# The Undara Lava Tube System, North Queensland, Australia:

# Updated Data and Notes on Mode of Formation

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## Introduction

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. Some aspects of its geology will be considered. This paper has been abridged from a previously published paper (Atkinson, 1991).

More than 60 caves and arches have now been discovered in the system. Most caves are less than 200 m long but the system includes Australia's longest lava tube, over 1350 m. More than 6 km of tubes have been surveyed.

The Undara volcano erupted 190,000 years ago (Griffin & MacDougall, 1975). With an average gradient of only 0.3°, one of the flows extended more than 160 km. This great length is attributed to very high effusion rates, favourable topography and lave tube efficiency.

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

Comparison of the Undara tubes with 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 palaeo-topography.

## Location and Geological Setting

The Undara lava tubes are found within basaltic lava flows from the Undara Volcano which is located approximately 200 km south-west of Cairns in northern Queensland, Australia. This volcano is situated near the centre of the McBride Province (Figure 1) which covers approximately 5,500 km$^2$, and topographically forms a broad dome. Only one volcano, Kinrara, is younger than the Undara Volcano (White, 1962). There are over 160 vents in the province (Griffin, 1976).

The Undara Volcano (Figure 2) is the highest point in the McBride Province. Its impressive crater is 340 m across and 48 m deep with inner slopes of up to 40°. The rim rises only 20 m above the surrounding lava field. Outward slopes from the rim vary from 30° to 5° on the north-west side where the major outflows occurred. The crater walls are mainly covered by angular blocks of highly vesicular to massive lava, up to several metres across.

The Undara lava flows cover 1550 km$^2$ in the province. 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. 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, 1987; Peterson & Holcomb, 1989; Peterson & Swanson, 1974; Rowland & Walker, 1990).

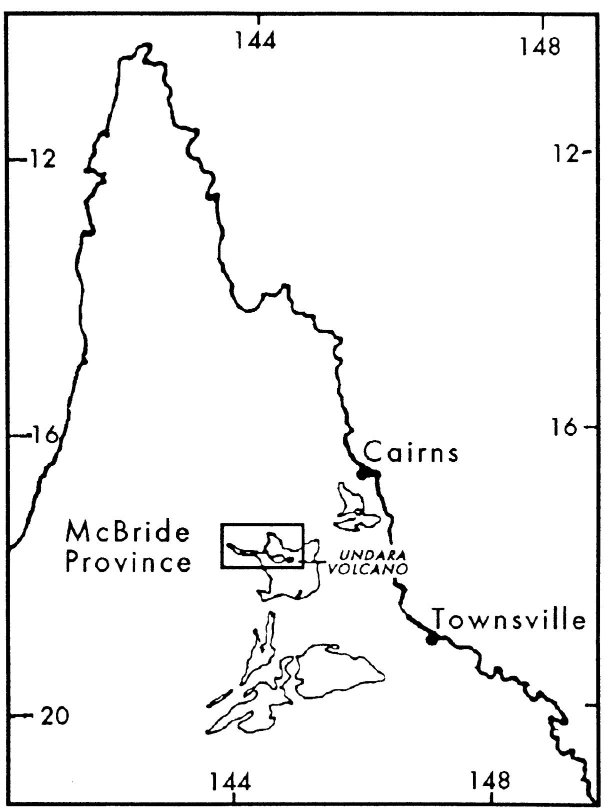


**Figure 1: The main areas (provinces) of Cainozoic basalt outcropping in north-eastern Australia. The boxed area is shown in Figure 2.**

The feeding channels 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-level tube discovered in the McBride Province is in three levels on the flank of the source volcano in an adjacent flow of slightly greater age.

Lava flowed in all directions from the Undara Crater, but the main flow was to the north-west (Figure 2). The flow to the north was approximately 90 km long and entered the Lynd River. The voluminous north-west flow followed precursors of Junction Creek, Cassidy Creek and the Einasleigh River for more than 160 km to become the longest single lava flow in the world (Walker, pers. comm., 1989). He considers that to reach a length in excess of 160 km, Undara's eruption may have continued for several years.

