The Undara Lava Tube System, North Queensland, Australia: Updated Data and Notes on Mode of Formation and Possible Lunar Analogue

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Abstract

The Undara Lava Tube System, North Queensland, Australia, is remarkable not only for its geology, but also for unique flora and vertebrate and invertebrate fauna. This paper considers some aspects of its geology.

More than 60 caves and arches have now been discovered in the system. Most caves are less than 200 meters long but the system includes Australia's longest lava tube, over 1,350 meters. More than six kilometers of tubes have been surveyed and the first profile ever to depict a source volcano in addition to representative caves and arches is presented.

190,000 years ago, the Undara volcano erupted 23 cubic kilometers of basaltic lava at temperatures ranging from 1,170° Celsius to 1,220° Celsius, covering an area of 1,150 square kilometers. With an average gradient of only 0.3°, one of the flows extended more than 160 kilometers to become the world's longest flow from a single volcano. This great length is attributed to very high effusion rates, favorable topography, and lava tube efficiency.

The lava tube system extends more than 110 kilometers and includes caves, arches, and an almost level ridge that is 35 kilometers long and is known as "The Wall." The Wall is considered the best Earth volcanic feature analogous to the smaller basaltic ridges on the Moon.

Adjacent to, or aligned with, the caves and arches there are oval and elongate depressions. Most of these depressions are much wider than the caves and arches and appear to have formed contemporaneously by the draining of lava ponds. Darker green "rain forest" type vegetation within the wider depressions contrasts sharply with that of the surrounding eucalypt woodland and is indicative of former greater areal extent of rain forests, now confined to coastal and near-coastal areas.

Comparison of features of the Undara tubes with those of currently active and Recent Period tubes elsewhere in the world, indicates that the tubes of the Undara System were formed by the draining of roofed lava channels, whose locations were determined by palaeotopography.

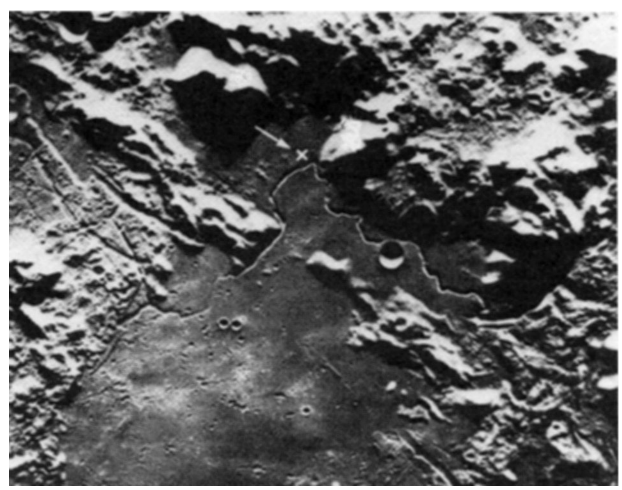

Figure 1—MOON—a meandering channel which may represent a collapsed lava tube in a lunar mare area near Apollo 15 landing site, indicated by arrow to cross. (Photo: Astronaut A.M. Woden, NASA Apollo 15 Mission)

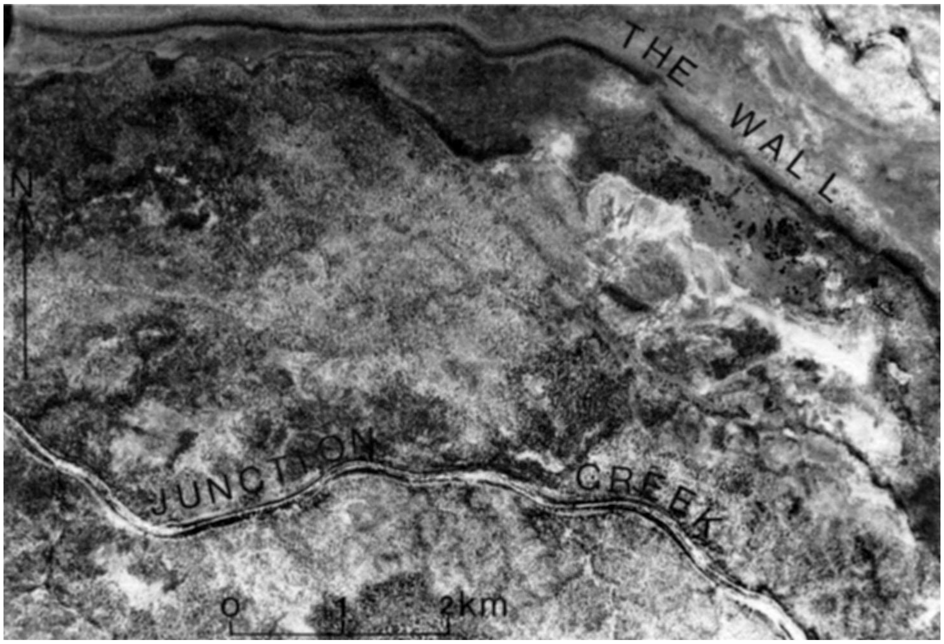

Figure 2a—EARTH—Vertical aerial photograph of the western end of the Wall Section of the Undara Lava Tube System (north at top). This low basalt ridge is 35 kilometers long and may be analogous to the sinuous ridges on the moon. (Photo: Department of National Mapping, Australia)

Introduction

In photographs of the lunar surface, the shape of channels (Figure 1) suggests fluvial origin. This hypothesis, however, had to be dismissed in the absence of atmosphere. A number of papers appeared suggesting that the sinuous rills on the Moon could be collapsed lava tubes (Kuiper, Strom, and Le Poole, 1966; Oberbeck, Quaide, and Greeley, 1969; Greeley, 1970 and 1971a; Cruikshank and Wood, 1972). These papers stimulated the study of lava tubes on Earth. Further impetus to this study came with the discovery 20 years ago that some of the first lunar rock samples were very similar, megascopically and microscopically, to terrestrial basalts with only minor geochemical differences (MacKenzie, Donaldson, and Guilford, 1982).

As an analogue to the smaller basaltic ridges of the Moon (Figure 2b), the length and shape of The Wall (Figure 2a) of the Undara Lava Tube System is considered Earth's best volcanic feature (Greeley, written communication, 1972 and 1991).

The first International Symposium on Vulcanospeleology and its Extra-Terrestrial Implications was convened in 1972 and, at the request of the chairman, Dr. Halliday, the first paper on the Undara Lava Tube System was

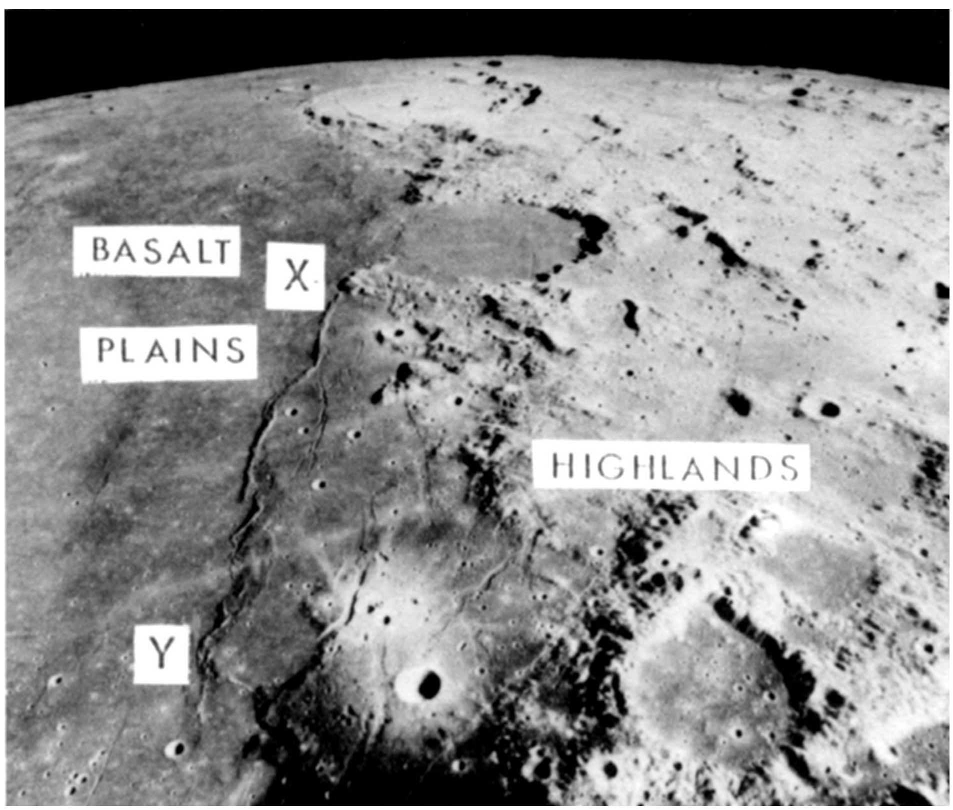

Figure 2b—MOON—View north across the eastern boundary of Mare Serenitatis (basaltic) and Highlands. X-Y indicates basaltic ridge. Circular depressions are impact craters. (Photo: NASA Apollo 17 Mission)

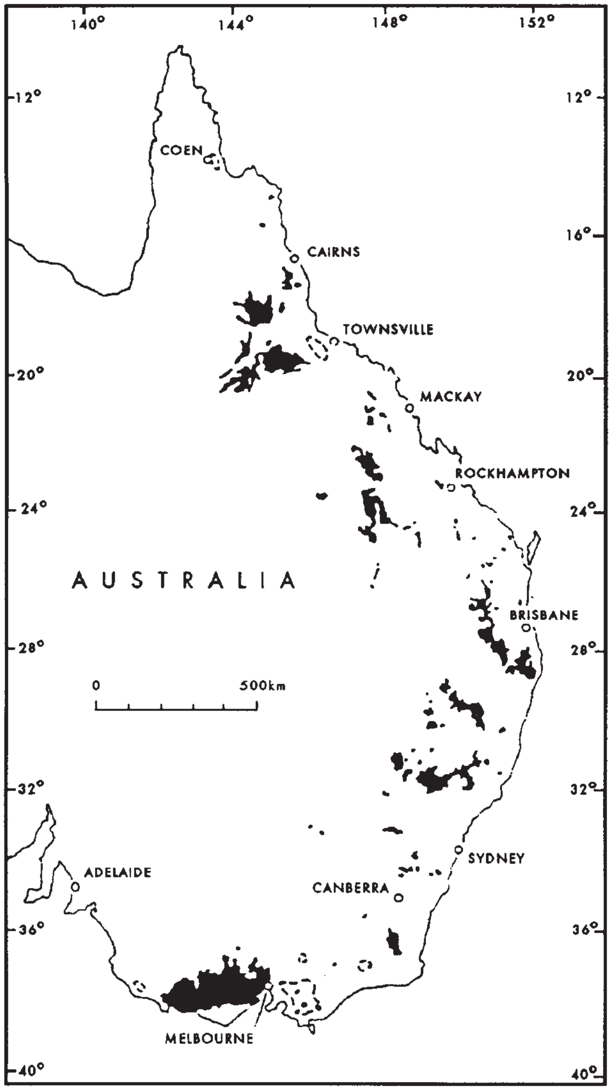

Figure 3 — Cainozoic basalt outcrops of eastern and southeastern Australia occur within 400 kilometers of the coast and extend for over 4,000 kilometers. (Stephenson et al.*, 1980)*

presented — six pages, including figures and references. From this initial study stemmed increasing interest and the current paper aims to place before you an account of our discoveries to date.

Location and Geological Setting of the Undara Lava Tube System

Cainozoic volcanism in eastern Australia extended more than 4,000 kilometers (Figure 3, Stephenson, Griffin, and Sutherland, 1980). In north Queensland, within 200 kilometers of the east coast, there are five major provinces (Figure 5).

