Undara Volcano, North Queensland, Australia and its Lava Field – Lava Caves, Depressions and The Wall – a 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 and provides details, in particular, of aspects relevant to discussion of the aligned depressions which mark the location of tubes from the Undara Crater to Barkers Pond.

More than 60 caves and arches have now been discovered in the system. Most caves are less than 200 metres long but the system includes Australia's longest lava tube, over 1,350 metres. More than six kilometres 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 kilometres of basaltic lava at temperatures ranging from 1,170° Celsius to 1,220° Celsius, covering an area of 1,150 square kilometres. With an average gradient of only 0.3°, one of the flows extended more than 160 kilometres to become the world's longest 'recent' flow from a single volcano. This great length is attributed to very high effusion rates, favourable topography, and lava tube efficiency.

The lava tube system extends more than 110 kilometres and includes caves, arches, and an almost level ridge that is 35 kilometres 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.

Introduction

In photographs of the lunar surface, the shape of channels (Fig. 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 et al. 1966; Oberbeck et al. 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 (Figs 4 and 5) and microscopically, to terrestrial basalts with only minor geochemical differences (MacKenzie et al. 1982).

As an analogue to the smaller basaltic ridges of the Moon (Fig. 2), the length and shape of The Wall (Fig. 3) of the Undara Lava Tube System is considered Earth's best volcanic feature (Greeley, pers. comm. 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

Fig. 1. View of the Moon, showing a meandering channel, 115 km long, which may represent a collapsed lava tube in a basaltic area. Apollo 15 landing site indicated by cross. (photo: Astronaut A.M. Worden, by courtesy NASA.)

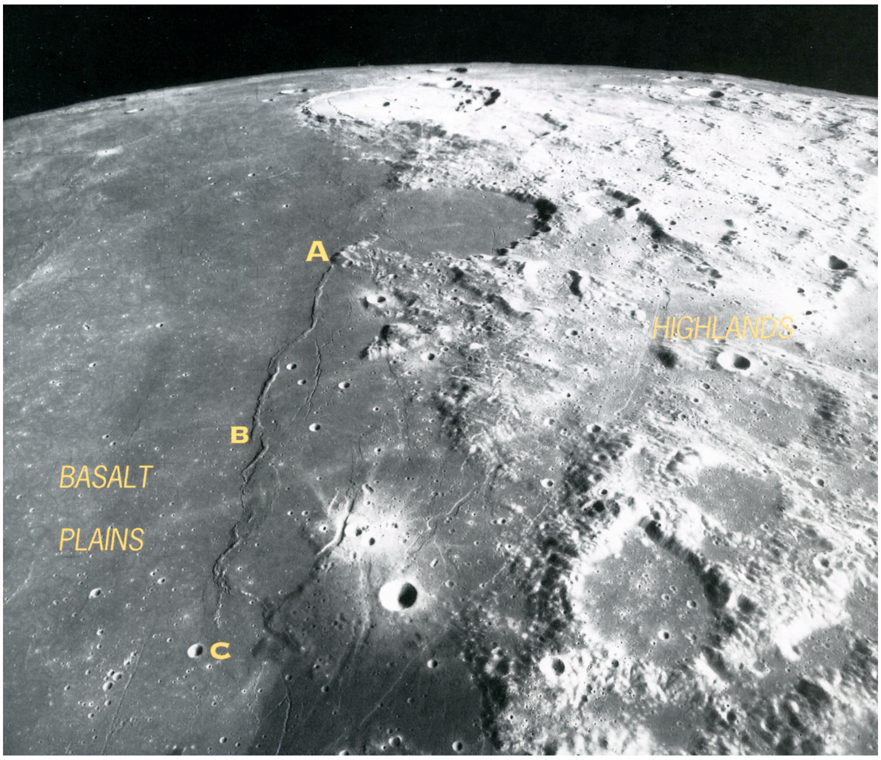


Fig. 2a. Area of the Moon showing Highlands and Basalt Plains (darker areas) where A-B-C indicates a ridge. The numerous 'pock' marks in the basalt plains are impact craters, not volcanic craters.

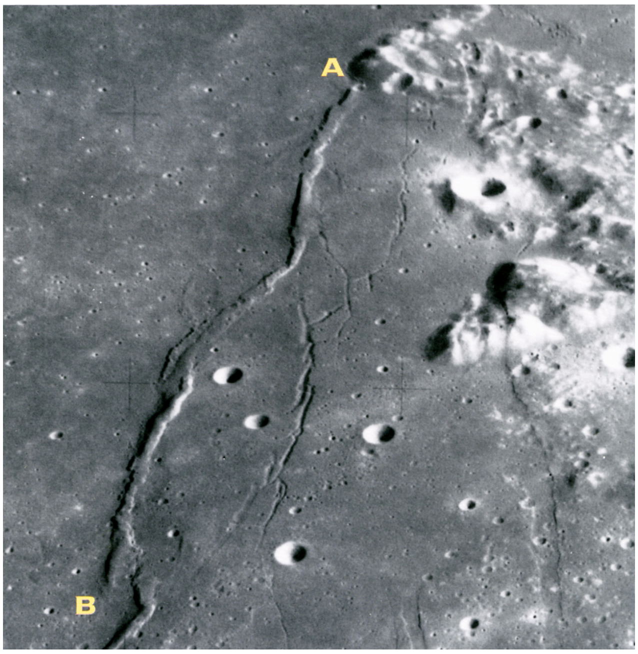


Fig. 2b. Detail of section A-B of the basaltic ridge marked A-B-C in photograph above. (photos: courtesy of NASA, Frame No. AS17-0939)

System was presented - six pages, including figures, map (Appendix 2) and references. NASA's astro-geologist Ron Greeley attended this symposium. The author requested he view the geological map of the Undara area and photos she had taken of the lava ridge known as "The Wall" near Mount Surprise, seeing it as a possible Earth analogue to a lunar ridge depicted in the National Geographic. Greeley and his colleagues had searched air photos of Earth's major basaltic areas and had found no Earth feature to compare with The Wall. He insisted the author bring the map and photos to NASA, in California. She returned to Australia with two requests from that meeting:

- To profile the Undara Crater and representative caves in the flow that led to The Wall;
- To make a study of The Wall.

Many of Undara's surface and lava tube features, have been photographed and described previously (Atkinson *et al.* 1976; Atkinson 1985–95; Atkinson and Atkinson 2001). However, for those not familiar with these features, this paper provides photographs, figures and descriptions of many and in particular, those relevant to discussion of the aligned depressions that mark the location of lava tubes between Undara Crater and Barkers Pond.

Location and Geological Setting of the Undara Lava Tube System

Cainozoic volcanism in eastern Australia extended more than 4,000 kilometres (Fig. 6, Stephenson, Griffin and Sutherland 1980). In north Queensland, within 200 kilometres of the east coast, there are five major provinces (Fig. 7).

The Undara Lava Tubes are found within lava flows from the Undara Volcano (Fig. 9) which is located approximately 200 kilometres southwest of Cairns in North Queensland, Australia. This volcano is situated near the centre of the McBride Province (Fig. 7) which covers approximately 5,000 square kilometres (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 (Fig. 8) rises to 1,020 metres above sea level (ASL) and is the highest point in the McBride Province. Its impressive crater (Figs 8, 9, 10) is 340 metres across and 48 metres deep with inner slopes of up to 40°. The rim rises only 20 metres 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 metres across) of highly vesicular to massive lava. Several indistinct terraces inside the

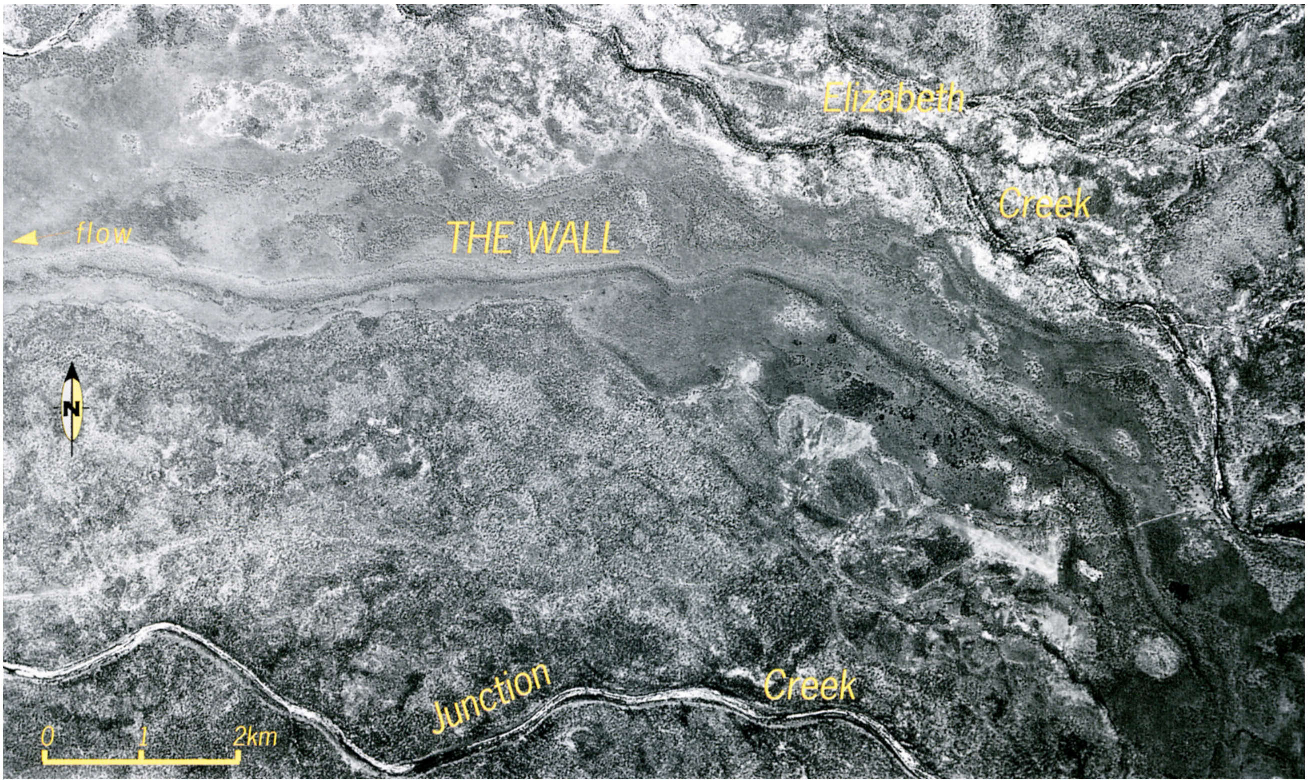


Fig. 3. Vertical aerial photograph of the western end of the Wall Section of the Undara Lava Tube System. This low basalt ridge is 35 km long and may be analogous to the sinuous ridges on the Moon. (photo: Dept. of National Mapping)

Fig. 4. Basalt from the Moon. Despite its age of ~4,000 million yrs, this specimen could be mistaken for a fragment of newly erupted terrerstrial lava. Its surface is not weathered because the Moon has no atmosphere. The numerous holes, or vesicles, formed when dissolved gasses expanded as pressure decreased during magma's ascent to the Moon's surface. When the lava cooled and solidified the bubbles were trapped within it. (photo: courtesy of NASA.)