Walker (1973) concluded that very long lava flows reflect continued high effusion rates. Stephenson & Griffin (1976) reached a similar conclusion in a study of eight long basaltic flows in Queensland.

The lava tube system from the Undara crater has been divided into four sections (Figure 2) in order to describe the locations of the caves and arches.

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

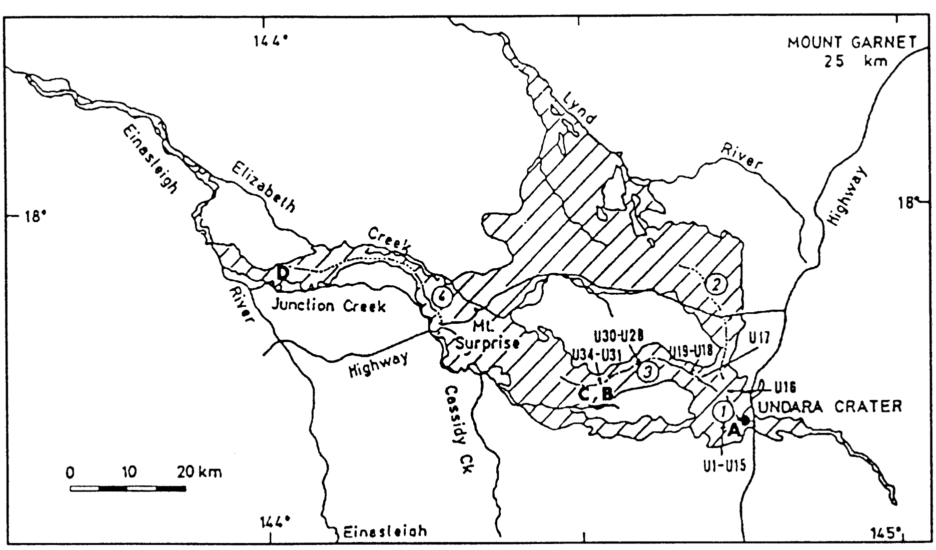


**Figure 2: The Undara lava field. Circled numbers denote sections of the lava tube system referred to in the text, namely: 1. Crater Section; 2. North Section; 3. Yaramulla Section; 4. Wall Section.**

# Investigations

The Undara lava tubes were described briefly by Twidale (1956), Best (1960) and White (1962). 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 (Stevens & Atkinson, 1975; Atkinson & others, 1975; Atkinson, 1988a, 1988b, 1990a, 1990b, 1991). At the same time, and subsequent to this investigation, the speleologists were continuing exploration of the caves. Grimes (1973, 1977) published a compilation of the results of earlier studies of Undara lava tubes. In the *Australian Karst Index*, Matthews (1985) recorded the cave names, numbers and brief descriptions.

The Chillagoe Caving Club commenced exploration of the lava tubes in 1988. In addition, a number of expeditions from the Explorers Club (New York) 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 a Q.N.P. & W.L.S. officer, they surveyed collapse depressions in the new Undara Crater National Park and in the 10 km upflow from Bayliss Cave, an area never previously studied. They discovered and surveyed five new caves. Their systematic search in the North Section resulted in the first discovery of caves in this section, viz. Dingbat Cave, Hot Hole and Wishing Well Cave, about 21 km 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.

# Caves and Arches

The Undara lava tube system can be clearly located on aerial photographs. It stands out because most of its collapse depressions support rainforest type vegetation which contrasts sharply with the open forest of the surrounding country. Some of the caves, for example Barkers Cave and Road Cave, have been known for more than eighty years. The majority of caves, however, were located by systematic exploration of the collapse depressions since 1972.

61 arches and caves have been discovered in the Undara Lava Tube System up to 1991, 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 the passage width reaches 19.8 m and a height of 13.5 m.

## Features of the Caves and Arches

Although the Undara lava tubes formed 190,000 years ago, they have retained many original features. These features show minimal alteration due to their protection from weathering.

Figure 3 shows plans of representative caves. Most of the cave passages are elongate in the direction of the lava flow. Figure 4 shows longitudinal profiles through representative caves in the Crater Section and Yaramulla Section of the lava tube system. These profiles illustrate the variation in shape, size and roof thickness of the caves.