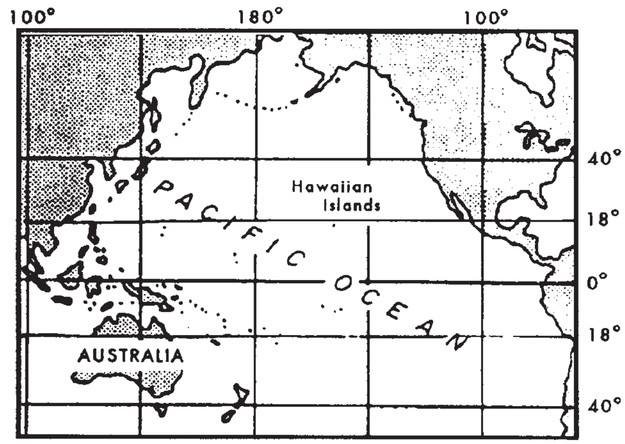

Figure 4 — Map of the Pacific Ocean to show relative locations of the Hawaiian Islands and northeastern Australia.

The Undara Lava Tubes are found within lava flows from the Undara Volcano (Figure 6) which is located approximately 200 kilometers southwest of Cairns in North Queensland, Australia. This volcano is situated near the center of the McBride

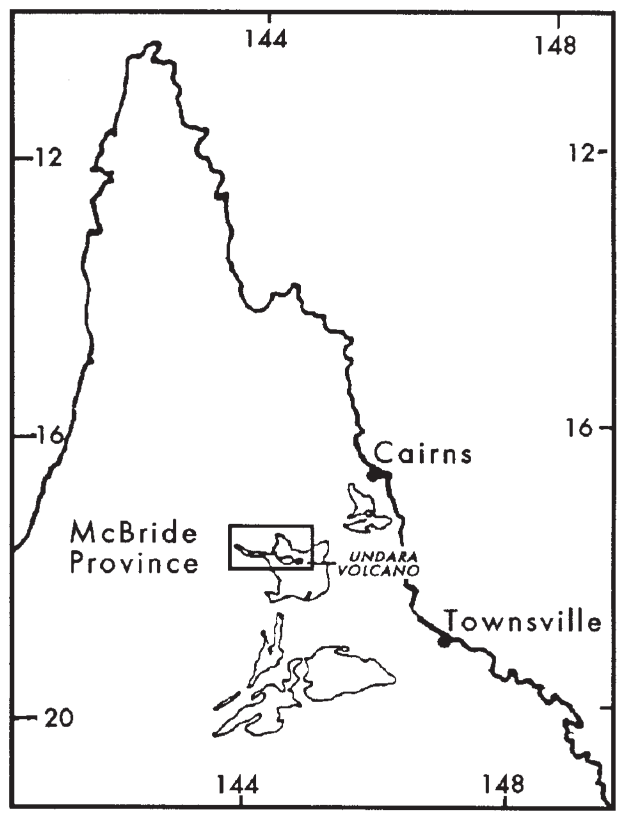

Figure 5 — The main areas (provinces) of Cainozoic basalt outcropping in northeastern Australia. The boxed area is shown in Figure 7.

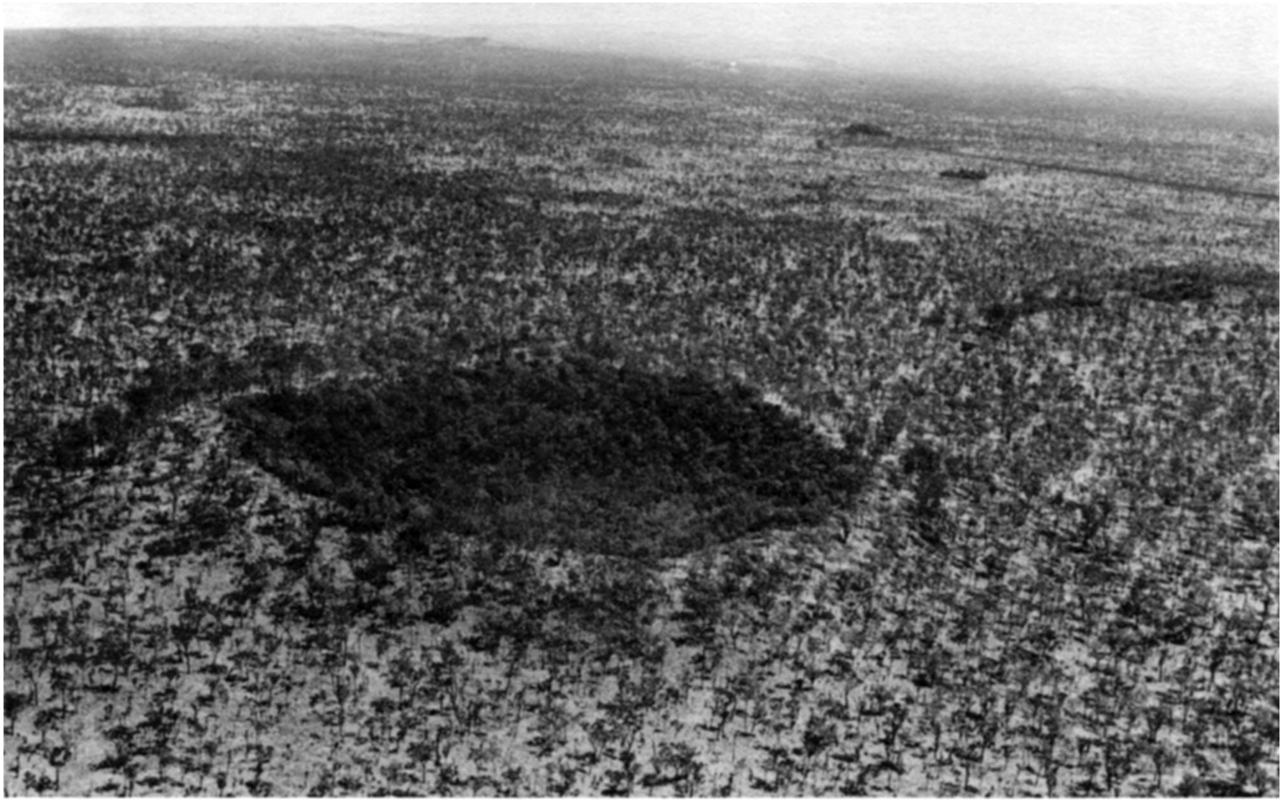

Figure 6—Aerial oblique view of Undara Crater, 340 meters across, looking west. The tube system commences in the line of the depressions that runs away from the crater towards the right. (Photo: Tom Atkinson)

Province (Figure 5) which covers approximately 5,000 square kilometers (White, 1962), and topographically forms a broad dome. There are over 160 vents in the province (Griffin, 1976), the majority of which are in the central region.

The Undara Volcano (Figure 7) rises to 1,020 meters above sea level (ASL) and is the highest point in the McBride Province. Its impressive crater (Figure 7) is 340 meters across and 48 meters deep with inner slopes of up to 40°. The rim rises only 20 meters above the surrounding lava field. Outward slopes from the rim vary from 30° to 5° on the northwest side where the major outflows occurred.

The crater walls are mainly covered by angular blocks (up to several meters across) of highly vesic-

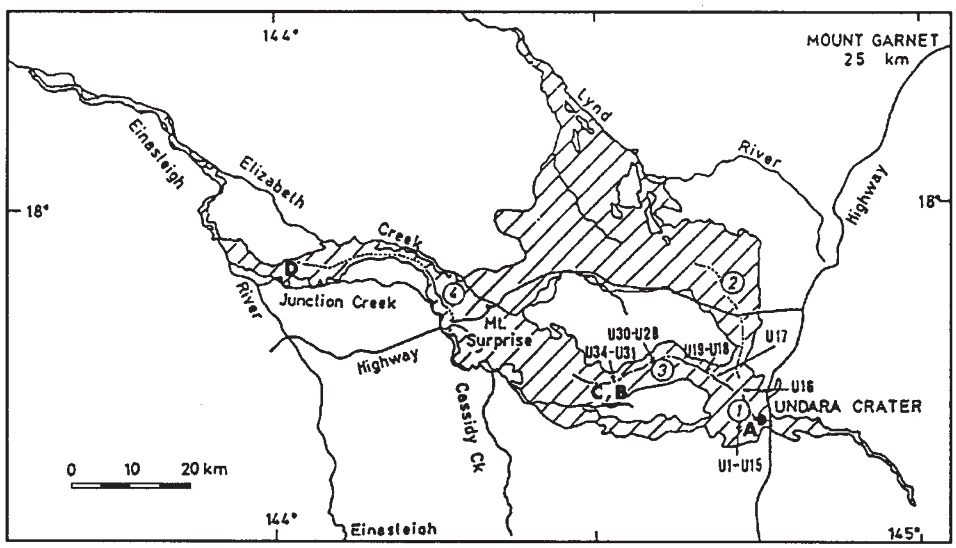

Figure 7—The Undara lava field. Circled numbers denote sections of the lava tube system referred to in the text, namely: 1. Crater Section; 2, North Section; 3, Yaramulla Section; 4, Wall Section. Other numbers are locations of cave entrances as shown in Figure 12. Letters "A" to "D" denote locations of basalt specimens chemically analysed (Appendix 1).

ular to massive lava. Several indistinct terraces inside the crater may mark former levels of a lava lake. Part of the crater floor is covered with a fine red soil containing small fragments of scoriaceous material and a small area of the floor is smooth pahoehoe basalt. The volcano erupted 190,000 years ago (Griffin and MacDougall, 1975).

In the McBride Province, only one volcano, Kinrara, is younger than the Undara Volcano (White, 1962). The Undara lava flows cover 1,550 square kilometers in the McBride Province and are basaltic in composition. Appendix 1 gives chemical analyses of four basalt specimens from the Undara flow.

One flow to the north is, in part, rough spinose aa basalt but most of the Undara lava field is of the smooth pahoehoe type. Present understanding, based on records of historic flows and observation of current flows, is that volumetric flow rate controls whether the flow will be of pahoehoe or aa type basalt – the historic lava flows in Hawaii are pahoehoe if they formed at a lower flow rate, which allowed time for de-gassing (Rowland and Walker, 1990).

It is in pahoehoe flows that the long lava tubes of the world have formed and can currently be observed forming on the Island of Hawaii (Greeley, 1971b, 1972, 1978; Peterson and Holcomb, 1989; Peterson and Swanson, 1974; Rowland and Walker, 1990). The feeding rivers of pahoehoe can be extremely complicated. Flow patterns frequently consist of an internal network of interconnecting conduits which sometimes attain considerable vertical and horizontal complexity (Wood, 1976). However, almost all the tubes of the Undara System are simple in plan and appear to be single-level. (To date the only multi-(three)-level tube discovered in the McBride Province is on the flank of the source volcano of an adjacent flow of slightly greater age).