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

Fig. 5. Undara basalt. These blocks, on the inner slope of Undara crater, have many gas holes, or vesicles, giving them some resemblance to the lunar basalt pictured at left. Zones of vesicular basalt are very comon in basaltic lava flows on Earth, especially at the tops of flows. (Pocket knife for scale is 10 cm.) (photo: Tom Atkinson)

Undara lava flows cover 1,550 square kilometres in the McBride Province and are basaltic in composition. Appendix 1 gives chemical analyses of six basalt specimens from the Undara flow.

One flow to the north is, in part, rough spinose a'a 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 a'a 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).

Fig. 6. Cainozoic basalt outcrops of eastern and southeastern Australia occur within 400 km of the coast and extend for over 4,000 km. (after Stephenson et al. 1980)

Fig. 7. The main provinces of Cainozoic basalt outcropping in northeastern Australia. The area within the rectangle is shown enlarged in Fig. 8.

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 & Holcomb 1989; Peterson & Swanson 1974; Rowland & 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 (Fig. 8). The flow to the north was approximately 90 kilometres long and entered the Lynd River. The voluminous northwest flow, however, followed precursors of Junction Creek, Elizabeth Creek and the Einasleigh River (Fig. 8) for more than 160 kilometres to become the longest single-volcano lava flow in the world (in relatively recent times). For lava to travel from Undara Crater to the termination of The Wall, Walker (pers. comm. 1972) believed would have taken no more than a matter of weeks, owing to increasing viscosity is the flow cooled. Later, in view of the insulation property of basalt, he believed that it would have taken considerably longer – perhaps a number of years (Walker 1973).

Jim Kauahikaua (pers. comm. 2010) advised that flows in lava tubes from Kilauea Volcano on the island of Hawaii have already been recorded for 28

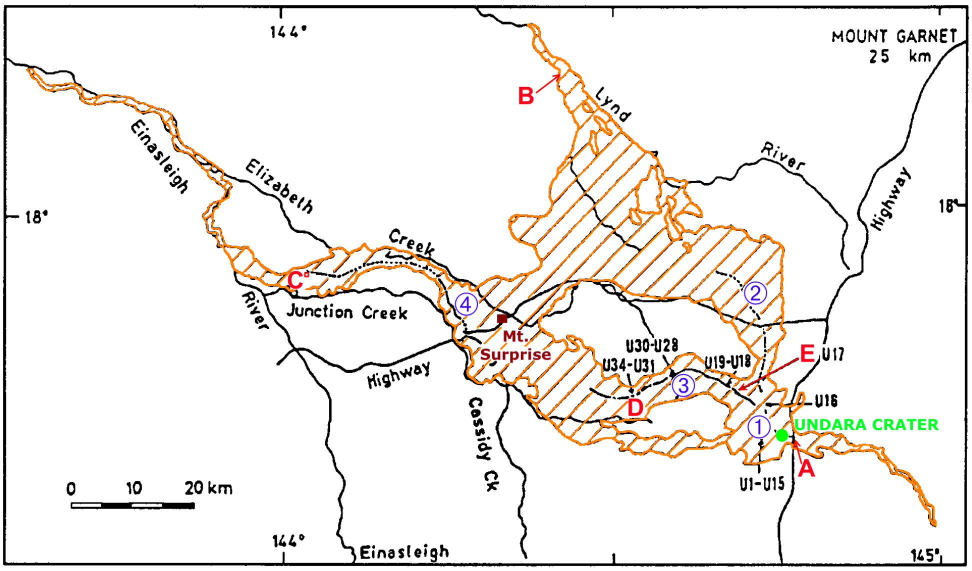


Fig. 8. The Undara lava field (orange outline). Circuled numbers denote sections of the lava tube system referred to in the text; other numbers refer to cave entrances. Letters A to E denote locations of basalt specimens chemically analysed (see Appendix 1)

Fig. 9. Aerial oblique view of Undara Crater, 340 m across, looking west. The tube system commences in the line of depressions that runs away from the Crater towards the right. (photo: Tom Atkinson)

years and are still active. This is the longest period of continuous volcanic activity in recorded history.

The Undara lavas were erupted at temperatures ranging from 1,175° Celsius to 1,220° Celsius (Roeder and Emslie 1970, cited in Atkinson et al. 1976). They do not appear to have unusual viscosities (Shaw 1972; Bottinga and Weill 1972; cited in Atkinson et al. 1976) 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 metres near the edges to up to 20 metres or more in the thickest parts. Along The Wall, west of Mt Surprise, the flow could be up to 40 metres 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 metres. If an average thickness of 15 metres is estimated for the whole flow, the total volume of lava erupted from the Undara Volcano is approximately 23 cubic kilometres.

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 metres is evident throughout the 90 kilometres from the crater to the termination of The Wall.

The constant range in size of jointing over a distance of 90 km 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.

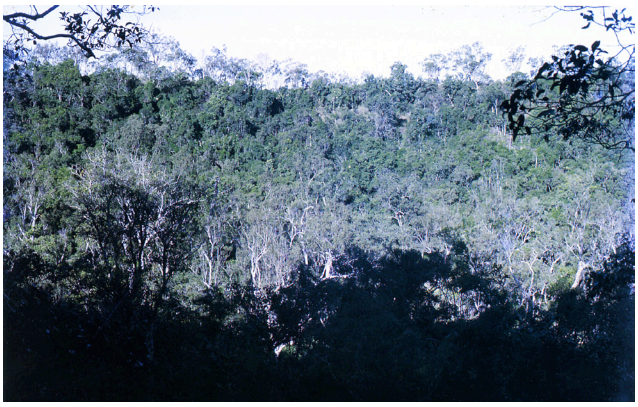


Fig. 10. Undara Crater viewed from the north rim,. early morning (Winter 1973). (photo: Anne Atkinson)

The lava tube system from the Undara Crater has been divided into the following five sections (Fig. 8) in order to describe the locations of the caves and arches:

Crater Section – extending north from Undara Crater for four kilometres; average slope 1°.

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

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

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

Wall Section – approximately 35 kilometres; 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 centres in the McBride Province, Twidale (1956) noted two lineaments; he incorrectly interpreted the aligned collapses (Figs 11 and 12) as " ... a clear arcuate fissure ... with a centre 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 (Figs 11 and 12) as a collapsed lava tube, with north and west branches.

Fig. 11. Aerial oblique view of wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara Lava Tube System. (photo: H.J.L. Lamont, JCUNQ)

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 kilometres west of the Crater and discovered ten caves. In addition, a number of expeditions from the Explorers Club 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 QNPWS officer Mick Godwin, they surveyed collapse depressions in the Undara Crater National Park and in 10 kilometres 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 kilometres 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 (Godwin 1993).

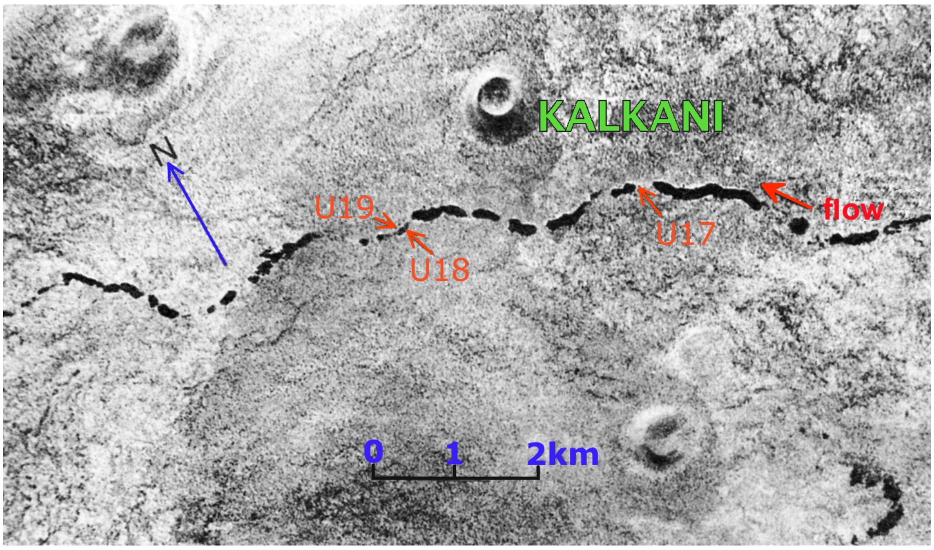


Fig. 12. Vertical aerial view of wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara Lava Tube system. (photo: Dept. of National Mapping, Australia).

Methods

The Undara Lava Tube System can be clearly located on aerial photographs (Figs 11 and 12). 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 Road Cave (Fig. 13) and Barkers Cave (Fig. 14). have been known for more than 100 years. The majority of caves, however, were located by systematic exploration of collapse 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 each cave entrance was marked with a 10cm square painted on a conspicuous block at the base of each entrance collapse. These squares were used as the datum for cave surveys. A surface datum was painted to correspond as closely as possible with the cave datum in order to ascertain roof thickness. Steel posts on the surface corresponded 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.* 1976) as plans with some transverse profiles (Fig. 15) and, as requested by NASA in 1972, as a longitudinal profile through the source crater and representative caves (Fig. 16) – the world’s first such profile ever to include the crater of origin.

