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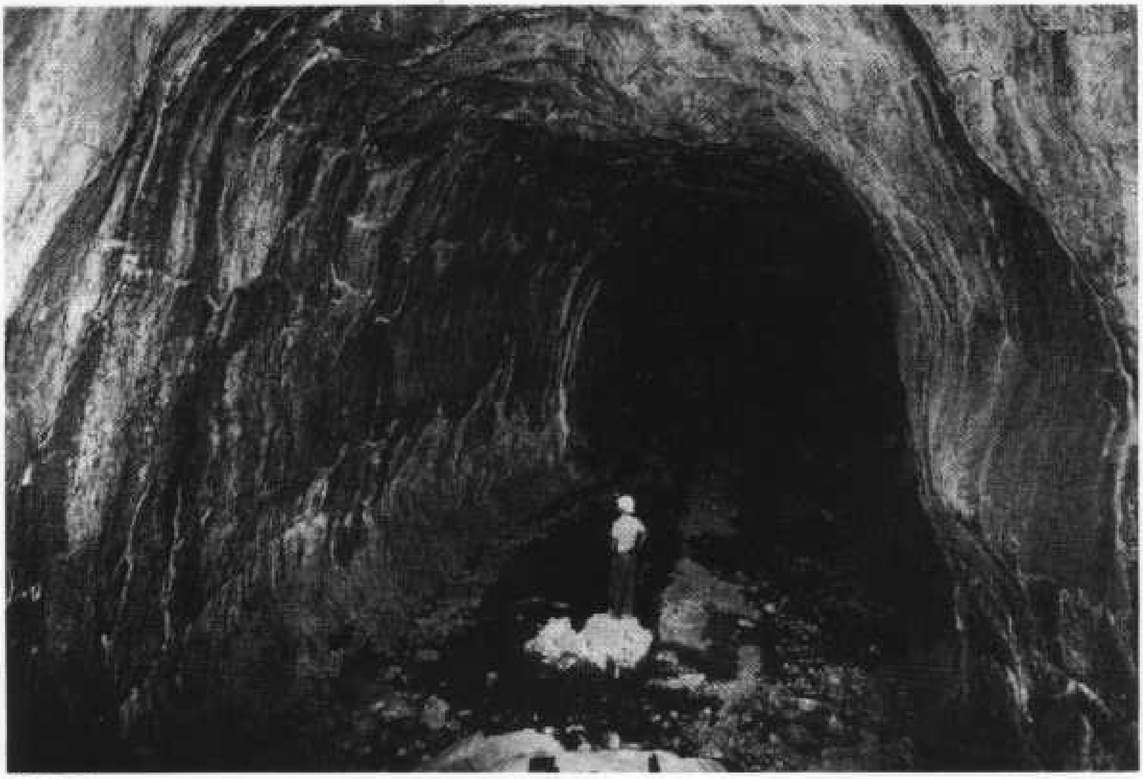

H. J. Lamont Barkers Cave, Undara

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PAPUA NEW GUINEA SPELEOLOGICAL EXPEDITION NSRE 1973. J.M. James 1974.
- the report of the 1973 Niugini Speleological Research Expedition to the Muller Range.

A BIBLIOGRAPHY OF THE JENOLAN CAVES. PART ONE: SPELEOLOGICAL LITERATURE.
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Cover Barkers Cave viewed from the entrance collapse. The original arched floor is exposed and has distinctive longitudinal "rope" structure. The distant cross-section is almost circular.
Photo: H.J.Lamont, J.C.U.N.Q.

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THE UNDARA LAVA TUBE SYSTEM AND ITS CAVES *

Anne Atkinson

This paper is dedicated to the memory of my dear son Tom who built the first stairs into Barkers Cave - and never lost interest in my studies of the Undara lava tube caves.

ABSTRACT

The cave system is located in flows from the Undara Volcano, McBride Basalt Province, North Queensland, Australia. An estimated volume of 23 km^3 of lava was erupted to form a lava field 1550 km^2. One of the flows extended over 160 km to become the longest single-volcano lava flow in the world. This great length is attributed to very high effusion rate, favourable topography and efficient distribution through a lava tube system. Temperature of eruption is estimated at approximately 1200°C, with no unusual viscosity.

The lava tube system has been studied for over 110 km. It is marked by caves, arches, depressions and a long level ridge known as the "Wall", which extends for 35 km. The Wall is the first Earth feature considered analogous to sinuous ridges on the Moon. Most of the known lava tube caves are found in the 40 km of the lava flow nearest to the crater.

More than 61 arches and caves have been discovered in the Undara lava tube cave system and over 6 km of cave passage has been surveyed. The longest lava tube cave is 1350 m. The widest passage measured in the caves is >21 m and the highest is >14 m. Some caves and the distinctive features within them are depicted and described.

The various depressions adjacent to, or aligned with the caves and arches have been examined and categorised according to their size. By studying the relationship of some surface collapses to adjacent lava tube caves, hypotheses have been put forward to explain their origins.

Despite the great age of the lava flow features that date from the formation of the lava tube caves have been preserved. By comparison of these features with those from active and recent lava tube systems around the world a mode of formation for the Undara lava system is proposed. It is concluded that the mode of formation of the Undara lava tube system is typical of tube systems that form in eruptions of highly fluid basaltic lava.

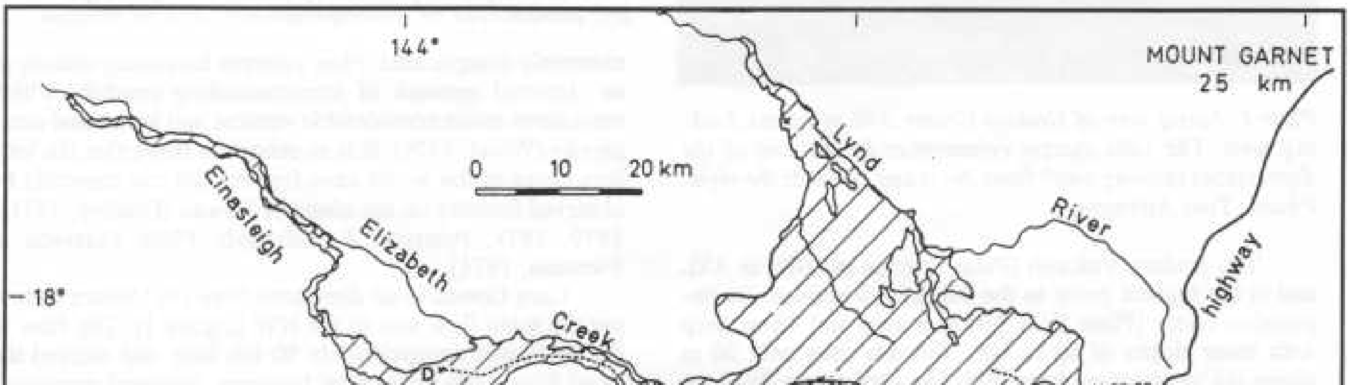


Figure 1: The main areas of Cainozoic basalt outcropping in northeastern Australia. Circled numbers denote sections of the lava tube system referred to in the text: 1, Crater Section; 2, North Section; 3, Yaramulla Section; 4, Wall Section. Other numbers are locations of cave entrances shown in Figure 3. The letters A - D show collection sites of basalt specimens for chemical analysis (Table 1).