Lava flowed in all directions from the Undara Crater, but the main flow was to the northwest (Figure 7). The flow to the north was approximately 90 kilometers long and entered the Lynd River. The voluminous northwest flow, however, followed precursors of Junction Creek, Elizabeth Creek, and the Einasleigh River (Figure 7) for more than 160 kilometers to become the longest single

Figure 8—Aerial oblique view of wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara Lava Tube System, North Queensland. Kalkani Volcano, a cinder cone, not connected with Undara, is on the left. (Photo: H.J.L. Lamont)

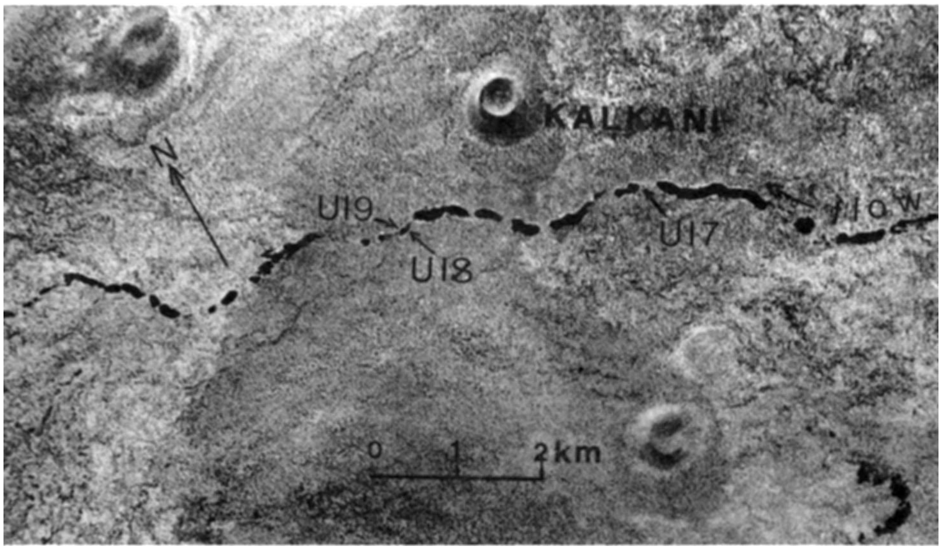

Figure 9—Vertical aerial view of wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara Lava Tube System, North Queensland. (Photo: Department of National Mapping, Australia)

volcano lava flow in the world (Walker, personal communication, 1989). Walker considers that to reach a length in excess of 160 kilometers, Undara's eruption may have continued for several years.

The Undara lavas were erupted at temperatures ranging from 1,175° Celsius to 1,220° Celsius (Roeder and Emslie, 1970, cited in Atkinson, Griffin, and Stephenson, 1975). They do not appear to have unusual viscosities (Shaw, 1972; Bottinga and Weill, 1972; cited in Atkinson *et al.*, 1975) which accords with the conclusions of Walker (1973), that very long lava flows reflect continued high effusion rate. Stephenson and Griffin (1976) reached a similar conclusion in a study of eight long basaltic flows in Queensland.

General thickness of the Undara lava field is estimated from 5 meters near the edges to up to 20 meters or more in the thickest parts. Along The Wall, west of Mt Surprise, the flow could be up to 40 meters thick but this is probably restricted to the width of The Wall. Exploratory drilling on the north side of The Wall showed basalt depth of 25 meters. If an average thickness of 15 meters is estimated for the whole flow, the total volume of lava erupted from the Undara Volcano is approximately 23 cubic kilometers.

Where rock is exposed near the axis of the flow, polygonal mega-jointing (Spry, 1962), which formed as the lava cooled and contracted, of up to 1.75 meters is evident throughout the 90 kilometers from the crater to the termination of The Wall.

The constant range in size of jointing over a distance of 90 kilometers seems to indicate an homogeneous flow. There may be similar jointing beyond the termination of The Wall, but this area has not yet been investigated.

The lava tube system from the Undara crater has been divided into the following five sections (Figure 7) in order to describe the locations of the caves and arches:

Crater Section—extending north from Undara Crater for four kilometers; average slope 1°.

West Section—west from the crater, extending approximately 15 kilometers; average slope 0.75°.

North Section—continuing north from the Crater Section at least a further 8 kilometers, possibly 28 kilometers, average slope 0.5°.

Yaramulla Section—extending west-northwest from the northern end of the Crater Section for over 35 kilometers; average slope 0.7°.

Wall Section—approximately 35 kilometers; an almost continuous narrow ridge, known locally as The Wall; average slope 0.09°.

The distribution of caves within the lava flow is as follows: The Crater, the West, and the Yaramulla Sections contain both caves and arches. In the North Section no caves had been found, but a line of collapse depressions suggested the presence of a lava tube. In 1989, systematic search in the North Section led to the discovery of three caves. The author believes that The Wall Section contains a major lava tube with a very thick roof but to date no access to such tube has been discovered.

Investigations of the Undara Lava Tube System

The Undara Lava Tubes had attracted the attention of three geologists prior to the investigations described in this paper. When discussing the distribution of volcanic centers in the McBride Province, Twidale (1956) noted two lineaments; he incorrectly interpreted the aligned collapses (Figures 8 and 9) as "... a clear arcuate fissure ... with a center of eruption at its southeast end". Best (1960) and White (1962) subsequently recognized the lava tube system. Without opportunity for detailed investigation, they interpreted the pattern of collapse features (Figures 8 and 9) as a collapsed lava tube, with north and west branches.

The first speleologists to visit the area were from the University of Queensland Speleological Society. They explored and mapped Barkers Cave (Shannon, 1969).

In 1972 the author's studies were commenced. It was proposed:

(1) To measure and map representative caves in order to establish whether there were any relationships between shape, size, and distance from the source volcano. This was undertaken at three locations, namely: in proximity to the crater, at a maximum distance from it, and at an intermediate location;

(2) To seek evidence of the mode of formation of the Undara Lava Tube System.

(3) To investigate the geomorphology of The Wall.

At the same time, and subsequent to this investigation, the speleologists were continuing exploration of the caves. Grimes (1973) published a compilation of the results of earlier studies of Undara Lava Tubes. In the Australian Speleological Federation Karst Index, Matthews (1985) recorded the cave names, numbers, and brief descriptions.

The Chillagoe Caving Club also continued exploration of the lava tubes. In 1988, members discovered the Wind Tunnel and Inner Dome Cave and in 1989 they investigated areas within six kilometers west of the Crater and discovered ten caves. In addition, a number of expeditions from the Explorers Club (New York) have examined the lava tubes and researchers, sponsored by the Explorers Club, consider that the invertebrate community in Bayliss Cave makes it one of the world's most biologically significant caves (Howarth, 1988).

In 1989, 100 volunteers (in groups of 20) from London-based Operation Raleigh camped on site for three months to investigate areas not explored by the author. Under the guidance of Q.N.P. and W.L.S. Officer Goodwin, they surveyed collapse depressions in the Undara Crater National Park and in 10 kilometers upflow from Bayliss Cave, an area never previously studied. They discovered and surveyed 23 new caves. Their systematic search in the North Section resulted in the first discovery of caves in this section, *viz*. Dingbat, Hot Hole, and Wishing Well Caves, about 21 kilometers north of the Crater. Their assistance in collection of specimens and data of flora and fauna led to valuable additions to the records of the Undara lava field.

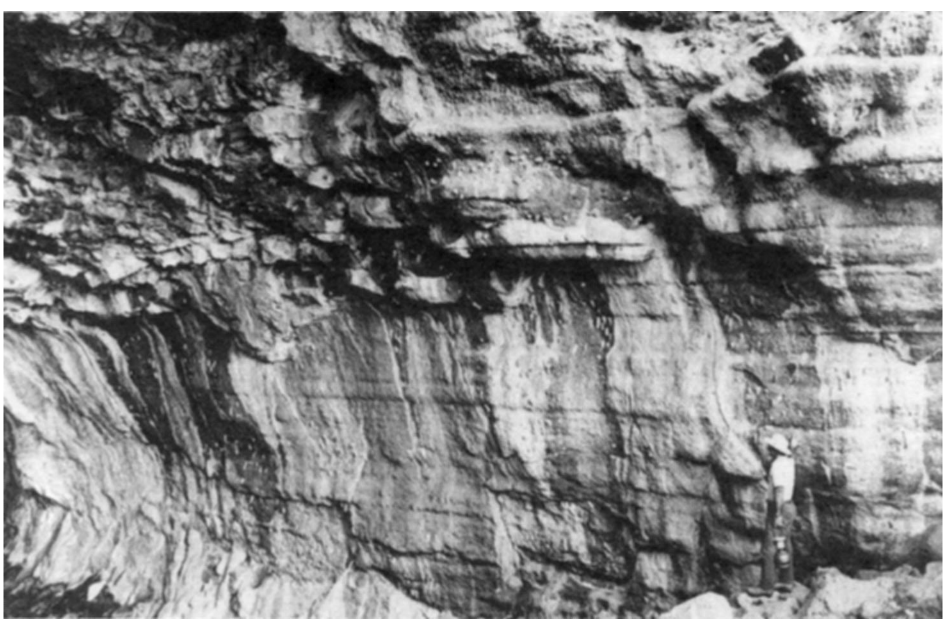

Figure 10 — Road Cave, north wall. Lava level lines extend from floor to roof of this cave. They are among the most distinctive yet discovered in the system and are more easily studied than at other locations as they are in daylight at the eastern entrance. (Photo: H.J.L. Lamont)

Methods

The Undara Lava Tube System can be clearly located on aerial photographs (Figures 8 and 9). It stands out because many of its collapse depressions support rain forest type vegetation which contrasts sharply with the open forest of the surrounding country. Some of the caves, for example Barkers Cave (Cover Photo and Figure 13) and Road Cave (Figure 10), have been known for more than 100 years. The majority of caves, however, were located by systematic exploration of col-

Table 1 – Undara Lava Tube System – Cave Dimensions
Revised and updated (Atkinson, 1990)

ASP * Number	Cave	Length	Maximum Width	Maximum Height	Survey by
U1	Hanson	40	12	3	**
U2 U3e	Dunmall Arch	-	6	2	**
U4	Taylor	108	16.3	10.8	**
U5	St. Pauls	30	-	-	**
U6	Sarah	10.7	0.9	1.4#	**
U7	Peter	13.8	9.9	3.8	**
U8	Ollier	49.4	10.4	3	**
U9 U10e	Harbour Bridge	35	14.3	5	**
U11 U12e	Greeley	103	12.4	3.8	**
U13	Frances	14#	6	3	**
U14	Opera House	30	10	7.5	**
U15	Peterson	102	17.1	3.7	**
U16	Stevens	70.4	8.8	3	**
U17	Pinwill	150	21	8.9	**
U18	Traves	67	14	10.6	**
U19	Atkinson	101.2	28	7.8	**
U21	Stephenson	156#	> 25#	> 10#	PD
U22	Arch	10.5#	28#	9#	PD
U23	Ewamin	162#	21#	> 8#	PD
U24	Picnic I (down)	420	22	15	PD
U25	Picnic II (NE)	45	12	> 14#	PD
U26	Dave I (up)	50	10#	8#	PD
U27	Dave II (down)	27	-	-	PD
U28 U29e	Road	220	21.2	9.4	**
U30	Bayliss additional (1988)	> 950 > 400	18.9	11.5	** PM, DR
U31	Darcy	99	16.3	6.3	**
U32 U33e	Matthew	40	7#	3#	**
U34	Barker	560+	19.8	13.5	CS
U35	Raleigh I	23	15.8	7.3	OR
U36	Raleigh II	29.8	17	8.5	OR
U37	Lost World	74.2	13.5	5.7	OR
U38	Tween	24	11.5	6.5	OR
U39	Eptesicus	42	22#	6.1#	OR
U41	Inner Dome	68	22	7.5	OR
U42	Wind Tunnel	293	32	8#	OR

Table 1 – Undara Lava Tube System – Cave Dimensions
Revised and updated (Atkinson, 1990)

ASP * Number	Cave	Length	Maximum Width	Maximum Height	Survey by
U43	Short Little Arch	15.8	5#	2#	OR
U44	Mikoshi	46.6	14#	11#	OR
U45	Misplaced Arch	22	22#	11#	OR
U46	Nasty	127	15	8#	MG
U47	Fortune	52.9	4.4#	2.5#	OR
U48	Temple of Doom	49.5	6#	4.5#	OR
U49	Fun	33.2	9.8	1.25	OR
U50	Ding Bat	60.4	17.1	7#	OR
U51	Hot Hole	171.9	13.5	3.5	OR
U52	Wishing Well	104	13	3.3	MG
U53	Moth	9.2	4	1.8	OR
U54	Sunset	> 30	5.2#	2.2#	OR
U55	Wallabys Hideaway	38.5	9	4#	OR
U56	Expedition I	30#	12	5#	DI
U57	Expedition II	28	20	4#	DI
U58	arch (unnamed)	8.5	10	2.2#	OR
U59	Tom Tom	34	9.5	2.5	OR
U60	arch (unnamed)	16	13	2.5#	OR
U61	Komori	> 85	9	3#	OR
U62	Speaking Tube	25.2	7.7	3.2	OR
U63	Flat Ceiling	80	15#	3#	DI
U64	Branch	10	10#	2#	DI
U65	San	25	10#	2#	DI
U66	Graham	22	3#	3#	PS
U67	Upper Secret	150#	-	-	PS
U68	Lower Secret	70#	-	-	PS
	Total	6,324.7			

* Australian Karst Index (Matthews, 1985)
** V. and A. Atkinson and assistants
Abbreviations: PD = P. Dwyer, PM = P. Mainsbridge, DR = D. Ray,
CS = C. Shannon, OR = Operation Raleigh, DI = D. Irvin, FS = F. Stone.
# Estimate only

lapse depressions by the author and assistants between 1972 and 1974, members of the Chillagoe Caving Club 1985 to 1988, and Operation Raleigh volunteers in 1989.