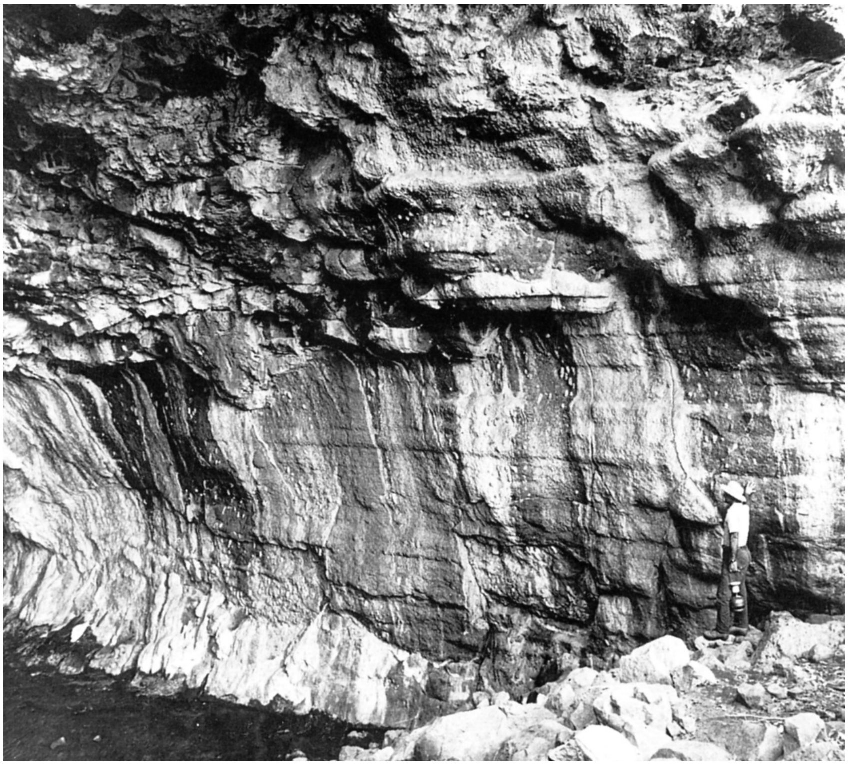


Fig. 13. Road Cave, north wall. Lava level lines extend from floor to roof of this cave. They are among the most distinctive yet discovered in the system and are more easily studied than at other locations as they are in daylight at the eastern entrance. There is an imprint of ropy lava above the entrance. (photo: H.J.L. Lamont)

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 6 km of lava tube caves has been surveyed. The largest passage yet measured is in Barkers Cave where passage width reaches 18.9 m and height 13.5 m.

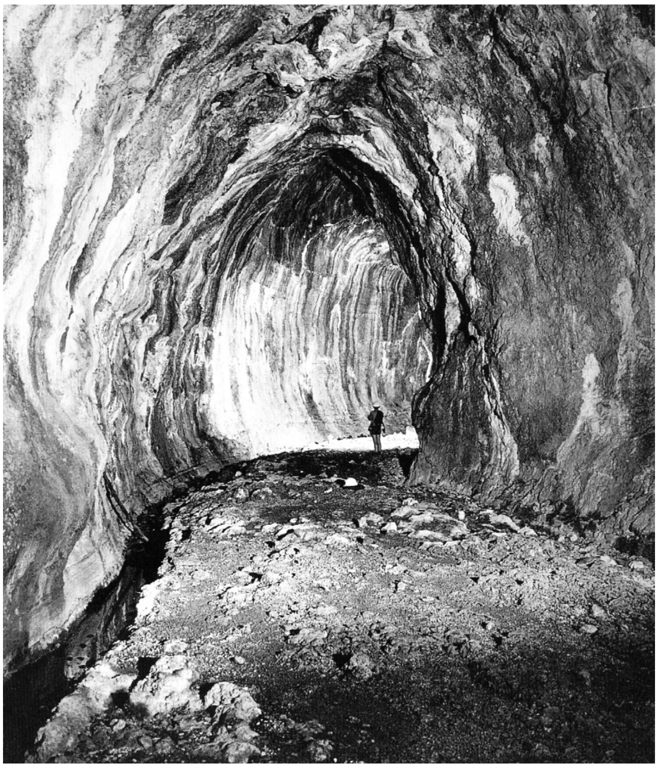
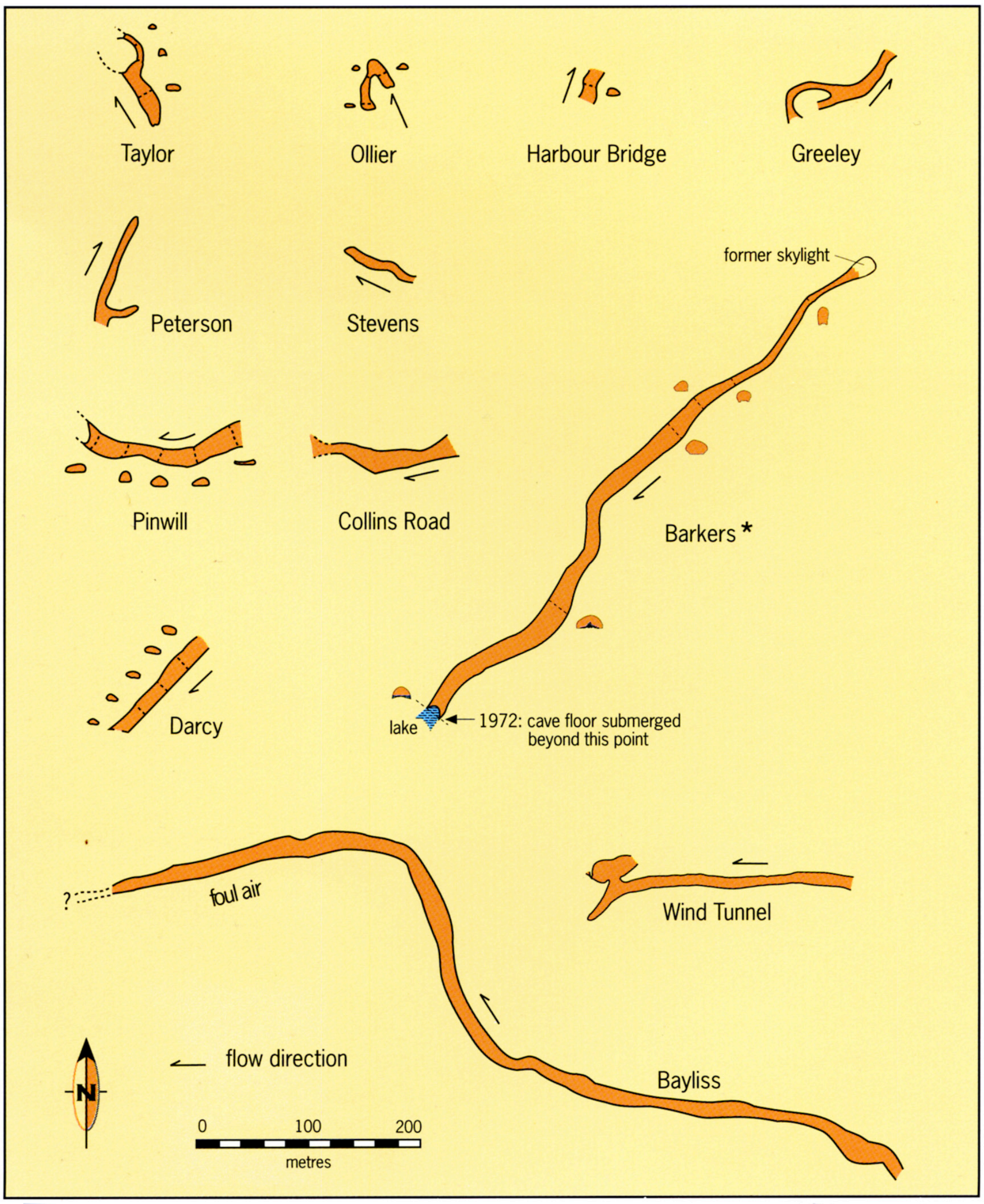


Fig. 14. Barkers Cave, 50 m from its entrance. Note the gutter on the left and, on the distant wall, near-horizontal ridges evident almost to the roof. these represent periods when the lava river remained at a constant level. The cave is 13.5 m high at this point, the greatest height measured to date in the Undara Lava tube system. (photo: H.J.L. Lamont, JCUNQ)

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

ASF * Number	Cave	Length	Max. Width	Max. 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 U20	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	> 950	18.9	11.5	**
	ext'n (1988)	> 400			PM, DR
U31	Darcy	99	16.3	6.3	**
U32 U33e	Matthew	40	7#	3#	**
U34	Barkers	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
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#	DR
U57	Expedition II	28	20	4#	DR
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#	DR
U64	Branch	10	10#	2#	DR
U65	San	25	10#	2#	DR
U66	Graham	22	3#	3#	FS
U67	Upper Secret	150#	-	-	FS
U68	Lower Secret	70#	-	-	FS
	Total	**6,324.7**			