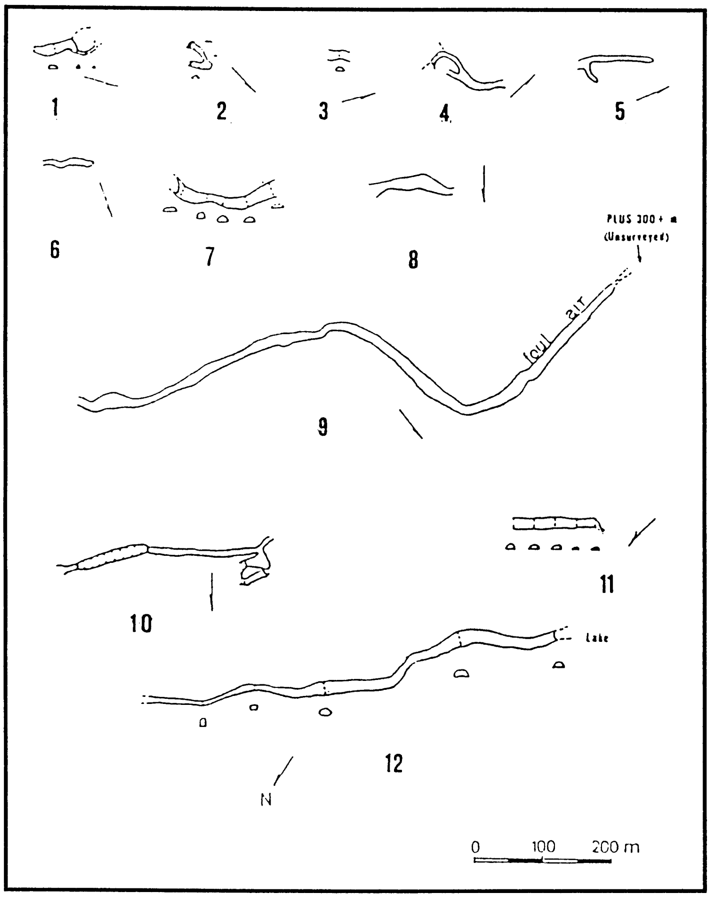


**Figure 3: Maps of selected caves with some cross sections.**
**1. U-4 Taylor, 2. U-8 Ollier, 3. U-9 & U-10E Harbour Bridge, 4. U-11 & U-12E Greeley, 5. U-15 Peterson, 6. U-16 Stevens, 7. U-17 Pinwill, 8. U-28 Road, 9. U-30 Bayliss, 10. U-41 Inner Dome & U-42 Wind Tunnel, 11. U-31 Darcy, 12. U-34 Barker**

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.

## 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 on the floor of Pinwill Cave, Yaramulla Section and Wishing Well Cave, North Section, the exposed floors are typical pahoehoe.

At the entrance to Barkers Cave, the floor is arched, with a single ropy structure running down-flow. Beyond this, the floor has distinct marginal gutters up to 1 m 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.