Initially the cave entrances were marked with a 10-centimeter square painted on a conspicuous block at the base of each entrance collapse. These squares were used as the datum for cave surveys.

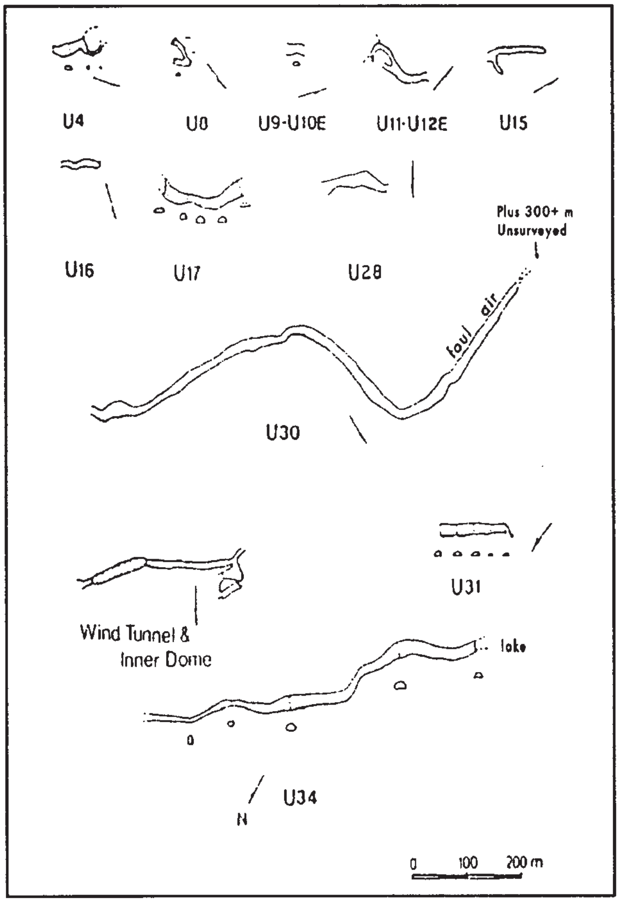

Figure 11—Maps of selected caves with some cross sections. Localities—see Figure 7; cave names—see Figure 12; Cave U11-12E is Greeley Cave (Atkinson et al., *1975); The Wind Tunnel and Inner Dome (1988) are shown. The 1987 extension of Bayliss Cave is not shown as it has not yet been surveyed.*

A surface datum was painted to correspond as closely as possible with the cave datum in order to ascertain roof thickness. Steel posts were left as surface markers to correspond with cave survey stations.

Caves and collapse depressions were surveyed using steel tape, prismatic compass, and Abney level. The same instruments were used to connect underground and surface datum points and to measure the lengths and inclinations of entrance collapses.

To provide data for longitudinal and transverse cave profiles, cave heights were measured with strong helium-filled balloons, a method recommended by R. Greeley. A narrow ribbon was marked, rolled onto a fishing reel and attached to the balloon. Helium was found to be the best gas for this purpose. On one occasion cheaper "balloon gas" was supplied by an agent trying to be helpful and reduce our costs. It proved to be quite unsatisfactory.

The results of the surveys were presented (Atkinson *et al.*, 1975) as plans with some transverse profiles (Figure 11) and as a longitudinal profile through the source crater and representative caves (Figure 12), the first such profile ever to include the crater of origin.

Caves and Arches

The results of the cave exploration and mapping are shown in Table 1. Sixty-one arches and caves have now been discovered in the Undara Lava Tube System and a total length of over six kilometers of lava tube caves has been surveyed. The largest passage yet measured is in Barkers Cave where passage width reaches 18.9 meters and height 13.5 meters.

Features of the Caves and Arches

Although the Undara Lava Tubes formed in a very short period 190,000 years ago, they have retained many original features. These features show minimal alteration due to their protection from weathering.

Even where floors have been covered with later sediment, sufficient features remain to provide evidence of the mode of formation of the Undara Lava Tubes. Original dark grey to black interiors are yellow, brown, or buff due to a thin coating of secondary minerals. In some roofs, white or light colored bands of secondary minerals up to 10 centimeters wide outline polygonal jointing.

Figure 11 shows the plans of representative caves. Most of the cave passages are elongate in the direction of the lava flow. Figure 12 shows longitudinal profiles through representative caves in the Crater Section and Yaramulla Section of the System. These profiles illustrate the variation in shape, size, and roof thickness of the caves.

The largest cave passages are found in the Yaramulla Section and they are mostly simple tubes. The only lava tube cave in this area to show complex development is Wind Tunnel and Inner Dome Complex but the development is on one level and is characteristic of the tendency of lava rivers to braid.

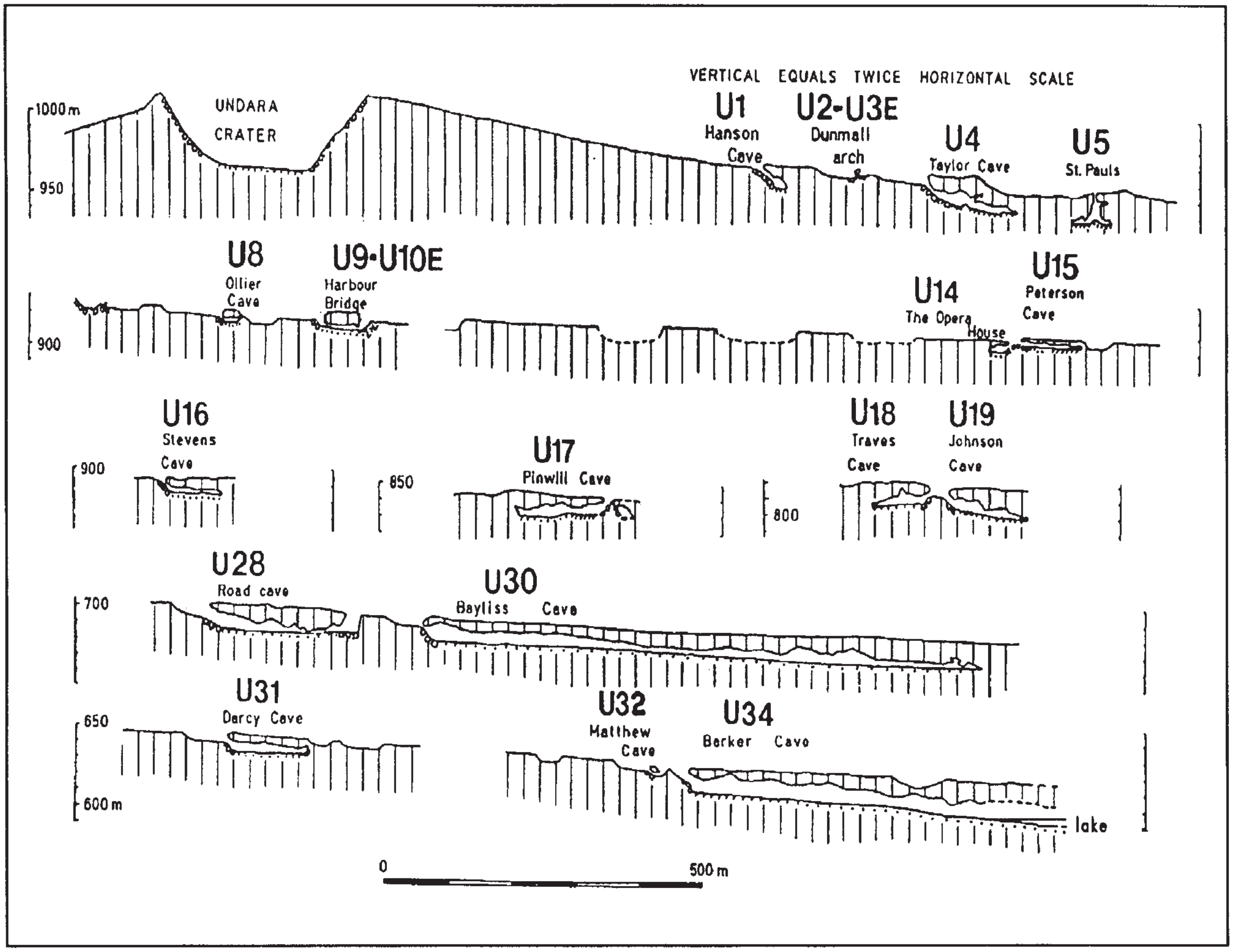

Figure 12—Longitudinal profiles of various caves down flow from Undara Crater. The A.S.F. Cave Register numbers are shown. Floor symbols: sediment (.....), ropy lava (/////) (Atkinson et al., *1975).*

Lava Tube Floors

Floors of the caves, when not covered by sediment or water, represent the final flow of lava in the tube. With the exceptions of areas of rough, spinose aa basalt (Macdonald, 1967) on the floor of Pinwill Cave, Yaramulla Section, and Wishing Well Cave, North Section, the exposed floors show features typical of pahoehoe type basalt flow.

At the entrance to Barkers Cave (Figure 13), the floor is arched, with a single rope structure running down-flow. Beyond this, the floor has distinct marginal gutters (Cover Photo) up to one meter deep. Fine lava level lines on the outer walls of the gutters correspond, but are absent on the inner walls, which show some evidence of formation as levees. The raised central portion of the cave is therefore interpreted as a final channel flow in this cave.

Good examples of ropy lava are visible in Pinwill Cave and the South Chapel of St. Pauls. In a central position near the entrance to Barkers Cave, crust fragments, approximately eight centimeters thick, have been rafted at varying oblique angles (Figure 15) in a manner similar to ice slabs on a frozen river. In Peterson Cave there is a small floor surface where lava drops from roof re-melt appear to have pitted the floor, as rain drops pit a muddy surface.

Prolonged flow at constant level is evidenced by the "pavements" in Taylor Cave (Figure 14). Where rate of flow is less against a convex bank, lava consolidates in a manner similar to the deposition of alluvium on convex banks of rivers.

Walls and Roofs

There is a lava lining on the walls and roof of most caves. Typically the lining is a single layer of

Figure 13—Bakers Cave viewed from the entrance collapse. Some of the original arched floor is exposed and has a distinctive longitudinal "rope" structure. It is noted with interest that a distinctive pattern of vesicles on the large block in the center foreground can be matched to one in the cave "roof" directly above it. (Photo: H.J.L. Lamont)

up to 20 centimeters, but in places may approach one meter in thickness. At various locations the tube lining has fallen off the wall to expose the host lava behind it. The lining is sometimes multi-layered. The best example of this is in Pinwill Cave where 15 layers, 2 to 4 centimeters thick are revealed at one location (Figure 15). At the entrance to the same cave, a thin slab of lining called The Table has become dislodged and now rests in a near horizontal position (Figure 17).