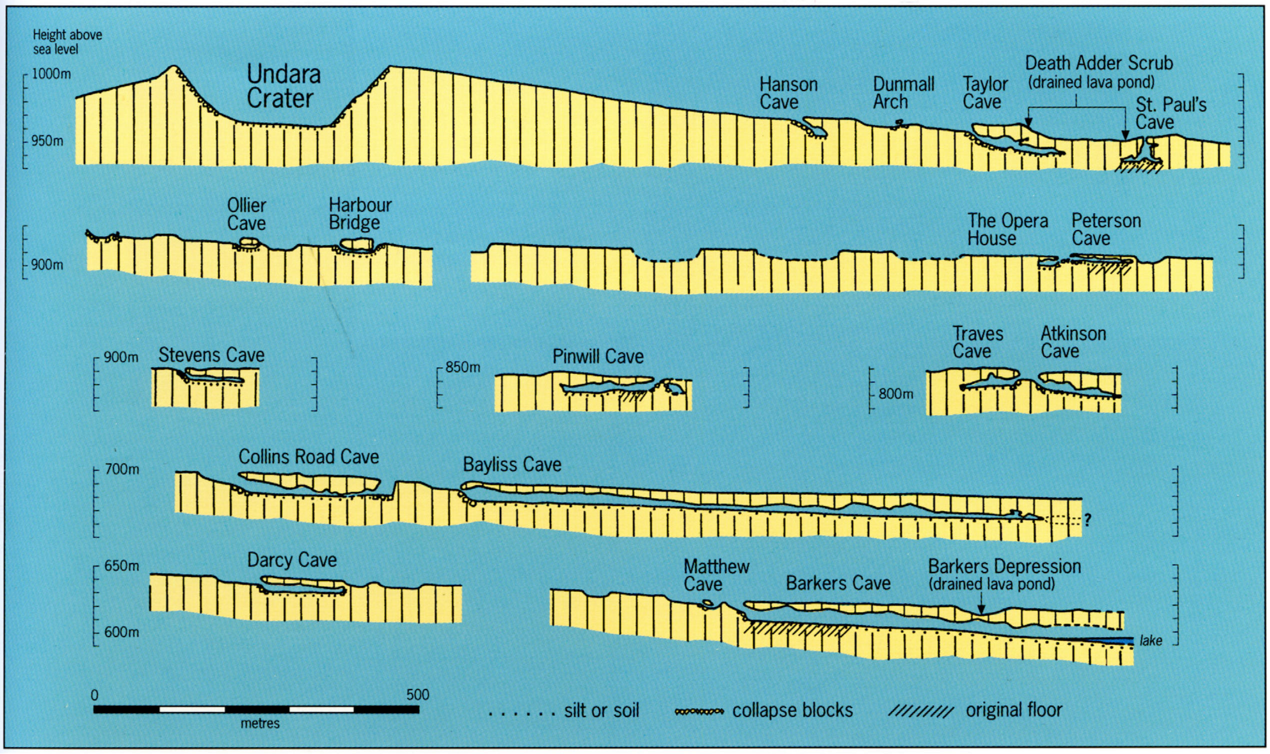
* *Australian Karst Index* (Matthews 1985)
\# Estimate only
** V. and A. Atkinson and assistants
Abbreviations: CS = C. Shannon, DI = D. Irvin, DR = D. Ray, FS = F. Stone, OR = Operation Raleigh, PD = P. Dwyer, PM = P. Mainsbridge.



< Fig. 15. Maps of selected caves with some cross-sections.

(Diagrams from Atkinson & Atkinson 1995, derived from those in Atkinson et. al. 1976)

v Fig. 16. Longitudinal profiles of selected caves down-flow from the Undara Crater. Floor symbols: sediment (.....), ropy lava (/////).



Features of the Caves and Arches

Although the Undara Lava Tubes were formed about 190,000 years ago (Griffin and McDougall 1975) 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 coloured bands of secondary minerals up to 10 centimetres wide outline polygonal jointing.

Fig. 17a. An area of floor in Pinwill Cave shows development of ropy structure, characteristic of pahoehoe (trewacle-like) lava flows. This structure sometimes forms when molten lava under still-plastic crust continues to move, causing the crust to twist into forms that resemble ropes. (photo: M. Williams, TCKRG)

Fig. 15 shows the plans of representative caves. Most of the cave passages are elongate in the direction of the lava flow. Fig. 16 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.

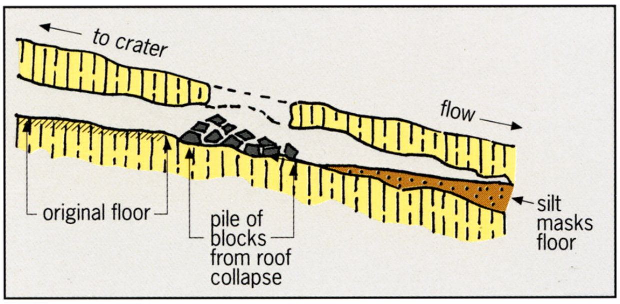


Fig. 17b. Why so little original cave floor is exposed in the Undara caves – less than 200 m of over 6 km surveyed. Most cave entrances are at the end nearer the crater which has allowed silt to wash in and mask floors. It is imperative that what remains visible is protected.

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 a'a 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 (Fig. 14) the floor is arched, with a single rope structure running down-flow. Beyond this, the floor has distinct marginal gutters up to one metre 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 (Fig. 17a) and the South Chapel of St. Pauls. In a central position near the entrance to Barkers Cave, crust fragments, approximately eight centimetres thick, have been rafted at varying oblique angles (Fig. 18) 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 (Fig. 19). 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 up to 20 centimetres, but in places may approach one metre in thickness. At various locations the tube lining has fallen off the wall to expose the host lava behind it.

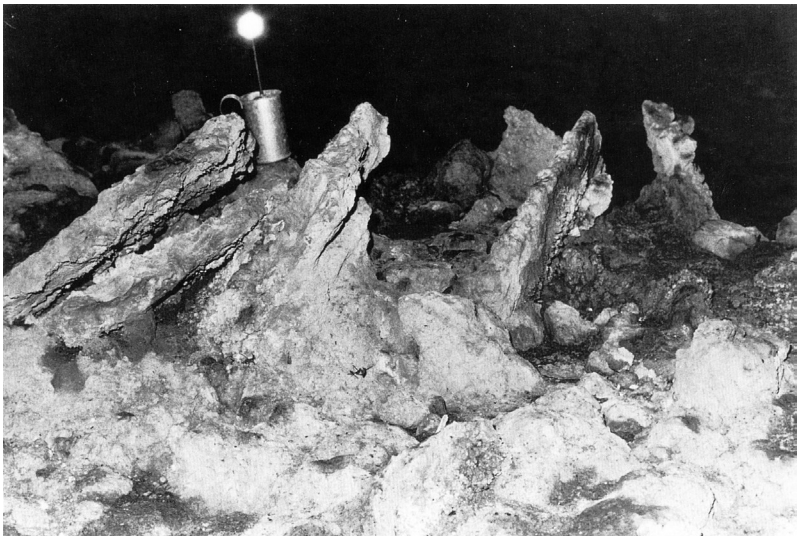


Fig. 18. "Rafted" blocks of the crust of the final flow in Barkers Cave have jammed at various angles. (photo: Vernon Atkinson)

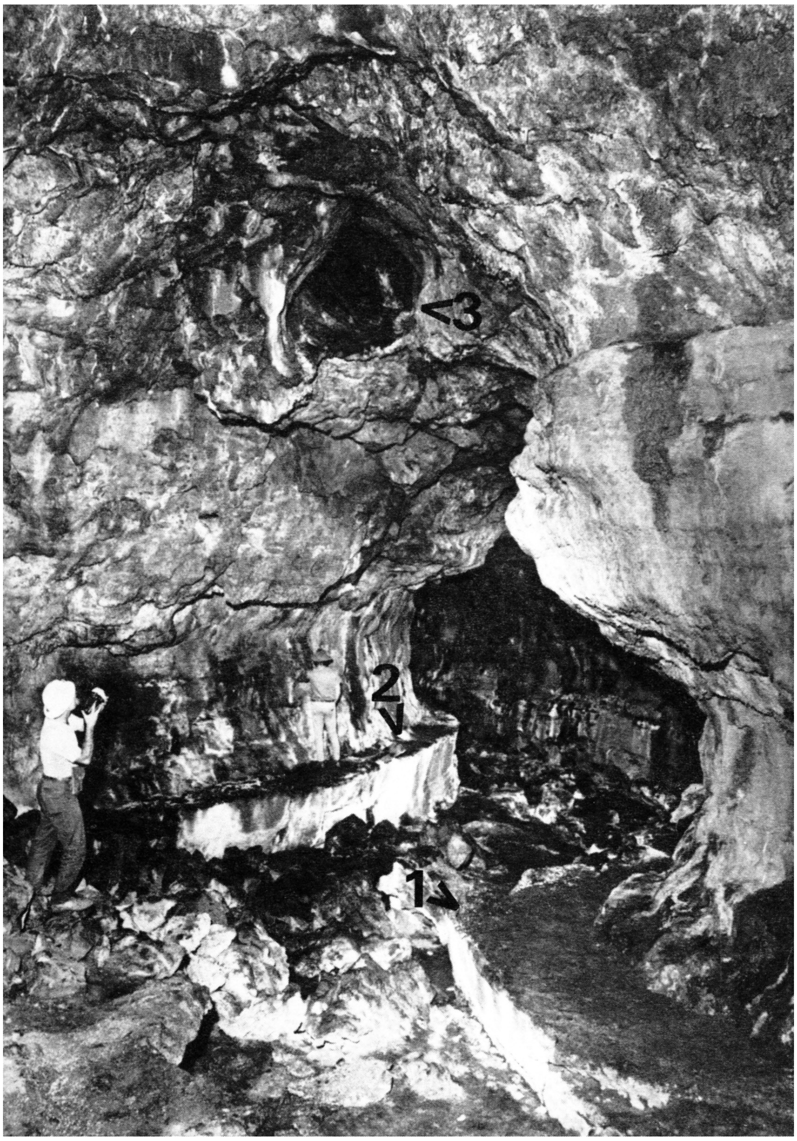


Fig. 19. The prominent "pavements" (marked 1 and 2) in Taylor Cave are evidence of an extended period of constant rate of flow. Solidification has been greatest at the apex of convexity, as in a fluvial river. There is a cylindrical opening (3) in the roof above the figure. The location of this openinmg suggests that some lava ponded in the death adder depression (in alignment to the north) drained back into the tube through this conduit. (photo: H.J.L. Lamont)

The lining is sometimes multi-layered. The best example of this is in Pinwill Cave where 15 layers, 2 to 4 centimetres thick are revealed at one location (Fig. 20). 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 (Fig. 22).

On most walls and roofs are some areas of very low vesicularity and showing drip and dribble structures resembling cake icing (Fig. 23). 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 lustre are appropriately termed "glaze," but in the Undara tubes the remelt surfaces have weathered to a dull or earthy lustre.

In places there are lavicicles (lava stalactites), commonly two centimetres to three centimetres and occasionally up to eight centimetres long, suspended from the roof, inclined walls, and in wall cavities (Fig. 25). 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 (Fig. 13), Arch, Ewamin, Picnic I, Picnic II and Barkers Cave (Fig. 14). 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 (Fig. 27), The Opera House (Fig. 28), Picnic and Wishing Well Caves terminate with walls.

Human Use of the Undara Lava Tubes

There is little evidence that the Undara lava tubes were used in prehistoric times.

Fig. 20. Multi-layered lining. Up to fifteen layers are exposed at this location in Pinwill Cave. (photo: Vernon Atkinson)

Local Aborigines believe 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.