* Abridged from Atkinson 1988a & b and updated.

INTRODUCTION

Location and Geological Setting

The Undara lava tube caves are found within the Undara lava flow (Figure 1), which is located approximately 200 km SW of Cairns in North Queensland, Australia.

Cainozoic volcanism in Eastern Australia extended more than 4000 km (Stephenson et al., 1980). In North Queensland, within 200 km of the east coast there are five major provinces. The Undara Volcano is situated near the centre of the McBride Province (Figure 1) which covers approximately 5000 km^2 (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.

Plate 1: Aerial view of Undara Crater, 340 m across, looking west. The tube system commences in the line of the depressions running away from the crater towards the right. Photo: Tom Atkinson.

The Undara Volcano (Plate 1) rises to 1020 m ASL and is the highest point in the McBride Province. Its impressive crater (Plate 1) 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 NW 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 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 & MacDougall, 1975). Only one volcano in McBride Province, Kinrara, is younger than the Undara Volcano (White,1962).

The Undara lava flow covers 1550 km^2 in the McBride Province and it is basaltic in composition. The results of various chemical analyses of the lava are shown in Table 1.

Most of the Undara lava field is pahoehoe* lava. Pahoehoe is regarded as the fundamental form of basaltic lava (Macdonald, 1967). The feeding rivers of pahoehoe can be

* *Polynesian term which means "having a satin-like appearance" (Dana, 1890) as seen on freshly erupted lava with low viscosity.*

TABLE 1: UNDARA LAVA TUBE SYSTEM MAJOR ELEMENT CHEMICAL ANALYSES

	SAMPLE			
	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
Fe_2O_3	2.52	11.0	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
P_2O_5	0.64	0.50	0.34	0.72
CO_2	0.13	n.d.	n.d.	n.d.
Total	**100.17**	**100.14**	**99.04**	**98.63**

See Figure 1 for sample localities.
B: Host rock, Barkers Cave entrance.
C: Cave lining, Barkers Cave entrance.

Analyses by;
A: T.J. Griffin using XRF; sodium by flame photometry; iron by titration.
B,C,D : P.J. Stephenson & T.J. Griffin using hydrofluoric-boric acid digestion followed by atomic absorption spectrometry; phosphorous by spectrophotometry; iron by titration

extremely complicated. Flow patterns frequently consist of an internal network of interconnecting conduits which sometimes attain considerable vertical and horizontal complexity (Wood, 1976). It is in pahoehoe flows that the long lava caves 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).

Lava flowed in all directions from the Undara Crater, but the main flow was to the NW (Figure 1). The flow to the north was approximately 90 km long and entered the Lynd River. The major flow however, followed precursors of Junction Creek Cassidy Creek and Einasleigh River for a total length of 160 km to become the longest single volcano lava flow in the world (Walker, pers. comm., 1989). Extrapolating the relationship presented in Walker, 1973, the average effusion rate of the Undara lava must have exceeded 1000 $m^3 s^{-1}$. Walker (pers. comm., 1974) concluded that to reach a length in excess of 160 km, the eruption was probably over in less than three weeks.

The Undara lavas were erupted at temperatures ranging from 1175°C to 1220°C (Roeder and Emslie, 1970, cited in Atkinson et al. 1975). They do not appear to have unusual viscosities (Shaw, 1972; Bottinga & 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 rates rather than unusually low viscosity. 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 m near the edges to up to 20 m or more in the thickest parts. Along the Wall, west of Mt. Surprise, the flow could be up to 40 m thick but this is restricted to the width of the Wall. Exploratory drilling on the north side of the Wall showed basalt depth of 25 m. If an average thickness of 15 m is estimated for the whole flow, the total volume of lava erupted from the Undara Volcano is approximately 23 km^3.

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 m is evident throughout the 90 km 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 a homogeneous flow.

The lava tube system from the Undara crater has been divided into the following five sections (Figure 1) in order to describe the locations of the caves and arches:-

Crater Section - extending north from Undara Crater for 4 km; average slope 1°.

North Section - continuing north from the Crater Section at least a further 18 km, possibly 28 km; average slope 0.5°.

Yaramulla Section - extending west from the Crater Section for over 35 km; average slope 0.7°.

Wall Section - approximately 35 km; 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 Section contains 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 Yaramulla Section contains most of the caves and arches. The Wall section is believed to contain a lava tube but to date no access to it 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. Twidale (1956), when discussing the distribution of volcanic centres in the McBride Province, noted two lineaments; he incorrectly interpreted the aligned collapses 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 (Plate 2) as a collapsed lava tunnel, 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 the absence of atmosphere, channels on the lunar surface (Atkinson 1988b, Fig 1) could not be explained as fluvial in origin. With the collection of basaltic specimens by the Apollo 15 Mission, there appeared a number of papers suggesting that the sinuous rills on the moon could be collapsed lava tubes (Kuiper, Strom & Le Poole, 1966; Oberbeck, Quaide & Greeley, 1969; Greeley, 1970 & 1971a; Cruikshank & Wood, 1972). These papers stimulated the study of lava tubes on earth. The length and shape of the Wall (Plate 3) of the Undara lava flow indicated that it was a potential terrestrial analogue to the sinuous ridges of the Moon (Greeley, pers. comm., 1972).

In 1972 the studies described in this paper were commenced. It was proposed:-

(1) To measure and map representative caves in order to establish any relationships between shape, size and distance from the source volcano. This was undertaken in two of the sections:
a) the Crater section;
b) the Yaramulla section;

(2) To seek evidence of the mode of formation of the Undara lava tube system.

(3) To investigate the geomorphology of"the Wall".

Plate 2: Wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara lava tube system, North Queensland, Air photo: Department of National Mapping Australia.