On most walls and roofs are some areas of very low vesicularity and showing drip and dribble structures resembling cake icing (Figure 18). At the entrance to Barkers and Picnic Caves these drips are deflected. In historic tubes such surfaces have been seen forming by remelting and, because of their luster are appropriately termed "glaze," but in the Undara tubes the remelt surfaces have weathered to a dull or earthy luster.

In places there are lavicicles (lava stalactites), commonly two centimeters to three centimeters and occasionally up to eight centimeters long, suspended from the roof, inclined walls, and in wall cavities (Figure 19). Lava stalagmites are rare, as are lava columns. No "straw" stalactites have been found—no doubt because of their extreme fragility.

In most caves, lava level lines and ledges on the walls represent fluctuating lava levels. The highest levels are usually evident close to the roof, as seen in Taylor, Road (Figure 10), Arch, Ewamin, Picnic I, Picnic II, and Barkers Caves (Cover Photo). The lava level lines usually slope down-tube at low angles, probably reflecting the original tube slope.

Termination of the Lava Tubes

The caves generally terminate down-flow with collapses, or with a gentle downward curve of the ceiling to a silt floor. Barkers Cave ends in a lake, the cave ceiling steadily declining to water level. Several caves have down-flow entrances and have little or no silt on their floors. Pinwill Cave (Figure 21), The Opera House (Figure 22), Picnic, and Wishing Well Caves terminate with walls.

Figure 14 – Taylor Cave. The prominent "pavements" (1 and 2) are evidence of an extended period of constant rate of flow. Solidification has been greatest at the apex of convexity, as in a fluvial river. There is a cylindrical opening (3) in the roof above the figure. The location of this opening suggests that some lava ponded in the Death Adder depression (in alignment to the north) may have drained back into the tube through this conduit.. (Photo: H.J.L. Lamont)

Human Use of the Undara Lava Tubes

There is little evidence that the Undara lava tubes were used in prehistoric times. Local Aborigines claim that their people would have avoided such places. No drawings or evidence of fires have been found in the caves, though some artifacts were found at one cave entrance.

Collapse Depressions and Their Relationships to Caves

This account would be incomplete without reference to the collapse depressions associated with the Undara Lava Tube System. For convenience these depressions are divided into two types, namely: narrow depressions, 30 to 50 meters wide, and wide depressions, 50 to 100 meters wide. Geologists and local residents had long questioned how the wide depressions had formed. The author correlated their appearance with an historic lava pond in Hawaii (Figure 23, from Macdonald and Abbott, 1972, p. 42). With the wonderful cooperation of D.W. Peterson (USGS), from across the Pacific came the confirmation.

Narrow Depressions

Narrow depressions commonly give entry to the lava tube caves suggesting that they were formed by the collapse of segments of the tube. Vegetation within these depressions differs little from that of adjacent open forest. However, rain forest trees and vines are found at most cave entrances, often concealing

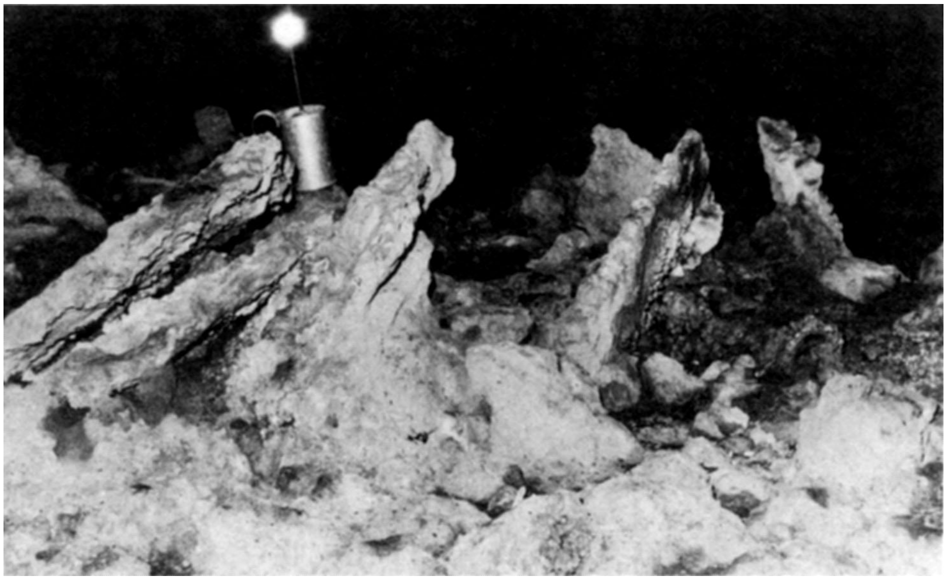

Figure 15– "Rafted" blocks of the crust of the final flow have jammed at various angles. Location: Barkers Cave. (Photo: Vernon Atkinson)

them and, as a result, cave entrances are difficult to locate on aerial photographs.

Wide Depressions

Wide depressions form a strong linear pattern, made conspicuous by rain forest vegetation (Figure 8). They seldom give access to caves and display features which distinguish them from the narrow depressions. Wide depressions vary in shape from circular or oval to elongate in the direction of the lava flow. An exception to this is seen west of Barkers Knob where depressions are less regular in shape and location, although there is some indication of three branching alignments. The erratic shapes are interpreted as possible indication that the flow traversed marshy ground in this area.

Figure 16–Multi-layered lining. Up to fifteen layers are exposed at this location in Pinwill Cave. (Photo: Vernon Atkinson)

Most wide depressions have elevated rims, suggesting that they represent former lava ponds as are seen associated with historic flows in Hawaii (Figure 23). Rims and slopes of the depressions are made up of blocks of various shapes and sizes. Local areas of blocks possessing flat upper surfaces with low vesicularity are thought to be segments of lava pond crust because of the similarities to collapsed lava pond crusts in Hawaii and Oregon, USA (Peterson and Greeley, personal communication 1974; Greeley, 1971a). Near the base of some depressions the lower surfaces of some blocks are moulded and occasionally contain embedded fragments. In rare cases, blocks have retained an original ropy lava surface.

Peterson and others of the U.S. Geological Survey in Hawaii (written communication, 1975) have observed that lava becomes ponded in specific areas, particularly where the slope is small. Once formed, the ponds tend to perpetuate themselves during the life of the flow, even when the flow front has advanced further. These ponds crust over and the molten lava beneath the crust is interconnected with lava tubes that had been developing in the flow both upstream and downstream from the pond. The crusted surfaces of these ponds have

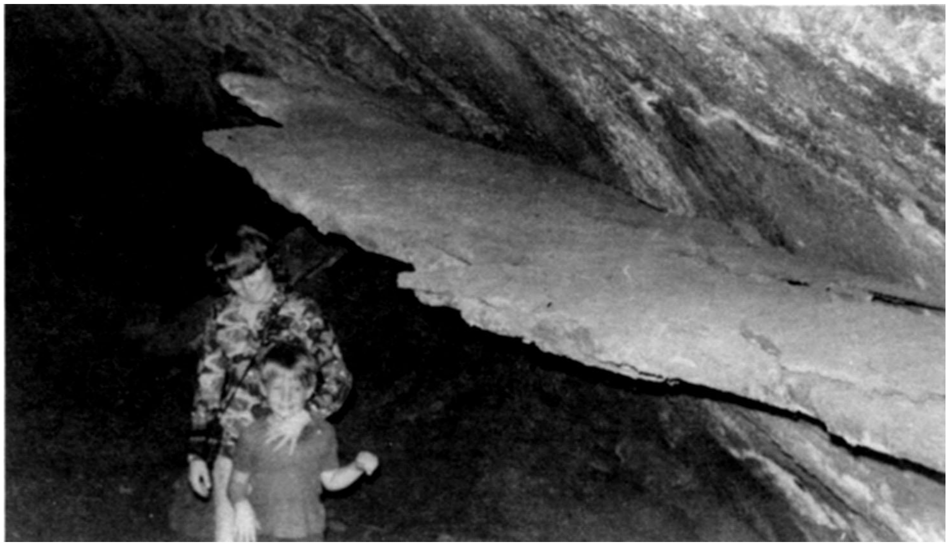

Figure 17 – "The Table" – a thin sheet of lining near the entrance to Pinwill Cave shows a degree of plastic deformation. (Photo: Vernon Atkinson)

been observed to subside as the flow dwindles and the ponded lava drains back into the tube. The wide depressions of the Undara lava flow have been interpreted as former lava ponds.

There is a depression 60 meters north of the entrance of Taylor Cave. This long depression lies directly in line with the entrance section of the cave. The cave was found not to terminate in a collapse beneath the depression, as was expected, but close to the edge of the depression. The cave branches and the two passages roughly follow the outer margins of the depression. Each branch closes to an inaccessible tunnel and near its termination the east branch divides again. The lava level lines in the east branch are nearly horizontal and proceed along both sides of the cave and across the wide pillar at the end (Figure 24).

The relationship of the Taylor Cave passages to the depression suggests the collapse interfered with the still functioning tube. When the lava pond drained and its crust collapsed the tube bifurcated

Figure 18 – Lava dribbles in Barkers Cave. (Photo: H.J.L. Lamont)

Figure 19 – Lavacicles up to six centimeters long in Bayliss Cave. (Photo: Vernon Atkinson)

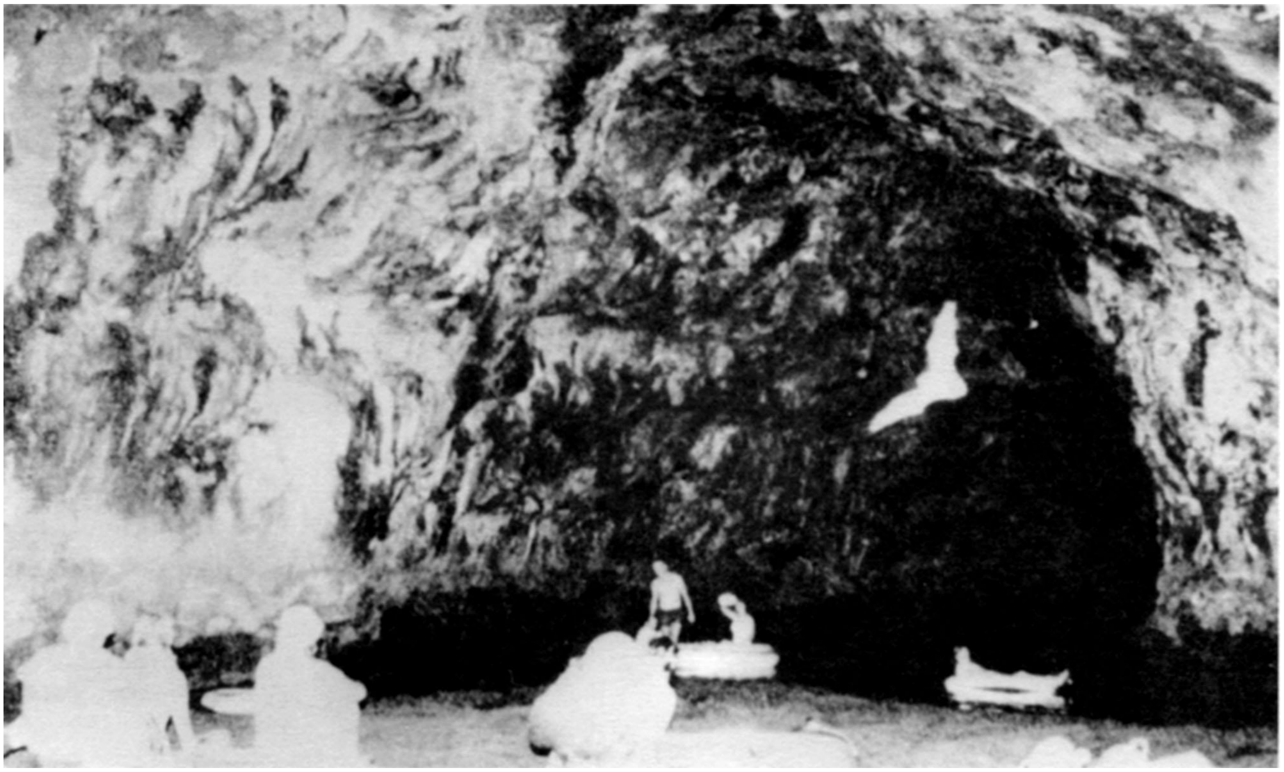

Figure 20—Boating party on the terminal lake, Barkers Cave. (Photo: R. Dutton)