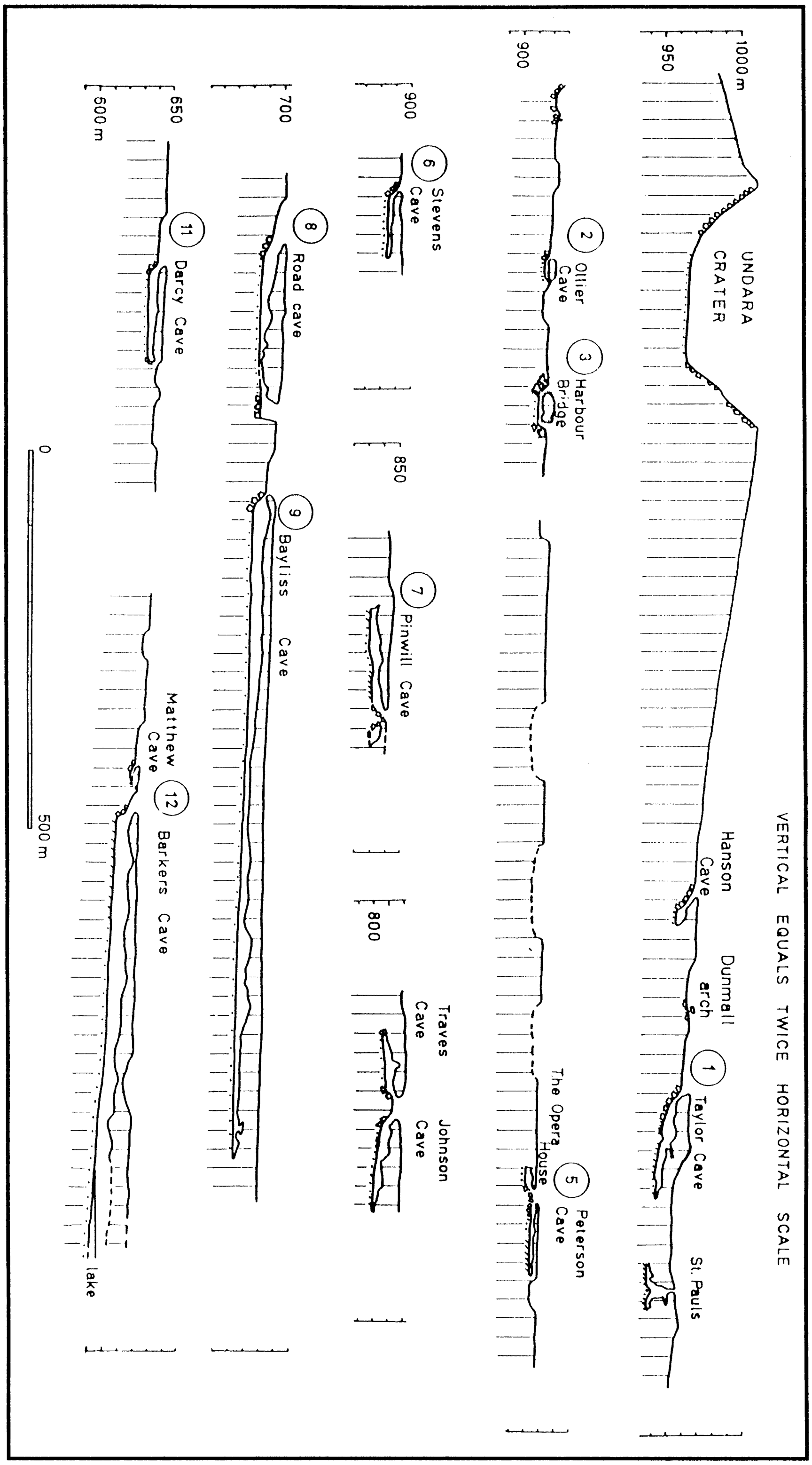


**Figure 4: Longitudinal profiles of various caves in the down flow from Undara Crater. Floor symbols: Sediment (......), Ropy lava (//////) (Atkinson et al., 1975)**

Good examples of ropy lava are visible in Pinwill Cave and the South Chapel of St. Paul's. In a central position near the entrance to Barkers Cave, rafted crust fragments, approximately 8 cm thick, have been tilted at varying oblique angles in a manner similar to ice slabs on a frozen river. In Peterson Cave, there is a small floor surface where lava drops from the roof appear to have pitted the floor, as rain drops pit a muddy surface. Prolonged flow at constant level is evidenced by the "benches" in Taylor Cave.

## Walls and roofs

There is a lava lining on the walls and roof of most caves. Typically the lining is a single layer up to 20 cm, but in places may approach 1 m 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 - 4 cm thick are revealed at one location. 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.

On most walls and roofs are some areas of very low vesicularity showing drip and dribble structures resembling candle wax. At the entrance to Barkers Cave, Collins Road Cave and Picnic Cave these drips are deflected. In historic tubes such surfaces have been seen to be formed by remelting and because of their lustre are appropriately termed "glaze". In the Undara tubes the remelt surfaces have weathered to a dull or earthy lustre.

In places there are lavacicles (lava stalactites), commonly 2 cm to 3 cm and occasionally up to 8 cm long, suspended from the roof, inclined walls and in wall cavities. 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 many caves: Taylor, Road, Arch, Ewamin, Picnic I, Picnic II and Barkers. 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, The Opera House, Picnic Cave and Wishing Well Cave terminate with vertical walls.