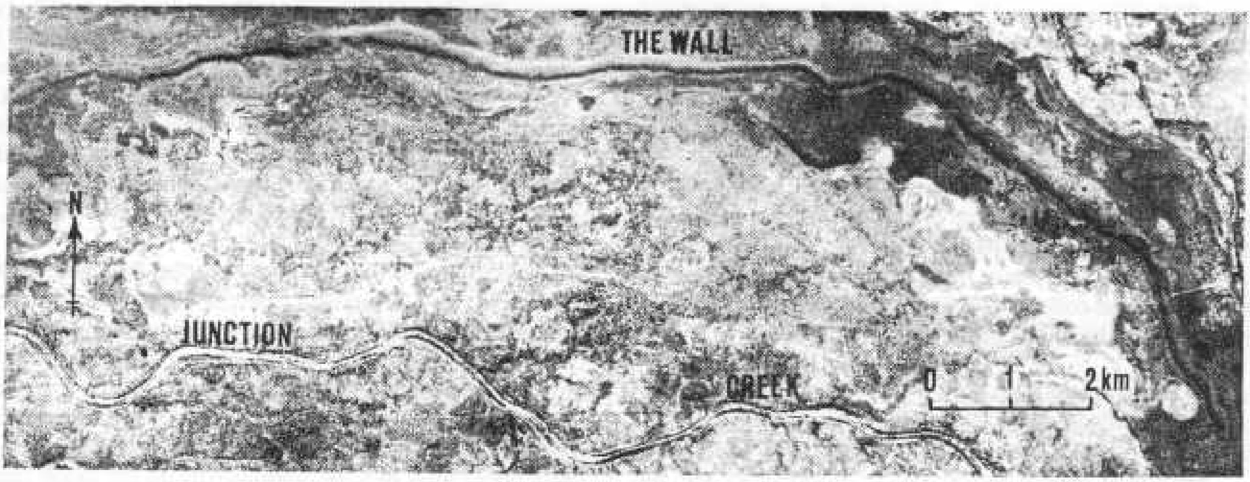


Plate 3: Air photograph of the western end of the Wall section of the Undara lava tube system. This low lava ridge is 35 km long and may be analogous to the sinuous ridges on the moon. Air photo: Department of National Mapping Australia.

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

The Chillagoe Caving Club has continued exploration of and scientific studies in the lava tube caves. In 1988, members D. Irvin and M. Godwin discovered and surveyed the Wind Tunnel and Inner Dome Cave. In 1988 and 1989 they, with other members, investigated areas within six kilometres west of the Crater and discovered ten caves. In addition, a number of Explorers Club expeditions, lead by Brother N. Sullivan, have examined the lava tube caves and researchers sponsored by the Explorers Club consider that the invertebrate community in Bayliss Cave makes it one of the world's most significant biological caves (Howarth, 1988).

In 1989, QNP&WLS officer M. Godwin and leader, B. Furniss, worked with 100 volunteers (in groups of 20) from London-based Operation Raleigh. They camped on site for three months to investigate and survey collapse depressions in the new Undara Crater National Park and in 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, Hot Hole and Wishing Well Caves, about 21 km north of the Crater. Unfortunately no arrangements had been made for them to work on the Yaramulla Holding, but their assistance in collection of specimens and data of flora and fauna led to valuable advances in records of the Undara lava field.

METHODS

The lava tube system can be clearly located on aerial photographs (Plate 2); it stands out as there are small pockets of rainforest in most of the collapse depressions which contrast 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 by the author and assistants between 1972 and 1974, and Operation Raleigh volunteers in 1989.

Initially the cave entrances were marked with a 10 cm 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 were left as surface markers to correspond with cave survey stations.

Caves and collapse depressions (Figures 2, 3 & 4) 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.

Cave heights were measured by a method recommended by R. Greeley: a narrow ribbon was marked and rolled on to a fishing reel and attached to a strong helium-filled balloon. Helium was found to be the best gas for this purpose; "balloon gas" was used on one trip and proved to be unsatisfactory.

The results of the surveys were presented as plans (Figure 2) and as a longitudinal profile through the source crater and representative caves (Figure 3).

CAVES AND ARCHES

The results of the cave exploration and mapping are shown in Table 2.

61 arches and caves have 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 19.8 m and height 13.5 m.

FEATURES OF THE CAVES AND ARCHES

Even though the Undara lava tube caves formed in a very short period 190,000 years ago, there are many features still remaining from that period. These features show minimal alteration due to their protection from weathering. In the places where surface streams have carried sediment into the caves, floors have been covered but sufficient features still remain for a clear picture to be drawn of the mode of formation of the Undara lava tube caves. 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 cm wide outline polygonal jointing.

TABLE 2: UNDARA LAVA TUBE SYSTEM - CAVE DIMENSIONS ##

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. Paul's	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
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	Wallaby's Hideway	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#	FS
U67	Upper Secret	150#			FS
U68	Lower Secret	70#			FS
	Total	6324.7			

* Australian Karst Index (Mathews, 1985)
** V and A Atkinson & 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 ## Revised and updated (Atkinson 1990)

The direction of passage development

Figure 2 shows the plans of a number of the caves. Most of the cave passages are elongate in the direction of the lava flow.

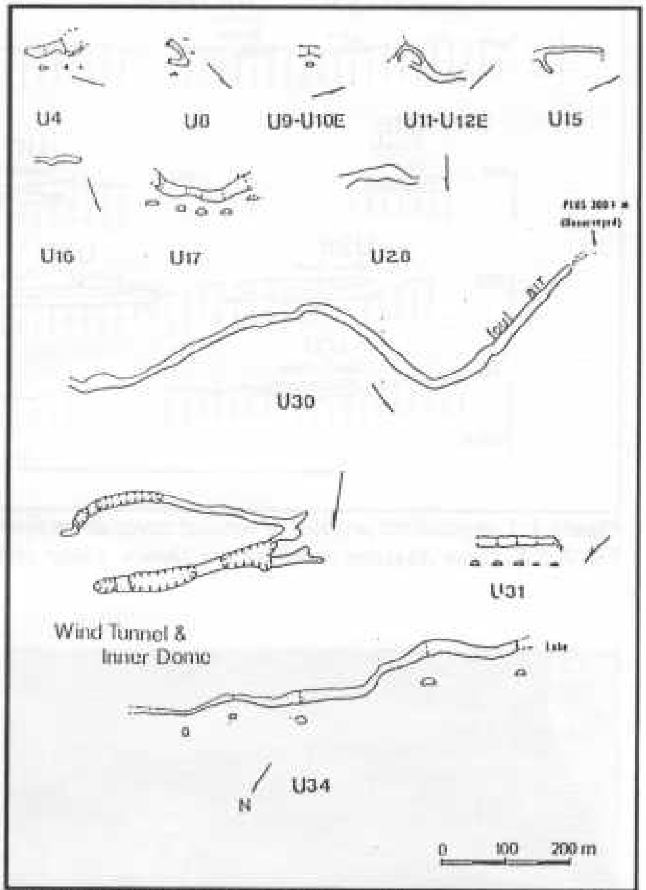


Figure 2: Maps of selected caves with some cross sections. In all cases, lava flowed through the cave passage from left to right. Localities - see Figure 1; cave names - see Figure 3. Cave U11-12E is Greeley Cave (Atkinson et al., 1975); The Wind Tunnel and Inner Dome plans are shown (Operation Raleigh & M Godwin, 1989). The 1987 extension of Bayliss Cave is not shown.