Figure 21—"The Wave"—termination of Pinwill Cave which has a downflow entrance. (Photo: Mick Williams)

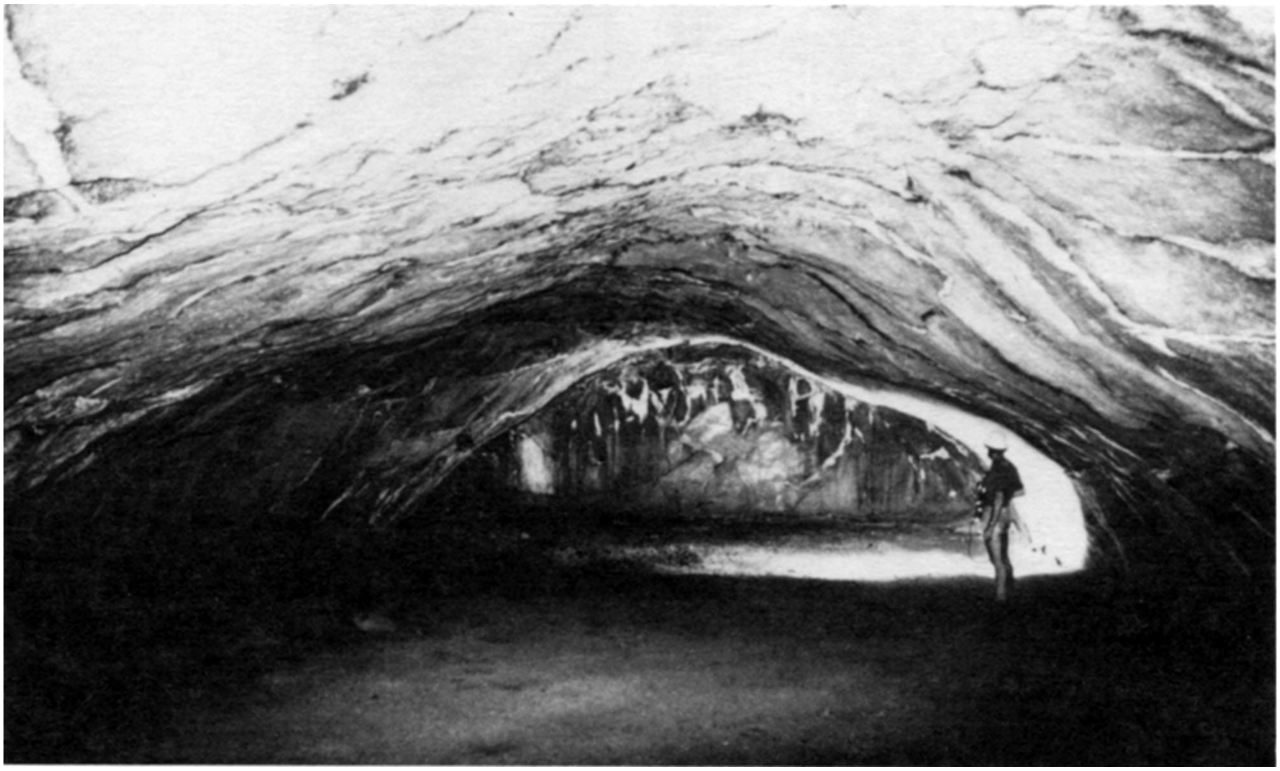

Figure 22 – Termination of The Opera House (note wings). Entrance is down flow. (Photo: H.J.L. Lamont)

around the collapse, but was then constricted and eventually dammed. Subsequently the dammed lava inside the tube drained through minor outlets. A cylindrical vent in the roof of Taylor Cave (Figure 14) is interpreted as a location where some of the lava that ponded above the main tube drained back into it. A minor lava fall, approximately one meter high, emerges from under the floor of the west

Figure 23 – Island of Hawaii, 1895, Halemaumau Crater within Kilauea Cladera. The lava lake is held in a lava ring (a ring-shaped levee) built up by spattering and repeated overflows such as those visible in the picture. (Photo from Ray Jerome Baker collection, Bishop Museum, Honolulu)

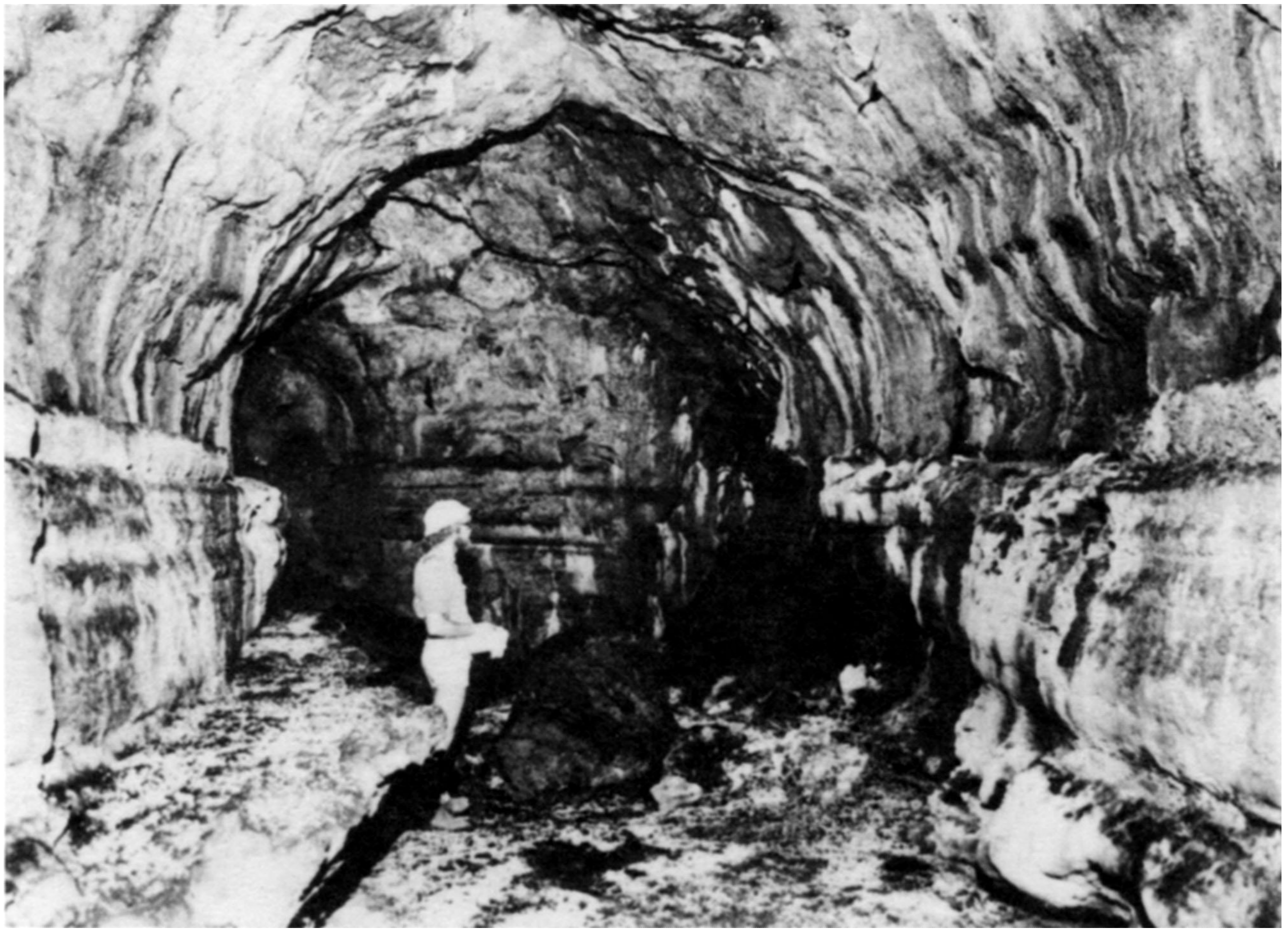

Figure 24—Termination of Taylor Cave (east branch) as two closing tunnels beyond the figure. Note horizontal lava level lines and ledges on walls and central column. (Photo: H.J.L. Lamont)

terminal branch of the cave and is interpreted as another point of "drain back."

Figure 25 shows how Barkers Cave changes its course, deviating around a major depression 220 meters west of the cave entrance. There is a small cavity in the cave roof under the eastern end of the depression and circular holes up to 1.5 meters across on the inner slope of the depression. This seems to indicate that the lava which had ponded in the depression drained back into a flowing tube, forcing it to alter its course.

The Wall

The Wall (Figures 2a, 26, and 27) consists of a very long, narrow ridge that rises up to 20 meters above the general level of the flow and can be traced for 35 kilometers. The upper surface of the ridge is relatively flat and varies in width from 70 meters to 300 meters. Its down-flow slope averages only

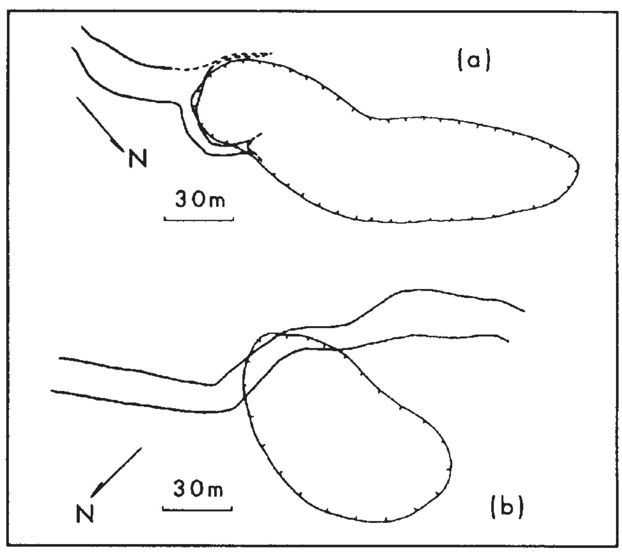

Figure 25—Relationship between surface depressions and caves: (a) Taylor Cave; (b) Barkers Cave (Atkinson, et al.*, 1975)*