Depressions in the Undara Lava Field and their relationship to Lava tube caves

There are two distinct types of depression for convenience here named Narrow Depressions and Green Depressions.

1. Narrow Depressions

The narrow depressions, 30-50 metres wide, commonly give entry to lava tube caves. They contain vegetation little different from the surrounding open forest and as a result, they are difficult to detect in aerial photography. They occur between some of the aligned green depressions. They are assumed to represent collapses of tube roofs.

2. Green Depressions

Green depressions, with rainforest type vegetation, and distinctive in aerial photography, occur in two areas:

a) In a clear alignment from Undara Crater to Barkers Pond (Fig. 11)

The aligned Green depressions vary in width from 50 to 100 metres and in shape from oval to elongate in the direction of the lava flow. To date no cave entrances have been found in them. Most have elevated rims and slopes are commonly covered with erratic shaped blocks of varying sizes.

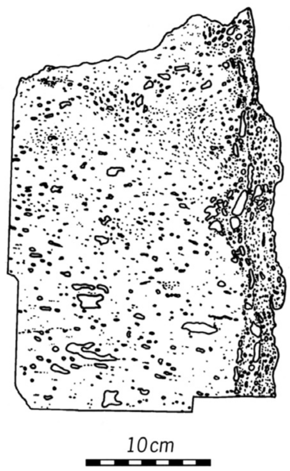


Fig. 21. Specimen from the entrance to Barkers Cave. When closely examined the apparent single lining (right edge) proved to consist of several distinct, annealed layers, indicating deposition of successive linings on still molten surfaces.
Note the elongation of the vesicles and the difference in their alignment; as would be expected, they are predominantly horizontal in the host rock but vertical in the lining. Specimen collected and presented to JCUNQ by Tom Atkinson. (diagram: P.J. Stephenson, JCU)

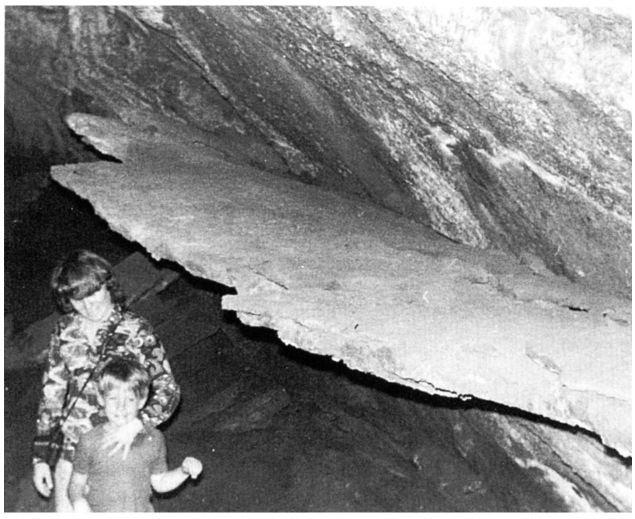


Fig. 22. "The Table" – a thin sheet of lining near the entrance to Pinwill Cave shows a degree of plastic deformation. (photo: Vernon Atkinson)

Fig. 23. Vertical lava dribbles in Barkers Cave. (photo: M. Williams, TCKRG)

Fig. 24. Deflection from vertical is evidence of the speed and heat of the final flow in the tube at this point in Road Cave. This may indicate that there was an opening in the roof of the chanel while the lava was flowing, or that the meeting of lava and groundwater caused a phreatic explosion nearby. (photo: M. Williams, TCKRG)

Fig. 25. Lavacicles up to 6 cm long in Bayliss Cave. (photo: Vernon Atkinson)

b) Green Depressions, non-aligned

In the area west of Barkers Pond the lava, no longer restricted by the granitic topography, spread to become a sheet flow. The depressions are irregular in shape, size and location. To date no cave entrances have been found in them. These depressions are wider than the tube and erratic in shape and location (Fig. 29). These features suggest that they may represent lava rise pits (Walker 1991), left by the collapse of lava rises formed by inflation of areas of semi-solid crust of a sheet flow.

Formation of the Aligned Green Depressions

Peterson, Scientist-in-Charge USGS's Hawaii Volcano Observatory 1970-75, viewed photographs and a map of the Undara area with Atkinson in 1972 and considered that the aligned Green Depressions of the Undara Lava Flow probably originated in the following manner: Peterson (pers. comm. 1975) and others of the US Geological Survey's Hawaii Observatory had 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 been observed to subside as the flow dwindles and the ponded lava drains back into the tube (Peterson pers. comm. 1975) (Fig 19). Peterson suggested mapping two of the aligned green depressions and the adjacent lava tubes. He was very pleased indeed to see the maps (Fig. 31).

Fig. 26. Boating party on the terminal lake, Barkers Cave (photo: R. Dutton)

Fig. 27. "The wave" – termination of Pinwill Cave which has a downflow entrance. (photo: Mick Williams, TCKRG)

collapse is now known as a lava rise pit (Walker 1991).

While this mechanism may be applicable to some of the depressions in the Undara lava field, the author doubts it can explain all the features of the aligned wider depressions between Undara Crater and Barkers Pond. In that area Peterson's observation of lava ponding in alignment with and adjacent to active flows in Hawaii seems to offer a more feasible mechanism.

There is a depression 60 metres in north of the entrance to 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 collapsed beneath the depression, as was expected, but close to the edge of the depression. The cave branches and two branches 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 (Fig. 30).

After discussion with Jim Kauahikaua (pers. comm. 2010) and intensive studies (Kauahikaua *et al.* 1998, Stephenson et al. 1998, Whitehead & Stephenson 1998, Orr 2010) an entirely different mechanism for the formation of the wide depressions in the Undara flow has been proposed. This mechanism involved lava rises (Walker 1991) that have formed above active lava tubes in sheet flows, then collapsed back into the sheet flow. That is possibly when the lava flowed on into the Einasleigh River then into the palaeochannel of Junction and Elizabeth Creeks. The flow may have filled the creek and formed levées. This type of

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 around the collapse, but was being constricted and eventually dammed. Subsequently the dammed lava inside the tube drained through minor outlets. A cylindrical vent in the roof of Taylor Cave (Fig. 19) is interpreted as a location where some of the lava that pondered above the main tube drained back into it. A minor lava fall, approximately a metre high, emerges from under the floor of the west terminal branch of the cave and is interpreted as another point of "drain back".

There is much interesting work to be done at Undara for many years to come, and many questions still to be answered – perhaps some questions will never be answered.

Barkers Pond

The oval depression 220 metres West of Barkers Cave entrance, known as Barkers Pond, is approximately 100 metres long and 60 metres wide. Fig. 31 shows how Barkers Cave changes its course seeming to deviate around the depression, Barkers Pond, 220 metres west of the Cave entrance. There is a small cavity in the cave roof under the eastern end of the depression. It seems that the lava, which had ponded in the depression, may have drained back into a flowing tube forcing it to alter its course. Near the top of the inner western margin of Barkers Pond is an area of very finely vesicular blocks – which may be termed a mosaic (Fig. 32). Close examination of these blocks indicates they were once adjacent – distinctive, fine cracks can be traced from each block to an adjacent block. This is interpreted as indicating they were once the degassed surface of former pond crustal blocks.

Fig. 28. Termination of The Opera House (note wings). Entrance is down flow. (photo: H.J.L. Lamont, JCUNQ

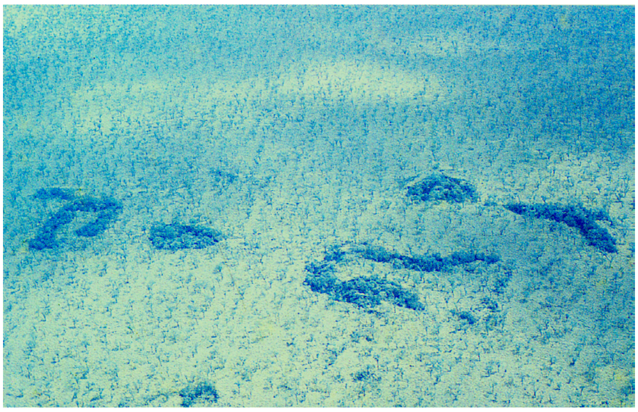


Fig. 29. Irregular shaped depressions which resulted from the draining of areas where lava had ponded during the period of active flow. (photo: Tom Atkinson)

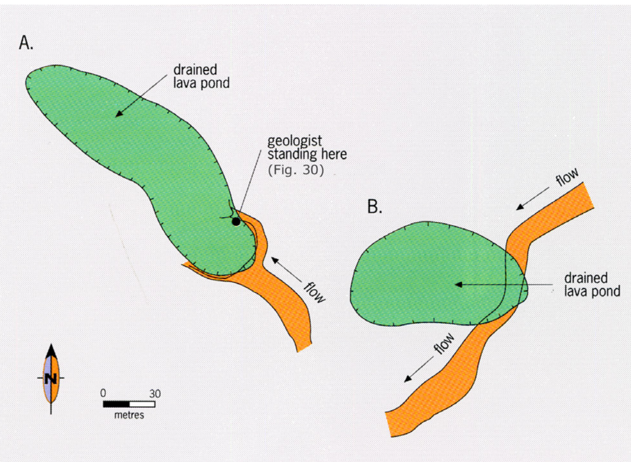


Fig. 31. Relationship between surface depressions and caves. (A) Taylor Cave, (B) Barkers Cave. (from Atkinson & Atkinson 1995)

Though in quite a different situation, the 1898 photo of the lava lake retained by its own levée in Halemaumau Crater within Kilauea Caldera (Fig. 33) shows features which the author sees as comparable with those of Barkers Pond before it drained.

Formation of Barkers Pond

With such a volume of lava contained in a low, cone shaped pond (with the apex at the bottom) irrespective of the rate of drainage, the rate of lowering of the Pond surface would have increased as drainage proceeded. This would seem to explain why the only 'mosaic' of crustal blocks is near the top of the inner west wall of the Pond.