Lava tube cave and surface sections

Figure 3 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 but the development is on one level and is characteristic of the tendency of lava rivers to braid.

Lava tube cave floors

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

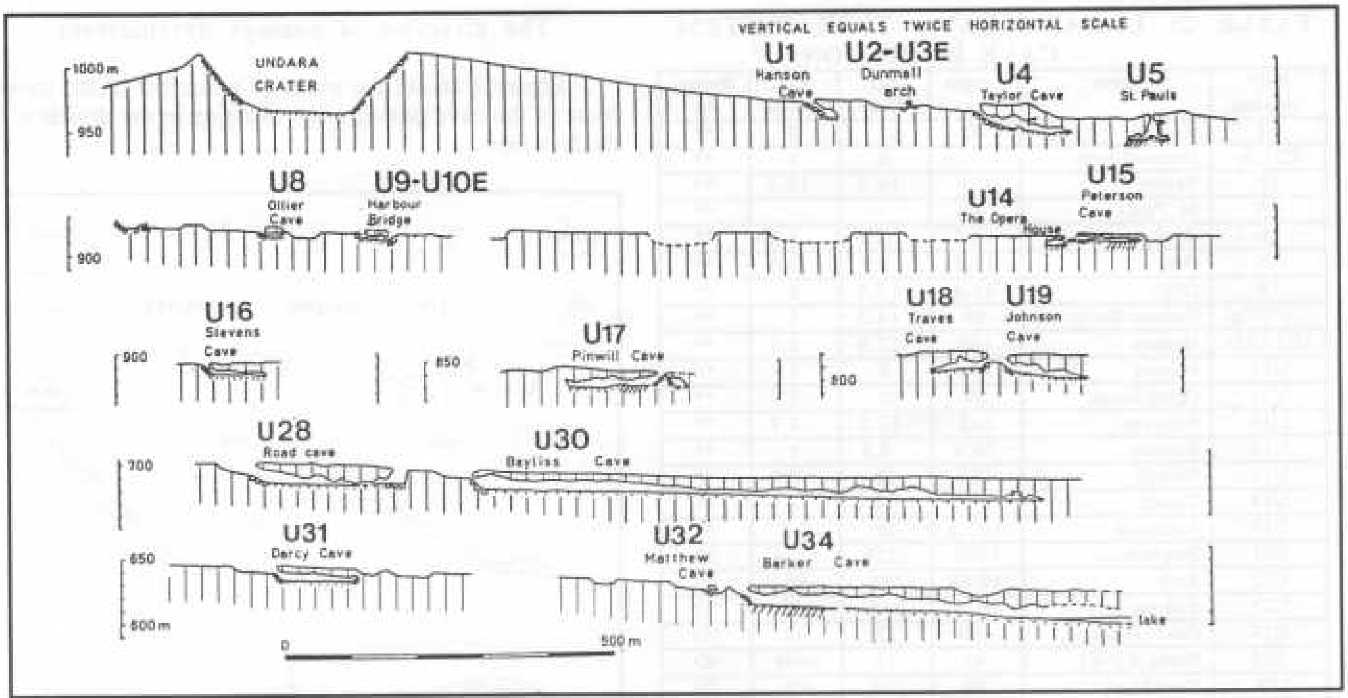


Figure 3: Longitudinal profiles of various caves down flow from Undara Crater.
The A.S.F. Cave Register numbers are shown. Floor symbols: sediment (.....), ropy lava (/////) (Atkinson et al., 1975).

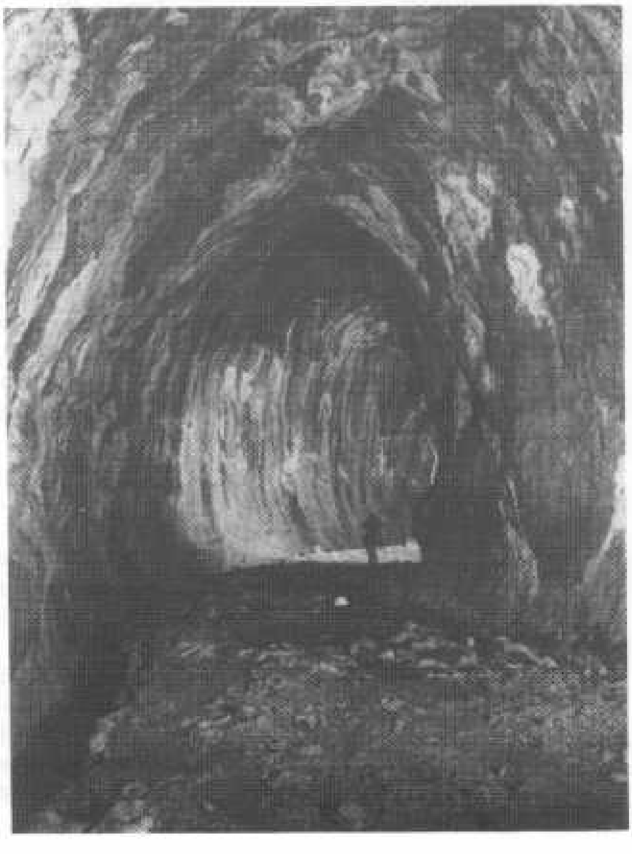


Plate 4: Barkers Cave, 50 m from its entrance. Note gutter on left and lava level lines evident almost to the roof on distant wall. The lava tube height is 13.5 m at this point - one of the highest in the System. Granite hills are in closer proximity here than at any other location along the tube system. A relationship is inferred between this and the height of the lava tube.Photo: H.J. Lamont, J.C.U.N.Q.