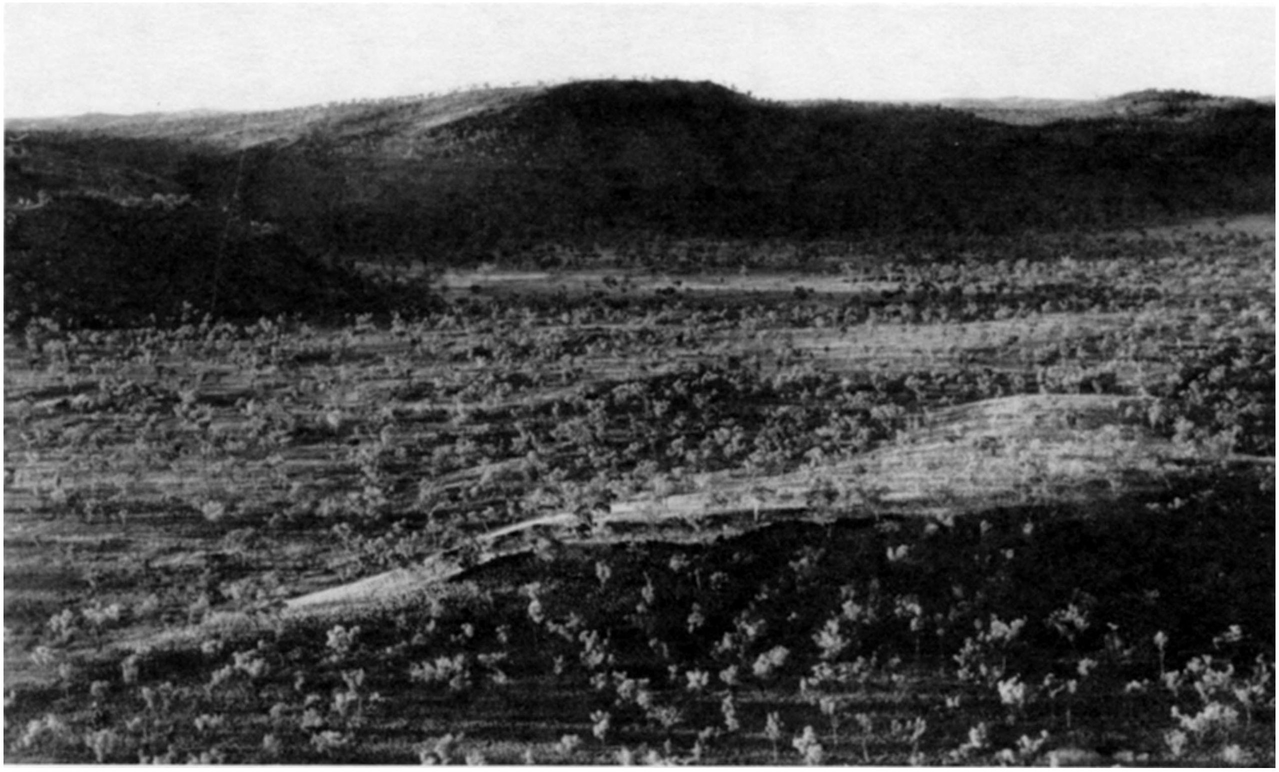

Figure 26—Oblique aerial view of "The Wall" from the south. Note megacolumns flanking central collapsed area at the termination. (Photo: Jon Edmonds)

1.72 meters per kilometer with occasional undulations. The side slopes of the ridge are up to 29°. There are several depressions within five kilometers of the termination of The Wall. One of these depressions may represent a collapsed lava pond which drained into the tube below. Edmonds Lake, a narrower axial oval depression has been interpreted as a collapsed segment of the tube.

The tongue of lava surmounted by The Wall flowed down a precursor of Junction and Elizabeth Creeks. Functional water bores in the vicinity of The Wall confirm that the narrow ridge is localized above a former stream bed.

Mode of Formation of the Undara Lava Tube System

Lava rivers and associated tube systems are the main distributors of the liquid rock during a pahoehoe lava eruption. The lava tube system and caves associated with it are formed in a short time; in the case of the Undara Lava Tubes, probably in several years (Walker, written communication, 1991). Evidence of how the lava tube system and the caves in it formed has been preserved for 190,000 years. This, together with observations of caves forming in active and recent lava flows in Hawaii (Jaggar, 1947, cited in Wood, 1976; Wentworth and Macdonald, 1953; Greeley, 1971b, 1972a and 1987; Macdonald and Abbott, 1972; Cruikshank and Wood, 1972; Peterson and Swanson, 1974; Peterson and Holcomb, 1989), and Iceland (Kjartansson, 1949, cited in Wood, 1976), has resulted in the following discussion of the mode of formation of the Undara Lava Tube System (Figure 28).

A river of pahoehoe lava, confined in a valley, quickly crusts over and develops a roof. The flow also begins to solidify against the valley walls and floor (Figure 28a). The roofing occurs in several different ways including growth of semi-solid surface crusts by cooling, crusts floating down the channel jamming and accumulating at obstructions, and the growth of levees from the channel sides through repeated overflows, splashing, and splattering. Examination of the roofs in the Undara lava tubes indicates that most of the roofing took place by the growth of semi-solid surface crusts.

As solidification of the roof, walls, and base continue, the flow becomes concentrated within a cylinder (Figure 28b). If the eruption ceases at this

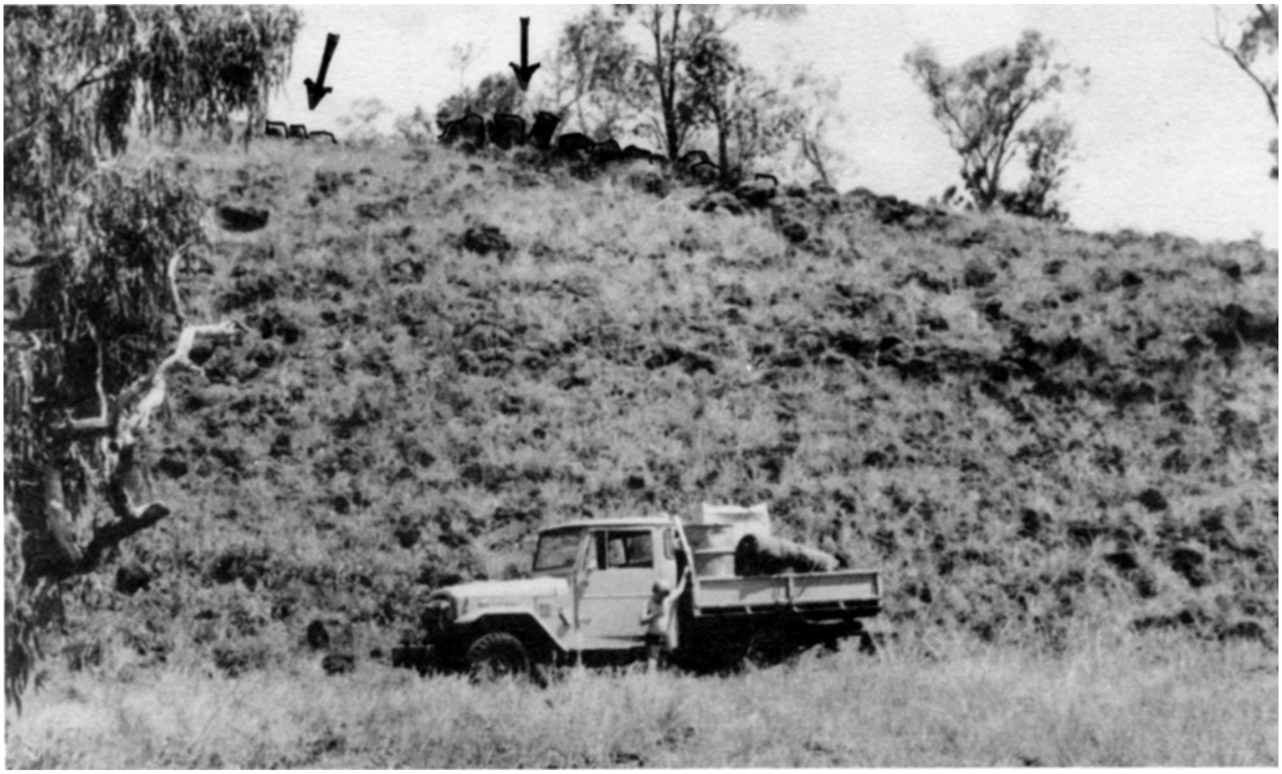

Figure 27—Termination of "The Wall" viewed from the north. Arrows point to the megacolumns on the horizon. (Photo: Tom Atkinson)

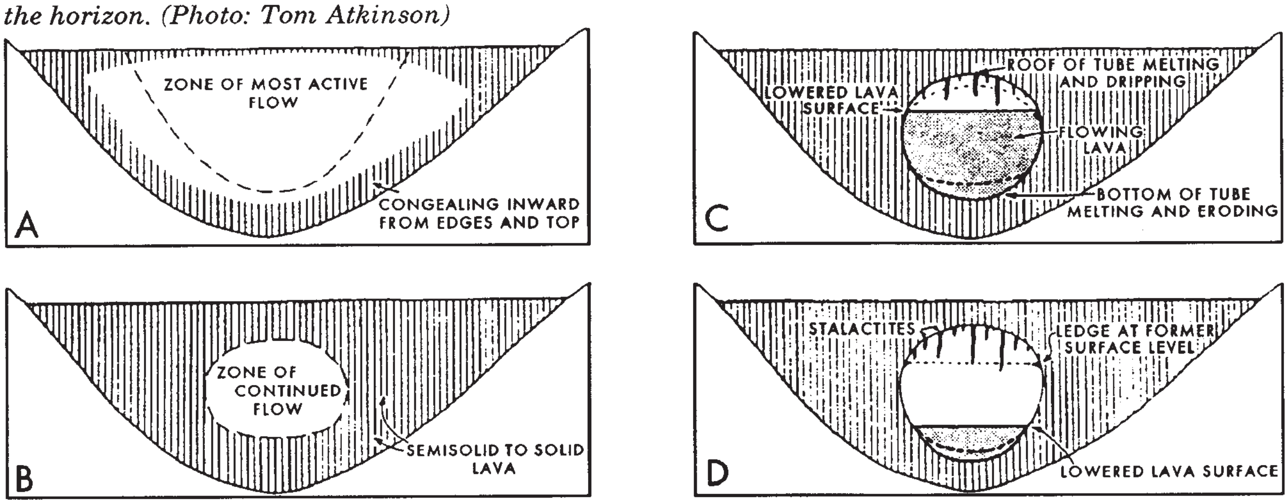

Figure 28—Stages observed in the development of the lava tubes in Hawaii (after Macdonald and Abbott, 1972). Examination of evidence in the Undara Lava Tubes indicates that this explanation is directly applicable.

a. *The lava flow, confined in a valley, develops a thin crust, by one or more processes and starts to solidify inwards from the edges, the center continuing to flow.*

b. *The active movement of liquid becomes restricted to a more or less cylindrical, pipelike zone near the axis.*

c. *The supply of lava diminishes and the liquid no longer fills the pipe, burning gases above the liquid heat the roof of the pipe and cause it to melt and drip.*

d. *Further diminution of supply lowers the level of the surface of the liquid which finally congeals to form the floor of the tube.*

Figure 29 – Roof structure inside Peterson Cave (east branch). The prominent arched flow unit just above the observer's head has a ropy interface. Higher ropy interfaces also occur. (Photo: H.J.L. Lamont)

Once the Undara Lava Tube System was formed in the major eruption, there was subsequent thickening of tube roofs by later flow units (Figures 16, 17, and 29). Some of these flow units passed over ropy surfaces and now bear rope imprints on their lower surfaces. The low incidence of ropy surfaces and imprints at Undara support the observation by Macdonald and Abbott (1972) that ropy structure is often evident only over a small proportion of any flow. Figure 30 shows the thickness of various lava tube cave roofs: (a) Taylor, (b) Harbour Bridge, (c) Peterson, (d) Pinwill, (e) Road, (f) Barker.

time, and the tube drains completely, its cross section is circular.

When the supply of lava diminishes during an eruption, it no longer fills the whole tube. Volcanic gases escaping from the flow into this cavity may ignite producing temperatures considerably higher than that of the molten lava. This may cause some remelting of the roof with drips of lava forming lavicicles (Figure 28c) which are commonly vertical. Deflection is rare and is thought to be caused by a current of very hot air. In the Undara Lava Tube caves deflection has been noted near the entrance to Picnic I and Barkers Caves.