# 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 - 50 m wide, and wide depressions 50 - 100 m wide. Their appearance is comparable with an historic lava pond in Hawaii (MacDonald & Abbott, 1972, p 42)

## 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, rainforest trees and vines are found at most cave entrances, often concealing 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 rainforest vegetation. 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.

Most wide depressions have elevated rims, suggesting that they represent former lava ponds as are seen associated with historic flows in Hawaii. 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, U.S.A. (Peterson & Greeley, pers. comm. 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 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 m north of the entrance of Taylor Cave (Figure 5). 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.

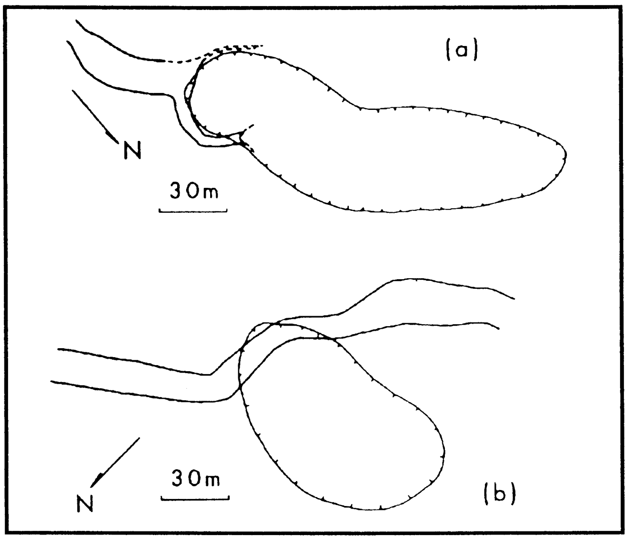


**Figure 5: Relationship between surface depressions and caves: (a) Taylor Cave; (b) Barkers Cave. (Atkinson et al., 1975)**

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 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 is interpreted as a location where some of the lava that ponded above the main tube drained back into it. A minor lavafall, approximately 1 m high, emerges from under the floor of the west terminal branch of the cave and is interpreted as another point of "drain back".

Figure 5 shows how Barkers Cave changes its course, deviating around a major depression 220m 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 m 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.

## Mode of formation of the Undara lava tube system

Lava channels and associated tube systems are the main distributors of the liquid rock during a pahoehoe lava eruption. The lava tube systems and caves associated with them form in a relatively short time. Earlier estimates of the time taken for their formation have to be modified in light of current tube activity on the island of Hawaii. Evidence of how the Undara 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 & MacDonald, 1953; Greeley, 1971b, 1972a, 1987; MacDonald & Abbott, 1972; Cruikshank & Wood, 1972; Peterson & Swanson, 1974; Peterson & 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 6).

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 6A). 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 by 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 6B). If the eruption ceases 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 lavacicles (Figure 6C) which are commonly vertical. Deflection of drips 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 Cave, Collins Road Cave and Barkers Cave.

Effusion rates fluctuate during an eruption but whenever a constant rate is maintained, near-horizontal ledges of lava solidify on the tube walls at lava level lines. Further diminution of the flow lowers the level in the tube and finally the flow congeals to form the floor (Figure 6D).

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.