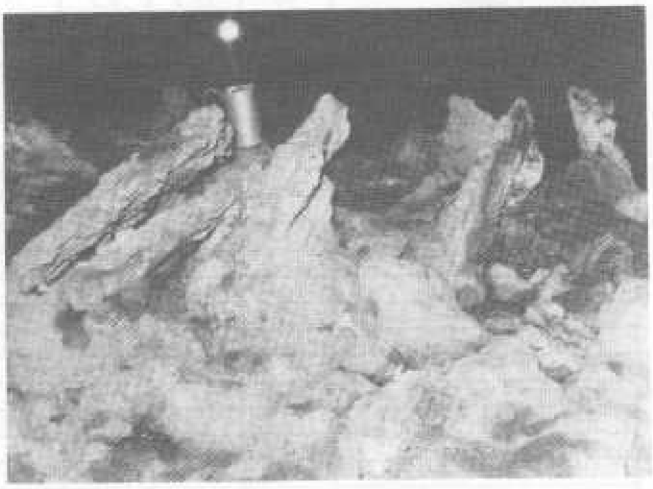


Plate 5: Rafted blocks of crust of the final flow have jammed at various angles. Location: Barkers Cave. Photo: V.G. Atkinson.

At the entrance to Barkers Cave (Front cover), the floor is arched, with a single rope structure running down-flow. Beyond this, the floor has distinct marginal gutters (Plate 4). 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 8 cm thick, have been rafted at varying oblique angles (Plate 5) 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 (Plate 6). Lava consolidates where rate of flow is less against a convex bank, similar to the deposition of alluvium on convex banks of rivers. Lava stalagmites are rare.

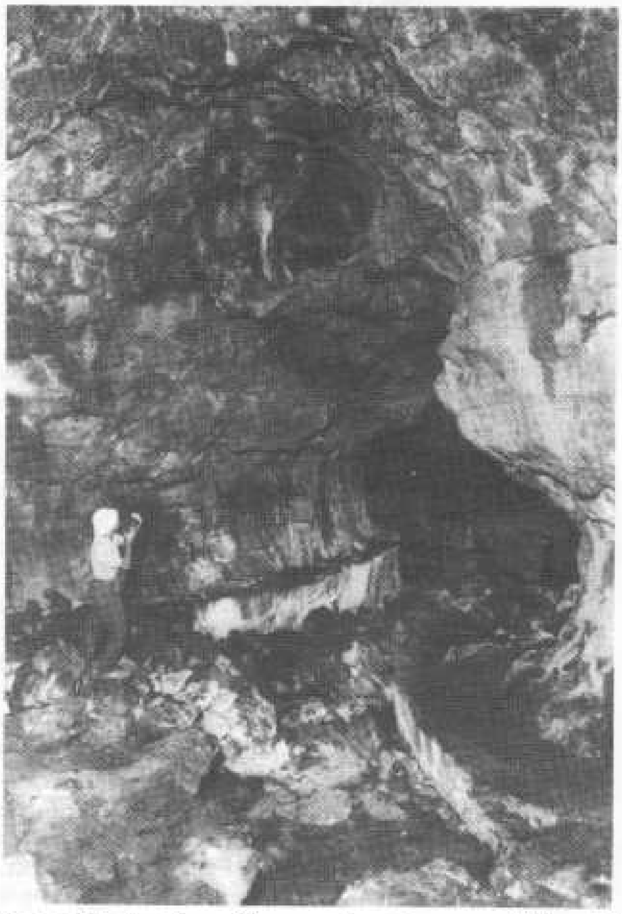


Plate 6: Taylor Cave. The prominent 'pavements' (1 and 2) are evidence of an extended period of constant rate of flow. Solidification has been greatest at the apex of convexity,as in a fluvial river. There is a cylindrical opening (3) in the roof above the figure. The location of this opening suggests 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. Lamont, J.C.U.N.Q.

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 (Plate 7). 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 (Plate 8). On most walls are areas of glazed melt surface with drip and dribble structures resembling cake icing (Plate 9). In places there are lavicicles (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 (Plate 10).

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 (Plate 11), Arch, Ewamin, Picnic I Picnic II and Barkers Caves (Plate 4).The lava level lines usually slope downtube at low angles, probably reflecting the original tube slope.

Plate 7: Multi-layered lining in Pinwill Cave. Up to fifteen layers are exposed at this location. Photo: V.G. Atkinson.

Plate 8: The Table - a thin sheet of lining near the entrance to Pinwill Cave showing a degree of plastic deformation. Photo: V.G. Atkinson.

Plate 9: Lava dribbles in Barkers Cave. Photo: H.J. Lamont, J.C.U.N.Q.

Plate 10: Lavicicles up to six cm long in Bayliss Cave. Photo: V.G. Atkinson.

Plate 11: Road Cave: Lava level lines extend from floor to roof of this cave. They are the most distinctive yet discovered in the system. Photo: H.J. Lamont, J.C.U.N.Q.

Termination of the lava tube caves

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 (Figure 3). Several caves have down flow entrances and have little or no silt on their floors. Pinwill Cave, The Opera House (Plate 12), Picnic and Wishing Well Caves terminate with walls.

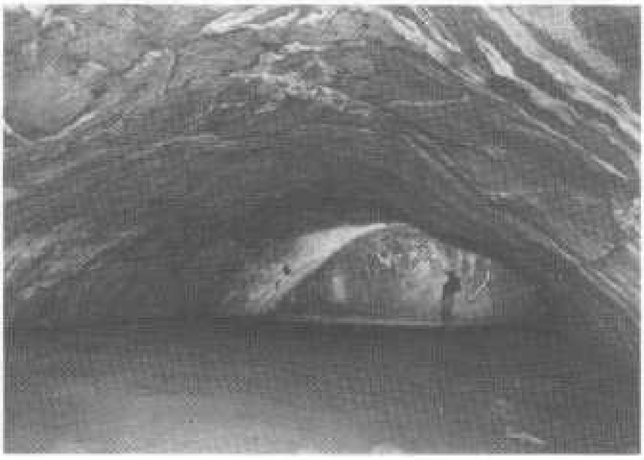


Plate 12: Termination of The Opera House (note wings). Entrance is down-flow. Photo: H.J. Lamont, J.C.U.N.Q.

Human use of the lava tube caves

There is little evidence that the Undara lava tube caves 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

The collapse depressions associated with the Undara Lava Tube System are divided into two types for convenience. These are narrow depressions 30 m to 50 m wide, and wide depressions 50 - 100 m wide.

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 (Plate 2). 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 erratic shapes may indicate that the flow traversed marshy ground.

Most wide depressions have elevated rims, suggesting that they represent former lava ponds. 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, Swanson 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.

Figure 4 (part a) shows a depression 60 m north of the entrance of Taylor Cave. This long deep 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.