As drainage progressed crustal blocks would have become broken and deposited in what Stephenson and Whitehead (1996) in their Chapman Conference Excursion Guide, termed "a frustrating complex of blocks, some ropy… chaotic in their distribution". They consider the chaotic distribution probably represents "mass-movement down the slope of the lava rise pit" (Walker 1991). Could these observations not equally indicate their origin as segments of pond

Fig. 30. Termination of Taylor Cave (east branch) as two closing tunnels behind geologist T.J. Griffin. Note the prominent horizontal lava level lines and ledges on walls and central column. (photo: H.J.L. Lamont)

< Fig. 32. Detail of inner wall of Barkers Depression to show a small "mosaic" of distinctive blocks of former pond crust. (photo: Sarah Collins)

Fig. 33. Halemaumau Crater within Kilauea Crater, Haewaii, 1895. The lava lake is held in a ring-shaped levée built up by spattering and repeated overflows, such as those visible in the picture. (photo: R.J. Baker Collection, Bishop Museum, Honolulu, Hawaii)

crustal blocks? If they had examined the blocks more closely they may have found some, as depicted in Fig. 34 with the gradation of vesicularity from a smooth, apparently non-vesicular surface to an opposite surface with quite large vesicles. Search for similar blocks lower on the pond walls and near the base of the Pond showed many blocks with gradation in vesicularity.

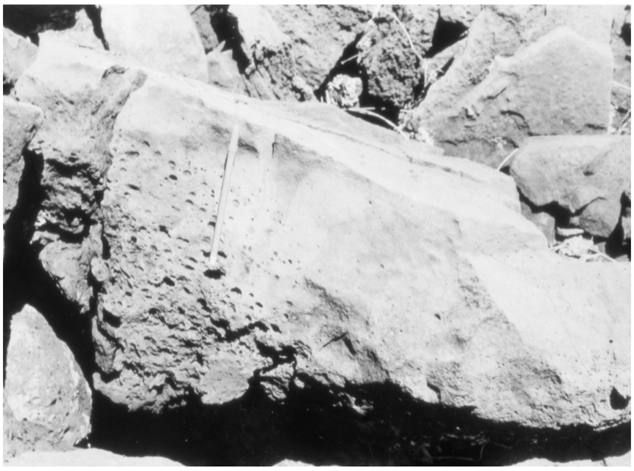


Fig. 34. Lava blocks in Barkers Pond, showing gradation in vesicularity from apparently none to quite large on the opposite surface. (photo: Anne Atkinson)

From the lowest area of the Pond voices are audible immediately below in the tube – a point assumed to be the place where lava drained back from the pond into the tube. At this point in the tube there is no indication of roof collapse, as stated by Stephenson & Whitehead (1996). The author's 1972 map of Barkers Cave (Fig. A2-1) shows two heaps of what she termed rock fall. These are some distance upflow and downflow from the location which she assumes to be the cave end of the drainage from Barkers Pond. From this point in the cave voices can be heard from the lowest point in Barkers Pond above. With more sophisticated modern instruments, mapping may prove that the 1972 map has some minor errors.

The Wall

The Wall (Figs 3, 35 and 36) consists of a very long, narrow ridge that rises up to 20 metres above the general level of the flow and can be traced for 35 kilometres. The upper surface of the ridge is relatively flat and varies in width from 70 metres to 300 metres. Its down-flow slope averages only 1.72 metres per kilometre with occasional undulations. The side slopes of the ridge are up to 29°. There are several depressions within five kilometres 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.

Formation of The Wall

Stephenson and Whitehead (1996) and Jim Kauahikaua (pers. comm. 2010) see The Wall as a lava rise ridge (Walker 1991). The author, however, believes this formation may have involved a different mechanism.

In July 1974 she observed (Appendix 3, Figs. A3.1, A3.2 & A3.3) lava flowing in, crustal blocks forming on, and moving on a channel built in three days by lava fountains on the floor of Kilauea Caldera. The steep channel walls appeared to have been built by levées. This allowed the mechanism depicted in Atkinson & Atkinson (1995) and Fig. 37, to be proposed as a possible mode of formation of The Wall and some of the features near its termination.

Mode of Formation of the Undara Lava Tube System

Lava rivers and associated tube systems are the main distributors of the lava during a pahoehoe lava eruption. Evidence of how the Undara lava tube system

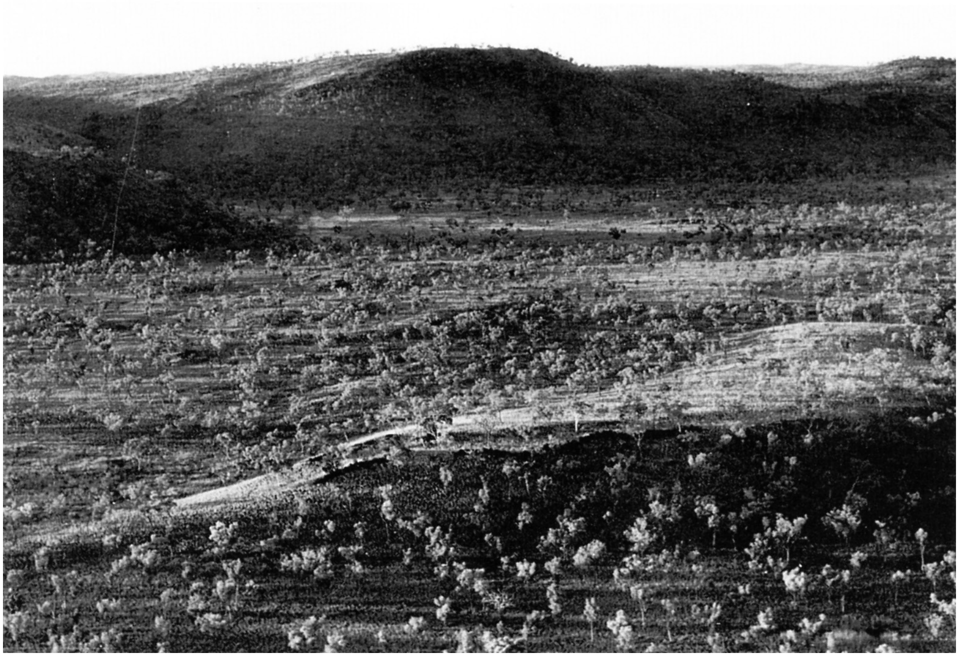


Fig. 35. Oblique aerial view of western end of 'The Wall' from the south. Note polygonal basalt columns flanking central collapsed area at the termination. (photo: Jon Edmonds).

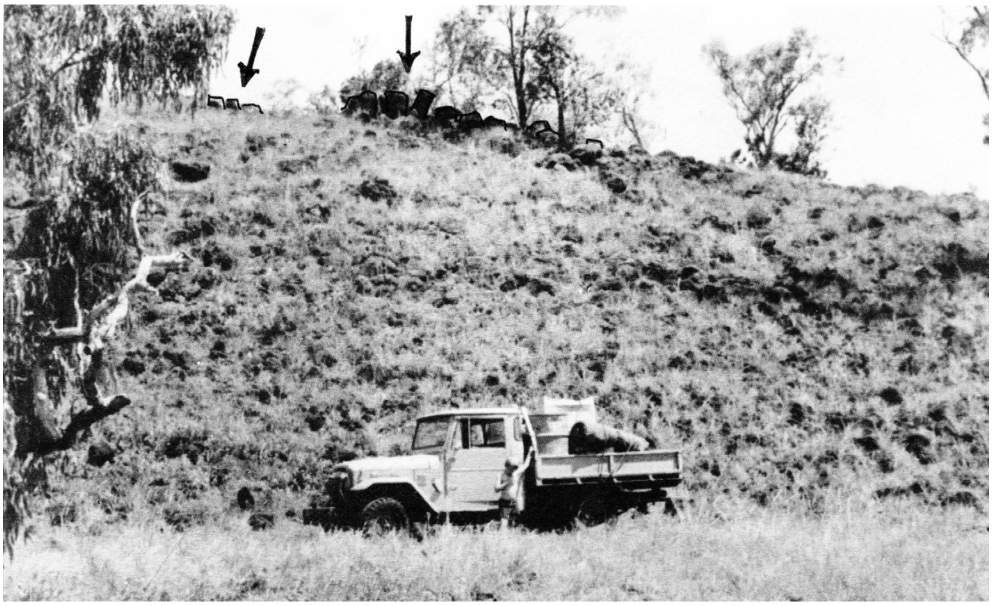
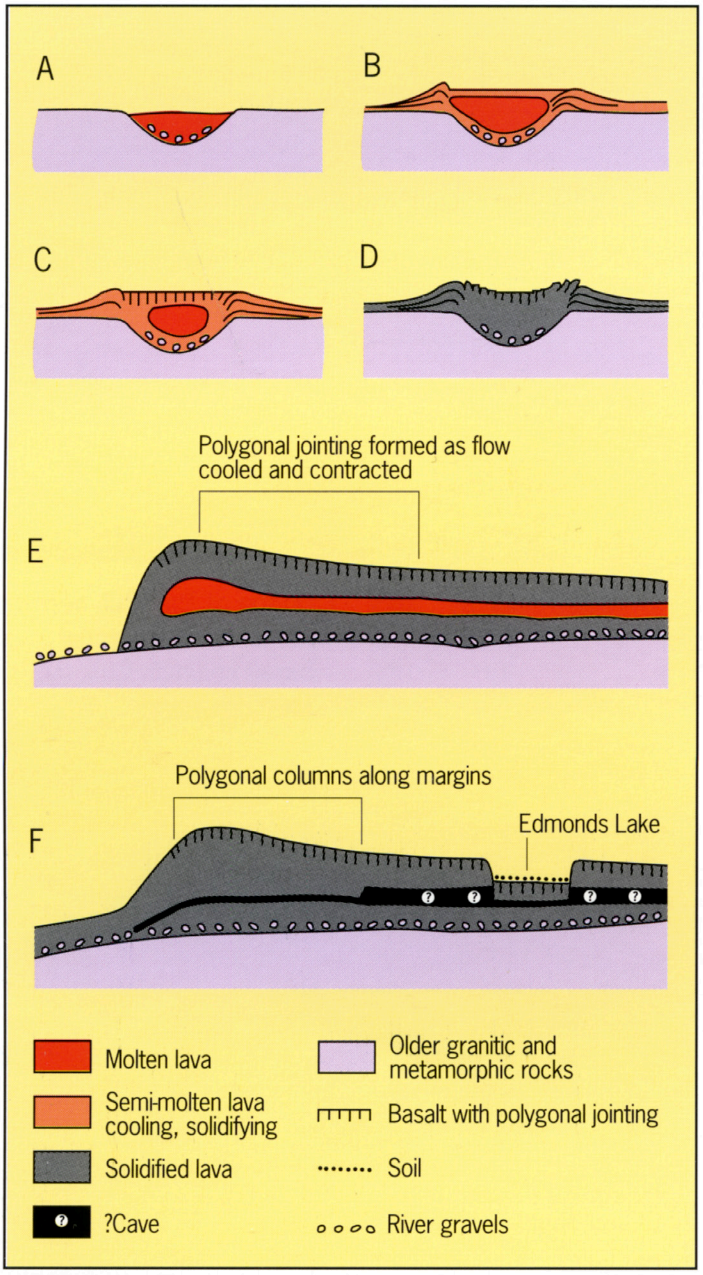


Fig. 36. Termination of 'The Wall' viewed from the north. Arrows point to the columnar blocks on the horizon. (photo: Tom Atkinson)

and the caves in it may have 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 1970; Cruikshank and Wood 1972; Peterson and Swanson 1974; Peterson and Holcomb 1989), and Iceland (Kjartansson 1949, cited in Wood



Transverse sections

A. Lava flowing in a valley …

B. … built up levées along its main channel.

C. Lava hardened against the valley walls, at the base and top of the flow and in the levées but the central tube allowed lava to flow on. As the top of the flow cooled, it contracted and polygonal joints formed. The resulting columns show remarkable similarity in cross-section measurements throughout the length of the flow. When the end of the flow hardened, the lava was dammed behind it.