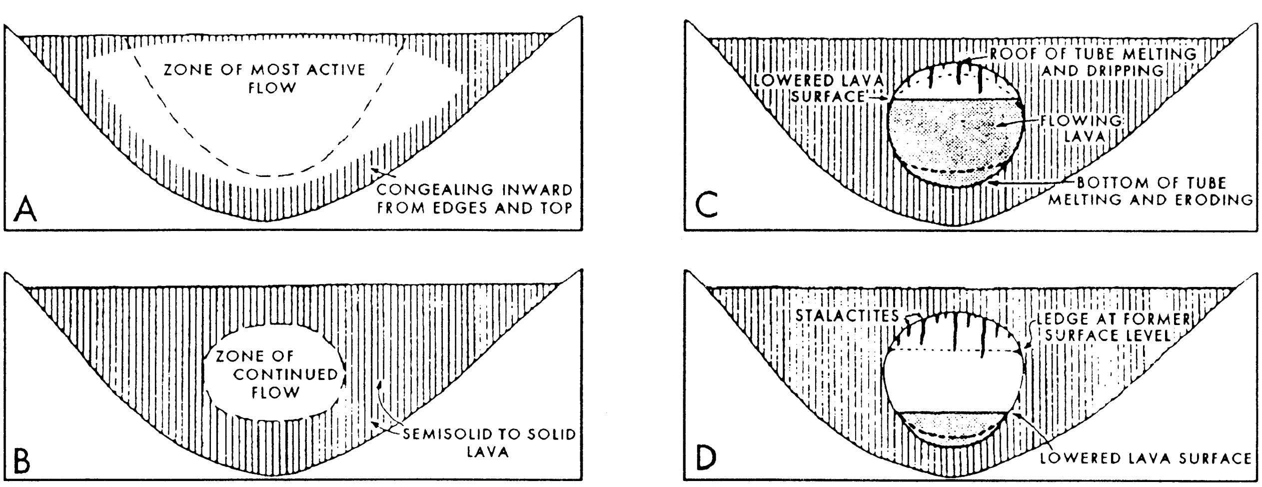


**Figure 6: Stages observed in the development of the lava tubes in Hawaii (after Macdonald & Abbott, 1972). Examination of evidence in the Undara Lava Tubes indicates that this explanation is directly applicable.**

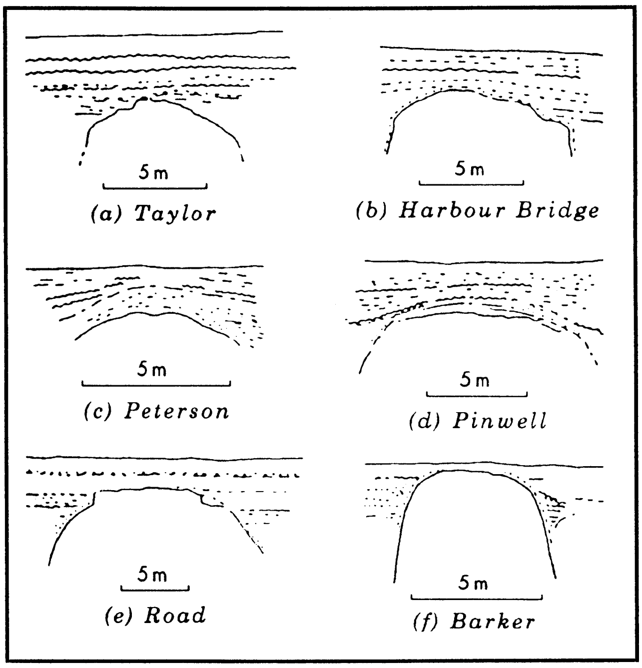


**Figure 7: Cave entrance structures showing thickening of roofs by successive surface flow units. Flow units are represented by wavy lines for recognised flow units surfaces. Other near-horizontal lines are major vesicle zones. (Diagram: P.J. Stephenson)**

Once the Undara lava tube system was formed in the major eruption, there was subsequent thickening of tube roofs by later flow units. Some of these flow units passed over ropy surfaces and now bear ropy 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 7 shows the thickness of various lava tube cave roofs.

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 flow there is such development in the Crater Section and in the proximity of the Wind Tunnel.

## Conclusion

Favourable 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 km 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.

## Acknowledgements

The author is indebted to many people for their help and assistance in the field and elsewhere; too many to name here. Special thanks are due to: Associate Professor Stephenson and Dr. Griffin for permission to use material from our joint paper. My husband, Vernon, and our family. Peter Stanton (Q.D.F. & H.), Associate Professor Stephenson, Professor Greeley (Arizona State University), Drs. Halliday (Tennessee), Peterson (U.S.G.S.) and Stevens (U.Q.), Julia James (S.U.) for their continued interest and enthusiasm. Mick Godwin (Q.D.F. & H., 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 1989. The advice and assistance of Susan White, Ken Grimes and Glenn Baddeley in the preparation of this abridged paper are gratefully acknowledged.

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