The relation of the Taylor Cave passages to the depression suggests the collapse interfered with the still functioning tube. When the 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 (Plate 6) is interpreted as a location where some of the lava ponded above the main tube for a time, then drained back into it.

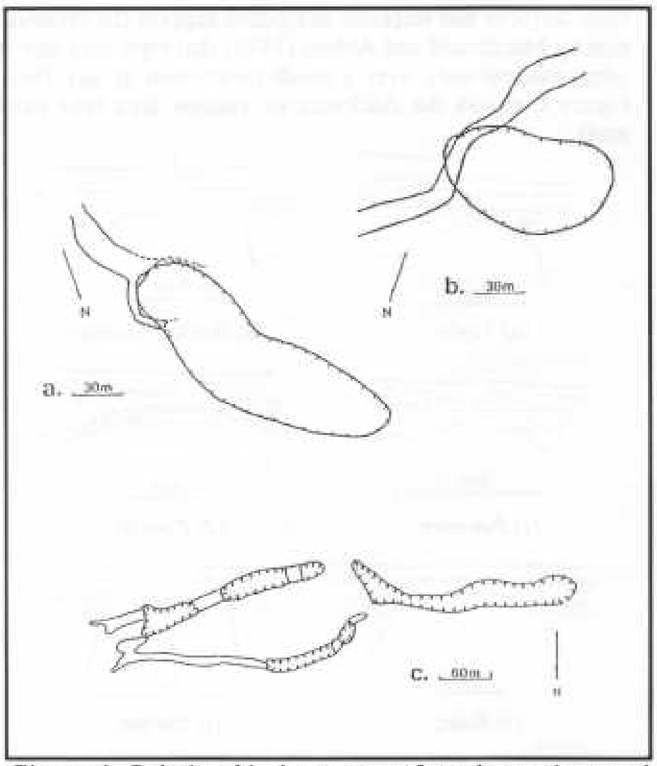


Figure 4: Relationship between surface depressions and caves: (a) Taylor Cave; (b) Barkers Cave (Atkinson et al., 1975); (c) The Wind Tunnel and Inner Dome.

Figure 4 (part b) shows how Barkers Cave changes its course, deviating around a major depression 220 m 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 indicates that the lava which had ponded in the depression drained back into a flowing tube, forcing it to alter its course.

The relationship between Wind Tunnel and Inner Dome and their associated depressions is represented in Figure 4 (part c). Entry to the 20 m long Wind Tunnel is achieved at the eastern side of the most easterly aligned depression. At the western end of the same depression there is the Inner Dome which branches in three directions; the northern branch opens into the same wide depression as the arch. No exit has been found to the northwest and southwest branches of the cave.

THE "WALL"

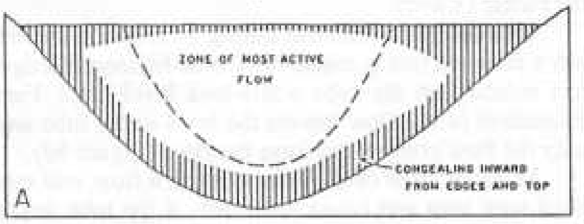
The Wall (Plate 3) consists of a very long narrow ridge that rises up to 20 m above the general level of the flow and can be traced for 35 km. The upper surface of the ridge is relatively flat and varies in width from 70 m to 300 m. Its down-flow slope averages only 1.72 m per km with occasional undulations. The side slopes of the ridge are up to 29°. There are several depressions within 2 km of the termination of the Wall. One of these depressions may represent a collapsed lava pond which drained to 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.

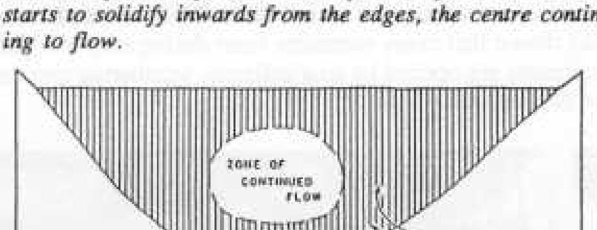
MODE OF FORMATION OF THE UNDARA LAVA TUBE SYSTEM

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 very short time; in the case of the Undara lava tube caves, probably in less than three weeks (Walker, pers. comm., 1974). 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 lavas 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 5).

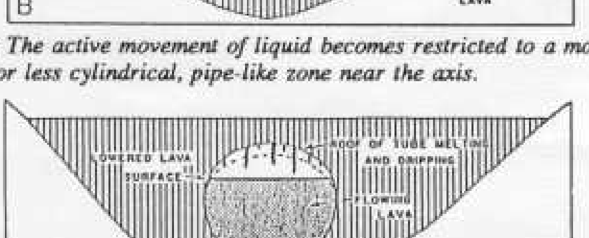
Figure 5: Illustrates stages observed in the development of the lava tubes in Hawaii (after Macdonald and Abbott, 1972). Examination of evidence in the Undara lava tube caves indicates that this explanation is directly applicable.



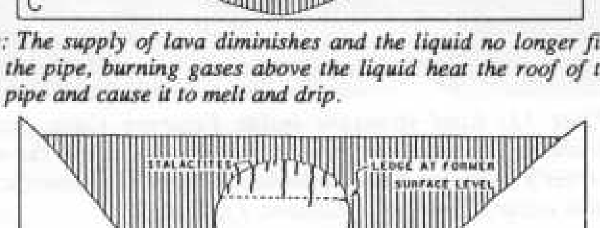
a: The lava flow, confined in a valley, develops a thin crust and starts to solidify inwards from the edges, the centre continuing to flow.



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 diminution of the supply lowers the level of the surface of the liquid which eventually congeals to form the floor of the tube.

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 5a). 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 tube caves 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 5b). 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 lavicicles (Figure 5c) 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 Barkers and Picnic I 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 5d).

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. A cave can only be entered if it has an entrance. 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.

Plate 13: 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. Lamont, J.C.U.N.Q.

Once the Undara lava tube system was formed in the major eruption, there was subsequent thickening of the ceilings by later flow units (Plate 13 and Figure 6). 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 6 shows the thickness of various lava tube cave roofs.