D. A surge of lava broke through the lava dam, allowing still molten lava to escape. The channel roof sagged, leaving the prominent marginal polygonal columns.

Longitudinal profiles

E. (corresponding to C. above) The roof of the elevated channel cooled and polygonal joints formed. Further pressure of lava caused slight elevation at the termination.

F. Renewed activity from the vent broke the terminal dam and allowed the lava to flow on to the Einasleigh River. With the final withdrawal of supporting lava, a central oval section near the termination collapsed to form Edmonds Lake.

Fig. 37. Possible mode of formation of 'The Wall', particularly its western termination. (from Atkinson & Atkinson 1995)

1976), has resulted in the following discussion of the mode of formation of the Undara Lava Tube System (Fig. 38).

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 (Fig. 38-A). 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 (Fig. 38-B). If the eruption ceases at this 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 (Fig. 38-C) 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 (Fig. 38-D).

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.

Once the initial Undara Lava Tube System formed there was subsequent thickening of tube roofs by later surface flows (as seen in Road Cave, Fig 13, and Peterson Cave, Fig. 39). Some of these flow units passed over ropy surfaces and now bear ropy imprints on their lower surfaces. A good example of this is found just inside the entrance of Road Cave. The low incidence of ropy surfaces and imprints at Undara support the observation by Macdonald and Abbott (1970) that ropy structure is often evident only over a small proportion of any flow. Fig. 40 shows the thickness of various lava tube cave roofs: (a) Taylor, (b) Harbour Bridge, (c) Peterson, (d) Pinwill, (e) Road, (f) Barker.

Subsequent flows, as well as thickening 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 vicinity of the Wind Tunnel.

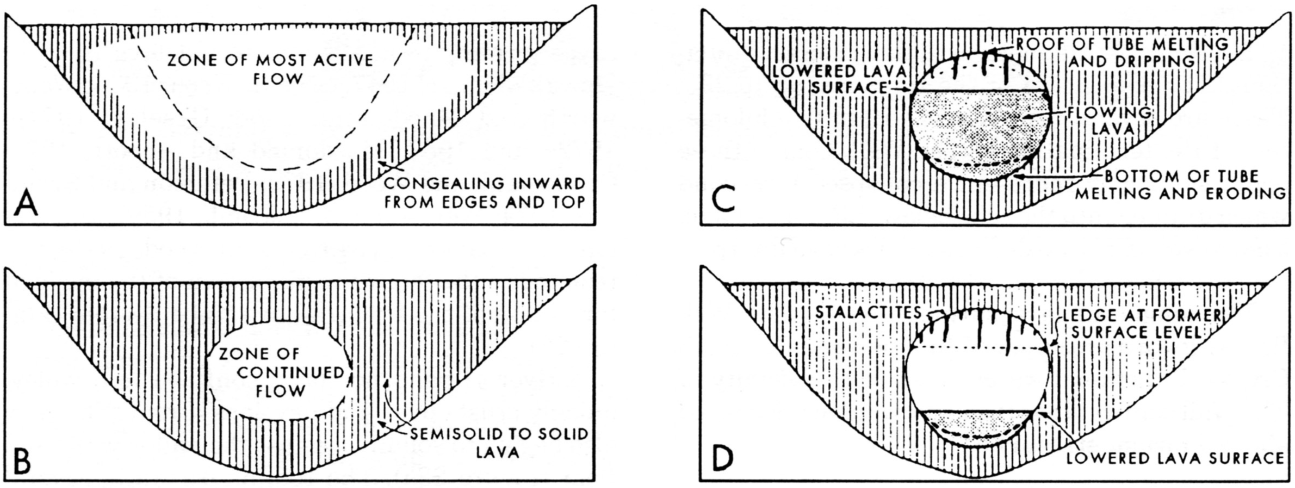


Fig. 38. Stages observed in the development of the lava tubes in Hawaii (after Macdonld and Abbott 1972). Examination of evidence in the Undara Lava Tubes indicates that this explanation is directly applicable.

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 centre continuing to flow.

b. The active movement of liquid becomes restricted to a more or less cylindrical, pipe-like 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 dimunition of supply lowers the level of the surface of the liquid which finally congeals to form the floor of the tube.

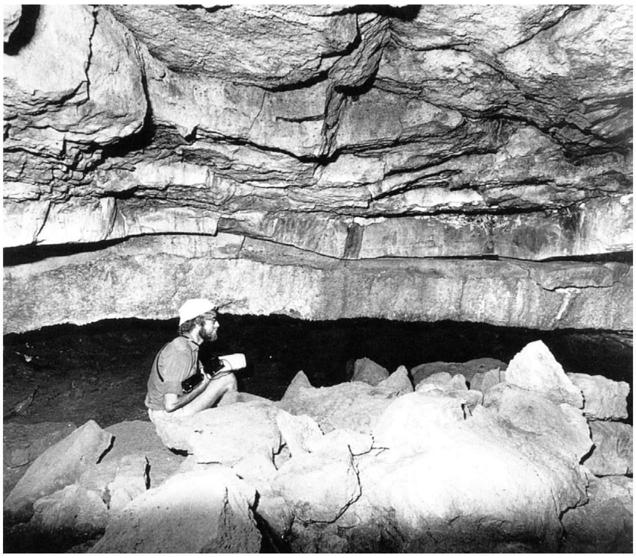


Fig. 39. Roof structure inside Peterson Cave (east branch). The prominent arched flow unit just above the observer's head has a ropy surface. Higher ropy surfaces also occur. (photo: H.J.L. Lamont)

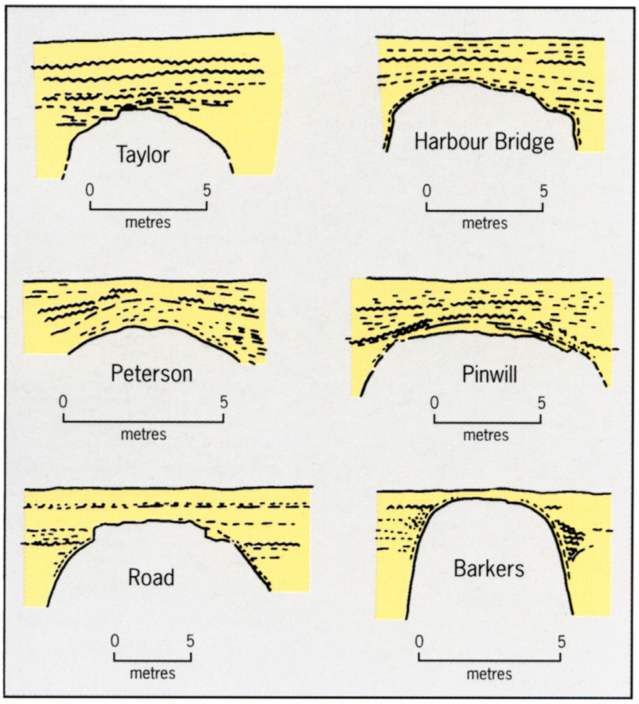


Fig. 40. Cave entrance structures showing thickening of roofs by successive surface flow units. Wavy lines indicate recognisable flow unit surfaces. Other near-horizontal lines are major vesicle zones. (diagram: P.J. Stephenson)

Beyond the Yaramulla Section, the continuation of the lava tube system is The Wall. That it is 20 metres 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 (Figs 35 and 36) 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 kilometres. Slumping of the tube roof at the termination left a colonnade of roughly columnar blocks (Fig. 36). It would be of great interest to confirm the structure of this unusual feature by geophysical investigation or drilling near the centre of the ridge.

Conclusion

Favourable palaeotopography, continued effusion and an efficient lava tube system, allowed one flow from the Undara Volcano to extend 160 kilometres to become the longest recent single-volcano flow in the world. This flow contains the longest lava cave in Australia – Bayliss Cave, with more than 1300 metres. 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 in Hawaii and Iceland.

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Mick Godwin, formerly of QNPWS, Cairns, who has done so much toward completing the Undara records and who arranged my safe entry to (and return from) the caves discovered in 1988.

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APPENDIX 1

UNDARA LAVA TUBE SYSTEM LAVAS – MAJOR ELEMENT CHEMICAL ANALYSES

(from Atkinson, Griffin and Stephenson 1976, Table 1)

Specimen	1.	2.	3.	4.	5.	6.
SiO_2	48.85	48.80	48.20	49.30	49.50	51.6
TiO_2	1.82	1.71	1.75	1.70	1.67	2.20
Al_2O_3	15.23	15.12	15.80	15.40	15.90	16.6
FeO_3	2.52	2.94	4.46	11.00	10.53	8.17
FeO	7.46	7.94	6.38	trace	0.06	0.66
MnO	0.16	0.17	0.17	0.15	0.15	0.13
MgO	8.55	8.88	7.85	8.10	7.10	2.80
CaO	9.16	9.73	8.02	8.02	8.39	5.50
Na_2O	3.90	3.34	3.57	4.20	3.87	5.30
K_2O	1.75	1.20	1.71	1.77	1.53	3.25
H_2O+	0.35	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O-	0.17	*	*	*	*	*
P_2O_5	0.64	0.34	0.72	0.50	0.34	0.87
CO_2	0.13	n.d.	n.d.	n.d.	n.d.	n.d.
Total	**100.69**	**100.17**	**98.63**	**100.14**	**99.04**	**97.08**
Location (Fig. 8)	A	B	C	D1	D2	E

*These analyses on samples dried at 110°C

n.d. = not determined

Specimen locations (A to E) are shown on Fig. 8. C is the western end of The Wall; D1 is host rock, Barkers Cave entrance; D2 is lining at Barkers Cave entrance; E is host rock lava drip, Pinwill Cave.

