and Herring, 1970). Would a system consist of caves separated by collapse only, or would systems segmented by lava seal or breakdown choke, necessitating return to the entrance and overland treks, be included? Would cave segments so short that they individually would not qualify as true caves, be counted in the length? and so forth.

Discussion:

Giuseppe Licitra (Sicily) remarked that he prefers to consider systems segmented by collapse as single caves, but systems segmented by lava seals as separate caves. My reply: this standpoint may well be defensible scientifically, but if everyone adheres to their personal opinions and ignores the international standards, no cooperative length ranking will be possible.

Takanori Ogawa (Japan) corrected my length figure for Bilemot Gul. The original figure of 12.4 km did have a source, but much recent searching has failed to disclose it. Ogawa's figure may be considered authoritative.

Fred Stone (Hawaii) pointed out that the cave measurement standards presented here need further refinement. He mentioned cases where the survey line zigzags from wall to wall; where a collapse entrance has a significant overhang, or a floor is deep at one end and shallow at the other; or where cavers might excavate an originally shallow collapse pit until its depth exceeded its width. I agree that these and other problems need to be addressed; nonetheless, these standards are far better than the chaos we had before, and hopefully, Chabert and his commission will continue to work on them.

Acknowledgements

I thank all the cave mappers from many countries who have contributed data for this and previous editions of this list, most of whom are cited by name above. Over and above these, I owe a special vote of thanks to Bill Halliday, who assisted greatly in compiling the data and made most of the international contacts that made such a list possible.

REFERENCES

Anonymous. 1981. Limelight cast on new world's longest lava cave. *Korea* (magazine) summer, pp. 23-25.

Chabert, C. (uncredited). 1979. International Union of Speleology: report of the Commission on Large Caves. *Caving International* 3:33-36.

Chabert, C. and Watson, R. A. 1981. Mapping and measuring caves: A conceptual analysis. *National Speleological Society Bulletin* 43:3-11.

Crawford, R. 1975. An historical study of Dynamited Cave *Northwest Caving* 6:3-8

Crawford, Rod. 1980. Man Jang Gul: A lava tube cave system of international importance *Cascade Caver* 19:69-75

Crawford, Rod. 1982. So Cheon Gul: A major lava tube cave system, with notes on the geology of Cheju Do. *Cascade Caver* 21:4-10

Gagne, W. C. and Howarth, F. G. 1975. The cavernicolous fauna of Hawaiian lava tubes, 6. Mesoveliidae or water treaders (Heteroptera). *Pacific Insects* 16 (4): 399-413.

Green, D. 1976. Duck Creek Lava Tube. *Inner Mountain News* 8(5):cover and articles inside.

Green, D. 1978. The depth of Duck Creek Lava Tube??? *Cascade Caver* 17:11.

Halliday, W. R. 1962. *Features and significance of the Mount St. Helens cave area, Washington.* Washington Speleological Survey Bulletin 2 (Western Speleological Survey ser. no. 22), 6pp.

Halliday, William R. 1978. The remapping of Ape Cave. *Cascade Caver* 16:91-95.

Hatheway, A. W. and Herring, A K. 1970. Bandera lava tubes of New Mexico, and Lunar implications. *Communications of the Lunar and Planetary Laboratory, University of Arizona* 8:297-327.

Montoriol-Pous, J. and de Mier, J. 1969. Estudio morfogenico de las cavidades volcanicas desarrolladas en el Malpais de la Corona (Isla de Lanzarote, Canarias). *Karst, Revista de Espeleologia* (Barcelona) 6(22):1-23, foldout map and sections.

Montoriol-Pous, J. 1974. Estudio volcanospeleologico de la Cueva del Viento (Icod de los Vinos, Isla Tenerife, Canarias). *Speleon* 21:5-24, fold-out map.

Montoriol-Pous, J., Romero, M. and Nebot, A. M. 1980. Estudio vulcanoespeleologico de la Cueva de Don Justo (Isla de el Hierro, Canarias). *Speleon* 25:83-92, map in pocket.

Nieland, J. R. 1975. Falls Creek Cave. *The Speleograph* 11:112-13.

Ogawa, T. 1982. Bilemot Cave in Cheju Island, Korea: Exploration and survey in the longest single lava tube. *Kagaku Asahi* (Monthly Journal of Science, Nov. 11, 1981, pp. 20-22. English translation in *Cascade Caver* 21:21-22.

Peck, S. B. 1976. Mapping the caves of the Headquarters Lava Flow, Lava Beds National Monument, California. In *Proceedings of the International Symposium on Vulcanospeleology and its Extraterrestrial Applications,* ed. William R. Halliday, pp. 20-25. Seattle: Western Speleological Survey.

Simons, J. 1976. Articles in Kenya Daily Nation, May 20, pp. 11-15. Reprinted in *Cascade Caver* 15:51-57.

Simons, J. 1978. Leviathan not the longest??? *Cave Exploration Group of East Africa, Quarterly Newsletter* 3:8-9.

Vance, R. 1978. Gypsum Cave, Lincoln County, Idaho. *Gem Caver* (map) 11:2:9.

Wood, C. A. and Mills, M. T. 1977. Geology of the lava tube caves around Icod de los Vinos, Tenerife. *Transactions of the British Cave Research Association* 4:453-69, 1 foldout map.

Wood, C. A. 1981. Caves of glass: lava tube caves of Kilauea volcano, Hawaii. Descriptive broadsheet; photos, diagrams and full cave surveys. C. A. Wood.

A SCIENTIFIC RATIONALE FOR VULCANOSPELEOLOGY

C. Wood

British Cave Research Association

Shepton Mallet Caving Club

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