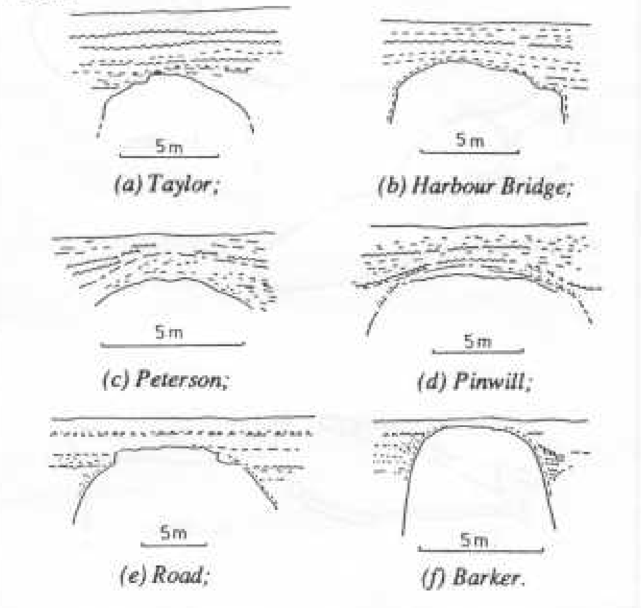


Figure 6: Cave entrance structures showing thickening of roofs by successive surface flow units. Flow units are indicated by wavy lines for recognised flow unit surfaces. Other near-horizontal lines are major vesicle zones. Diagram: P.J. Stephenson.

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.

In the Yaramulla section, where the lava has been confined in a narrow valley between granite hills, the largest passages have developed. In addition, many of these passages have not been too deeply covered in the proximity of their entrances by the later minor flows. This may be why the majority of the cave entrances are in this section.

Beyond the Yaramulla section, the continuation of the lava tube system is the Wall. Two possible mechanisms for its formation allowing it to rise 20 m above the its parent lava flow are presented in Atkinson, 1988b. Both explanations require the Wall to have been a major lava tube. As it is in a narrow section of the lava flow, it is likely to have been large and delivered sufficient lava to flow a further 70 km beyond its termination. The nearly level course of the Wall would have made it difficult for the lava to drain from it and thus for most of its length the final flow probably solidified in it. An elevated filled lava tube would survive weathering processes better than an elevated lava tube cave. It should be possible to establish the origin of this unusual structure by geophysical investigation or drilling on the centre of the ridge.

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 tube 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 lava tube system and the caves in it formed in a manner similar to those that have been observed forming during eruptions of pahoehoe lava.

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THE CHANGED ROUTE OF THE GRAND ARCH STREAM, JENOLAN - MORE EVIDENCE

Trevor Shaw

Plate 1 - The bed of Camp Creek in 1894, opposite the old entrance to Imperial Cave in the Grand Arch

Ernst Holland (1988) postulated the Camp Creek used at one time not to flow right through the Grand Arch but to sink in Flitch of Bacon Cave and pursue a hidden course until reappearing near what is now the Blue Lake. This is confirmed by the 19th century literature which, in conjunction with contemporary drawings and photographs, gives some indication when the change to the present course was taking place.

The key statement is that of Wilkinson (1879) which appeared in the appendix he wrote for the first edition of The Railway Guide of New South Wales:

> *After heavy rains the water of the Camp Creek flows through the Grand Archway, but at other times it disappears from the creek bed just above the upper entrance, passes through some unknown channel, and comes out again in the bed of the creek a few yards below the lower or north-eastern entrance.*

This appendix was in fact an official report written by Wilkinson in his capacity as the Geological Surveyor in Charge of the New South Wales Geological Survey (Wilkinson, 1880).

The statement about the course of Camp Creek was reprinted in later editions of The Railway Guide of New South Wales, up to 1886, and also in the text accompanying the album of photographic prints referred to later (Wilkinson, 1887), but this is no evidence that the stream was necessarily continuing to behave in the same way at these later dates.

Nevertheless when Samuel Cook wrote the articles published in the Sydney Morning Herald in 1886 and subsequently reprinted in book form (Cook, 1889), he mentioned the emerging of the underground water (pp. 29-30):

About 50 yards down this dry creek (from the Grand Arch), and about 20 yards below the junction of the roads from the Grand Archway and the Devil's Coach-house, is the "Rising of the Water". Here among the rocks in the bed of the creek the water bursts out of the ground like a sparkling fountain of considerable volume............

Myers (1886, p. 152), too, implies that the creek rises outside the eastern end of the Grand Arch, referring to 'the trees.......and varied fern growth about the edge of the rapidly-flowing water; for the creek springs to light again here from its hidden currents in the caves'. The engraving on p. 149, however, shows water inside the entrance, perhaps from flood, so Myers' evidence is not conclusive. A photograph in the possession of Elery Hamilton-Smith (pers. comm.) which appears to be the source of this engraving shows no water, and it may be that this was an addition by the engraver.

On the other hand, by the 1890s the stream flowing through the Grand Arch was regarded as normal rather than just an occurrence after heavy rains.

Foster (1890, pp. 13-14) wrote:

There is a stream of water, called "Camp Creek", flowing through this arch from one end to the other, which has twice to be crossed on planks; it is railed in by a wire rope, which serves to guide the footsteps where the light is imperfect.

Foster's plan of the caves, printed in 1889 and included in this book, shows the course of Camp Creek running continuously form the 'Accommodation Houses', through The Grand Arch to the junction with McEwan's Creek. Although the plan in the guidebooks of Trickett (1899 and later editions) show Camp Creek apparently rising halfway through the Grand Arch, this is no more than its reappearance after flowing in a culvert beneath the road constructed in 1896.

The French traveller, Albert Tissandier, visited Jenolan Caves in 1894 and also referred to Camp Creek as flowing through the Grand Arch (Tissandier, 1895). Furthermore, two of the drawings he made there show the creek flowing in its bed opposite the old entrance to Imperial Cave, a little in front of the view shown in Holland's Plate 1. Opposite the wooden steps leading up to the Imperial Cave, the stream was crossed by a four plank bridge with no handrails (Plate 1). The originals of both these drawings are in the Mitchell Library in Sydney (Tissandier, 1894) and one of them is reproduced in his 1895 article.

An undated photograph by Charles Kerry (Plate 2), taken from almost the same spot as one of Tissandier's drawings, shows the stream crossed by only a single plank and so is likely to be earlier. Kerry is recorded (Davies & Stanbury, 1985, p. 186) as a professional photographer from 1883. The negative number (717) may enable someone to date the picture more closely, though Hamilton-Smith (pers. comm.) points out that Kerry's photographs were not numbered consecutively.

Thus, the change in the course of Camp Creek from fully underground to its present channel in the Grand Arch must have occurred between 1879 and 1894, and probably before Foster's plan of 1889. Descriptive and pictorial cave records cannot, at present, assign a more precise date to the event, and it is necessary to look for some other occurrence during the period which could have caused it.