Effusion rates fluctuate during an eruption but whenever a constant rate is maintained, near-horizontal ledges of lava solidify on the tube walls – lava level lines. Further diminution of the flow lowers the level in the tube and finally the flow congeals to form the floor (Figure 28d).

Many or most of the lava tubes in a flow will remain filled with lava and caves form only if the tube drains or partially drains. Examination of recent lavas in Hawaii and Iceland has shown that many entrances form during eruption. Other entrances are opened by roof collapse, weathering processes, or excavation by man.

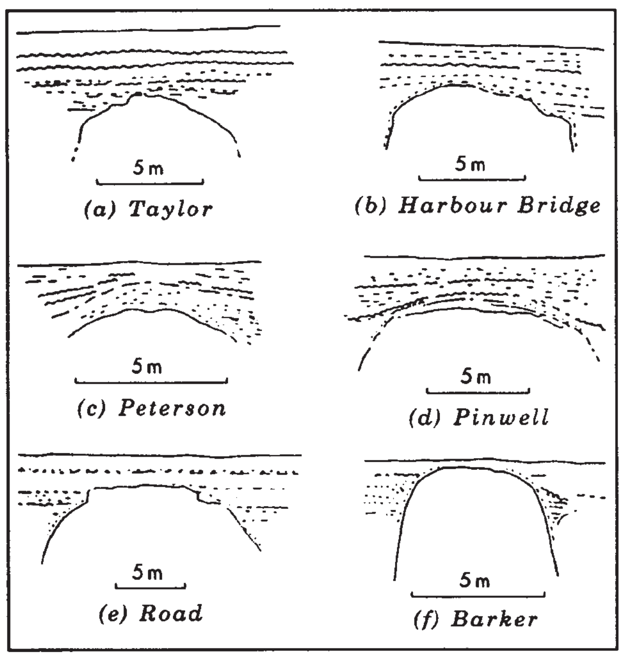

Figure 30 – Cave entrance structures showing thickening of roofs by successive surface flow units. Flow units are represented by wavy lines for recognised flow unit surfaces. Other near-horizontal lines are major vesicle zones. (Diagram: P.J. Stephenson)

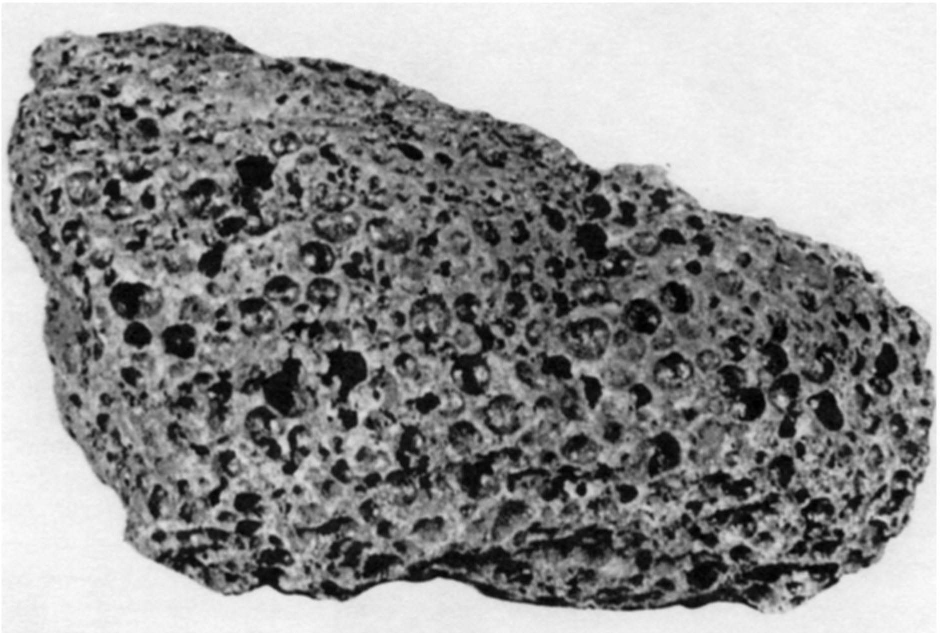

Figure 31—Lunar vesicular basalt. More than half this specimen is "pore" space. The pores or vesicles, are formed by frothing and bubbling during volcanism and indicate high gas activity at one time on the Moon. The appearance in the hand specimen and under the microscope show no marked difference from terrestrial basalts but there are slight chemical differences. (MacKenzie et al.*, 1982) (Photo: NASA, USA)*

Subsequent flows, as well as thickening of the tube roofs, may form additional lava tubes. If these connect with existing caves, a complex cave system will develop. In the Undara Lava Field there is such development in the Crater Section and in the proximity of the Wind Tunnel.

Beyond the Yaramulla Section, the continuation of the lava tube system is The Wall. That it is 20 meters above the associated lava field with a minimal gradient, suggests that it represents an elevated channel flow whose "toe" solidified initially where The Wall now terminates. This caused a temporary blockage which allowed the channel to roof over to form a major lava tube. The large polygonal jointing (Figures 26 and 27) is taken to evidence considerable roof thickness. A surge of lava through the tube broke down the toe of the flow and continued a further 70 kilometers. Slumping of the tube roof at the termination left a colonnade of roughly columnar blocks (Figure 27). It would be of great interest to confirm the structure of this unusual feature by geophysical investigation or drilling near the center of the ridge.

Conclusion

Favorable topography and a very high rate of effusion, coupled with an efficient lava tube system, allowed one flow from the Undara Volcano to extend 160 kilometers to become the longest single-volcano flow in the world. This flow contains the longest lava cave in Australia. Within the caves and arches of the lava tube system, protection from weathering has allowed the preservation of many features similar to those in active and recent lava flows. From such features it can be concluded that the lava tube system and the caves in it formed in a manner similar to those that have been observed forming during historic eruptions of pahoehoe lava.

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APPENDIX 1

UNDARA LAVA TUBE SYSTEM MAJOR ELEMENT CHEMICAL ANALYSES
Specimen locations are shown on Figure 7

*These analyses on samples dried at 110°C
n.d. = not determined

	A	B	C	D
SiO_2	48.85	49.30	49.50	48.20
TiO_2	1.82	1.70	1.67	1.75
Al_2O_3	15.23	15.40	15.90	15.80
FeO_3	2.52	11.00	10.53	4.46
FeO	7.46	trace	0.06	6.38
MnO	0.16	0.15	0.15	0.17
MgO	8.55	8.10	7.10	7.85
CaO	9.16	8.02	8.39	8.02
Na_2O	3.90	4.20	3.87	3.57
K_2O	1.75	1.77	1.53	1.71
H_2O+	0.35	n.d.	n.d.	n.d.
H_2O-	0.17	*	*	*
P_2O_5	0.64	0.50	0.34	0.72
CO_2	0.13	n.d.	n.d.	n.d.
Total	100.69	100.14	99.04	98.63
Locality (Fig 7)	A	B&C	B&C	D

Analyses
"A": Host rock, Barkers Cave entrance,
"B": Cave lining, Barkers Cave entrance.

Analyses:
"A" T.J. Griffin, using XRF; Na, flame photometric; Fe^2, by titration.
"B"-"D" P.J. Stephenson and T.J. Griffin, using Atomic Absorption (HF-Boric Acid digestion); P, spectrophotometric; Fe^2, by titration.

APPENDIX 2

Author's first map and transverse sections,
Undara Lava Tube System.

Data: Tom and Anne Atkinson, 1972.

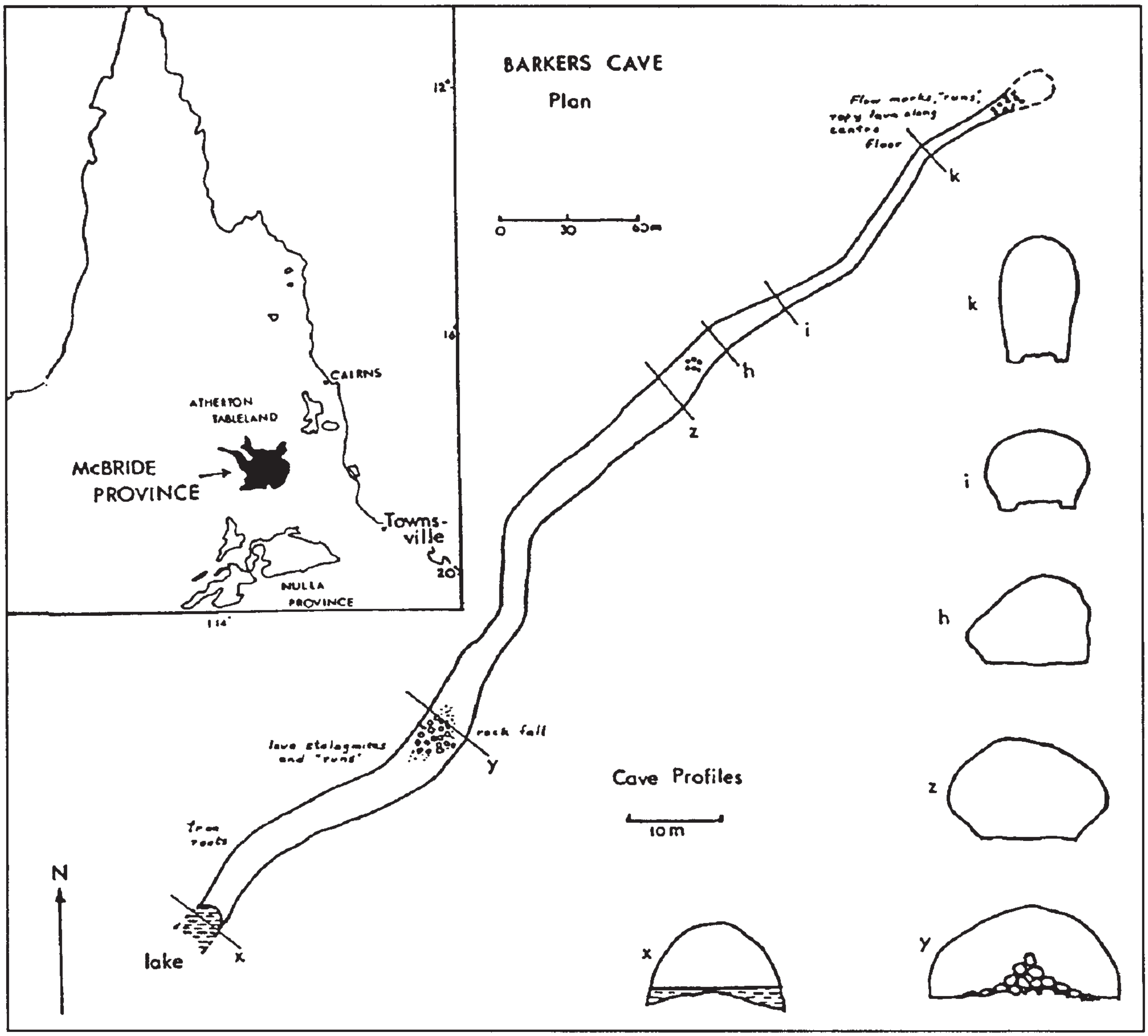

Figure 14-8: Map of Barkers Cave.

From: Stevens, N.S. & F.A. Atkinson, (1975): The Undara Lava Tubes, North Queensland, Australia. In W.R. Halliday, (Ed.) *Proceedings of the International Symposium on Vulcanospeleology and its Extraterrestrial Applications.* A special Session of the 29th Annual Convention of the National Speleological Society, White Salmon, Washington, August 16, 1972.