Analytical techniques used for specimens:

1. XRF; Na, flame photometric; Fe^2, by titration - by T.J. Griffin

2 - 6. Atomic absorption (HF - Boric acid digestion; P, spectrophotometric; Fe^2, by titration - by P.J. Stephenson and T.J. Griffin.

APPENDIX 2

THE AUTHOR'S FIRST MAP AND TRANSVERSE SECTIONS, BARKERS CAVE, UNDARA
(modified for Atkinson & Atkinson 1995)

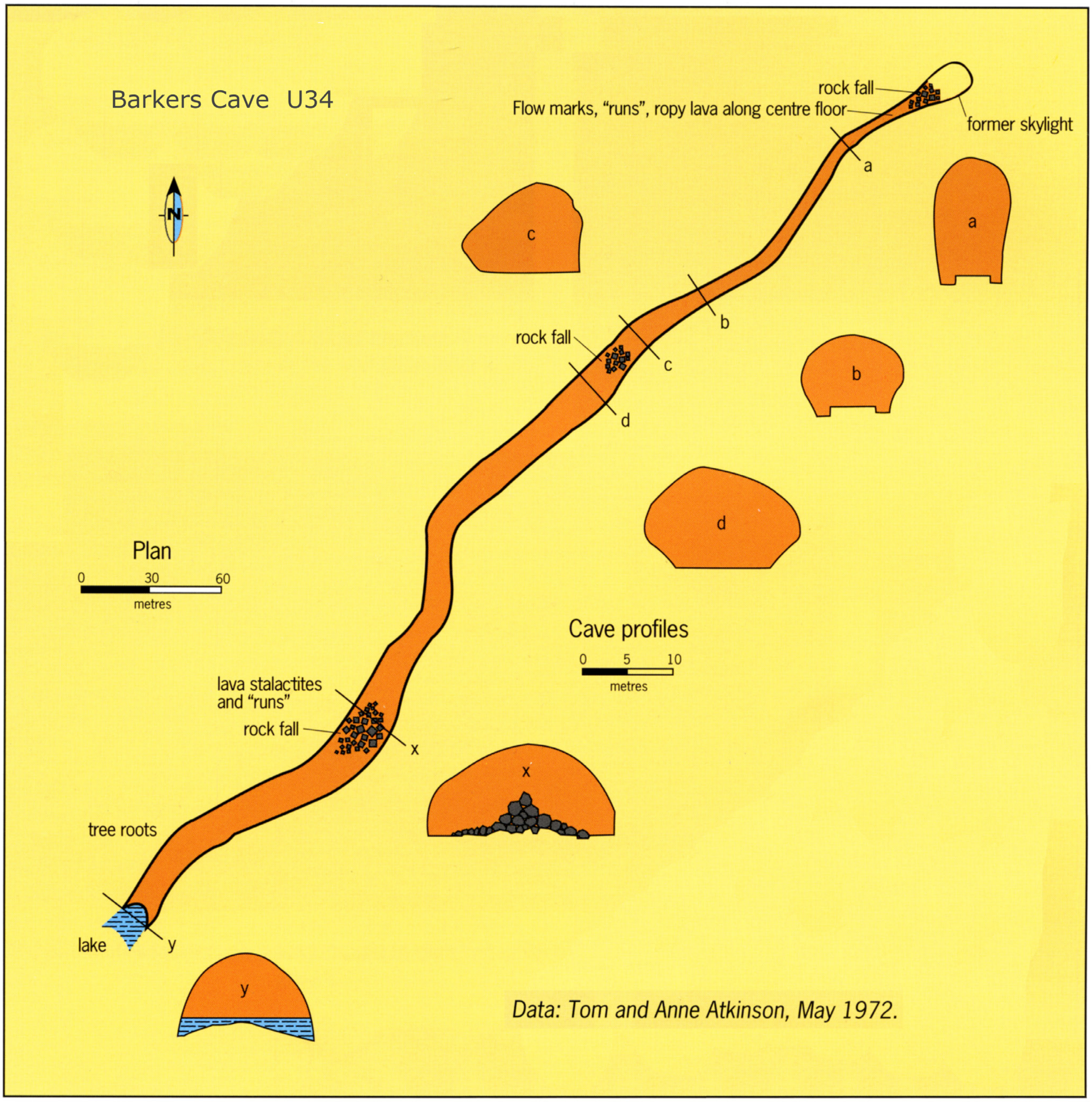


Fig. A2-1. Map of Barkers Cave (survey data by Tom and Anne Atkinson, 1972) (first published in Stevens & Atkinson 1975).

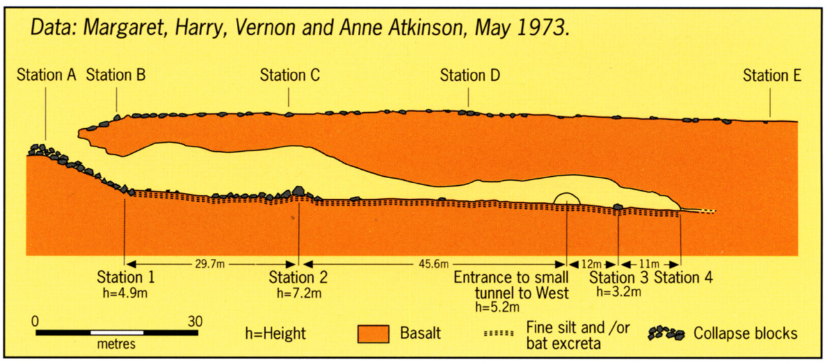


Fig. A2-2. First longitudinal profile, Undara Lava Tube System: Atkinson Cave.

APPENDIX 3 – **HAWAII**

Under the guidance of Dr Donald Peterson, Scientist-in-Charge (1970-75), USGS Hawaii Volcanoes Observatory, and later with Christina Heliker, a senior field geologist, the author had the extraordinary good fortune to see:

- 1972: waves of lava flowing into a lava lake, summit Mauna Ulu;
- 19 July 1974: spectacular lava fountains, Kilauea caldera floor, (Fig. A3-1);

- 20 July 1974: minor flows from final fountaining built their own levées; crustal blocks forming and moving on cooling surface. The side of channel was near vertical (Figs. A3-2, A3-3);

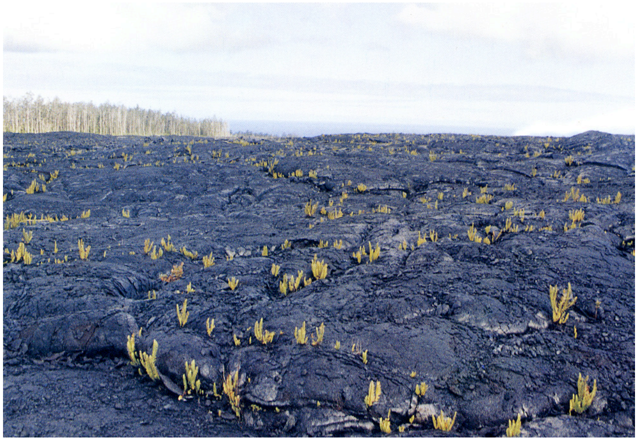
- 21 July 1974: eruption nearly over (Fig. A3-4);

- Patches of ropy lava forming in the semi-solid crust on the gentle slope near sea level (Fig. A3-5);

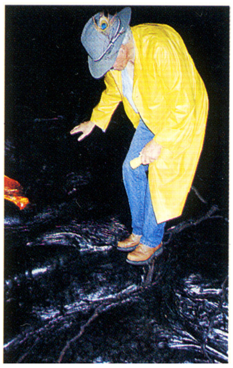
- 1991: lava flowing in a lava tube (Figs. A3-6, A3-7).

• 1991:

• An earlier lava flow



• Vernon Atkinson standing on very new Pahoehoe lava watching “toes” bud and ropy lava form.



Though she will never claim to be an authority on any matters vulcanological, these incredible sights and sounds had a profound influence on the author.

Discussions by letter and in person with members of USGS Hawaii Volcano Observatory staff, Dr Donald Peterson, Scientist-in-Charge 1970-75, Christina Heliker, a senior field geologist, Jim Kauahikaua, present Scientist-in-Charge, and others were invaluable. Their knowledge and the opportunity to observe the above phenomena have greatly influenced the author’s opinion re likely mode of formation of many surface and lava tube features in the areas selected for field work in 1972 of the 190,000 year old Undara lava field.

Hawaii – Suggested additional reading

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APPENDIX 4

CHEMICAL COMPOSITION OF LAVAS

Composition of lava influences its viscosity. Similarity of composition of Undara lava (Griffin 1977) and average Hawaiian lava is noted in the table below. For interest, average composition of lava from Mt. St. Helens 1980 explosive eruption is also given.

	Undara*	Hawaiian Islands#	Mount St. Helens (1980)
Silicon SiO_2	48.9	48.4	63.5
Titanium TiO_2	1.8	2.8	0.6
Aluminium Al_2O_3	15.2	13.2	17.6
Iron FeO	10.5	11.2	4.2
Magnesium MgO	8.6	9.7	2.0
Calcium CaO	9.7	10.3	5.2
Sodium Na_2O	3.9	2.4	4.6
Potassium K_2O	1.8	0.6	1.3
Other Oxides	-	1.4	1.0

Table of average chemical composition *of lavas expressed as weight percent oxides from the Hawaiian Islands, Mt. St. Helens, U.S.A., explosive eruption (1980) and one analysis from an Undara flow.*

Average of 53 analyses of olivine basalts.
* Host rock, Barkers Cave entrance; analysis: T.J. Griffin.