The change in stream course is most likely to have been sudden, for it would have resulted from the rapid blocking of the lower route rather than the slow creation of a new upper one. Such blocking is commonly caused by flood debris which, having once dammed the flow, is then consolidated and compacted by more and increasingly fine material. Dr Guy Cox has drawn my attention to the New South Wales rainfall records for these years (Commonwealth Bureau of Meteorology. 1948, pp. 165, 166). At Mount Victoria very heavy rainfall was recorded in May 1889 (16.19 inches), February 1890 (15.06 inches) and March 1890 (21.34 inches) , compared with the highest average for any month of the year over 72 years of 3.96 inches, and a previous maximum (in February 1880) of 12.08 inches. Regular recording at Oberon did not begin until 1889, but the figures for the same three months are high there also (7.36, 5.34 and 10.29 inches respectively, compared with a highest monthly average over 56 years of 3.41. Rainfall records at Jenolan itself did not start until 1896. Bearing in mind that it is the first heavy flood of a series that finds the greatest amount of debris to carry, and also the fact that Foster's plan of 1889 shows Camp Creek running through the Grand Arch, it is most probable that the Creek's previous sink became blocked in May 1889. The even greater rainfall of the following year would have further scoured out the present channel in the Grand Arch.

The photographs reproduced by Holland are later than the 1870s. Imperial Cave was not discovered until 1878 (Havard, 1934, p. 36) and was opened to the public probably in 1880 (Dunlop, 1950), so Plate 1 cannot be earlier than that. Both photographs were published in the form of actual prints in the very large album of photographs issued with a title page and one page of text by Wilkinson (1887). A copy is in the Mitchell Library. Although the date of these two photographs is not stated , others in the book can be shown to have been taken in 1887, after installation of electric lighting and the dynamo. Again, although the photographer is not specifically identified for these pictures, many of the others were by A.E.Dyer, who was employed as a photographer by the Department of Public Works form 1884 (Davies & Stanbury, 1985, p. 156). Holland's Plates 1 and 2 therefore date almost certainly from 1887 or a little earlier. This does not prejudice his conclusion that the original course of the stream was not through the Grand Arch, for that is now supported independently.

Holland, however, believed that the earlier route of Camp Creek persisted until 'the placing of the road and the cutting of the drainage channel for Camp Creek'. This took place in 1896 but the evidence given here shows that the stream was already flowing through the Grand Arch at least two and probably seven years before then.

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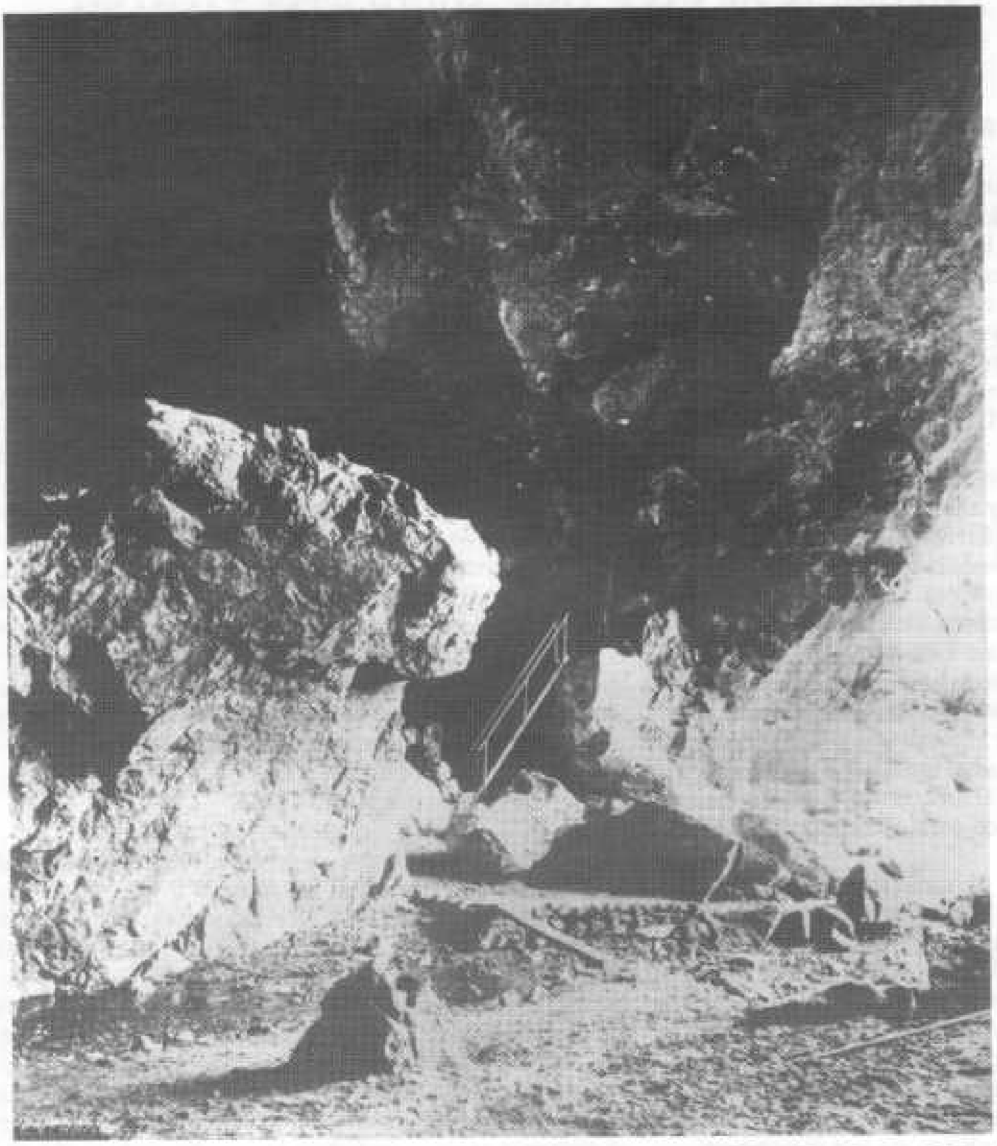

Plate 2 - The bed of Camp Creek in the Grand Arch, probably in the late 1880s.

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BATHYMETRY AND ORIGIN OF LAKE TIMK, SOUTH-WEST TASMANIA.

Kevin Kiernan

ABSTRACT

The bathymetry of Lake Timk suggests that it is a glacially over-deepened rock basin but one which owes much of its form to preglacial karst processes. Underground drainage from the lake forms part of an integrated karst conduit system. The lake bed does not provide the base level of vadose circulation in the karst at the present time as at least one negotiable cave extends under the lake.

INTRODUCTION

The evolution of most of Tasmania's karst areas has been influenced by Quaternary climatic change, and several karsts have been glaciated (Kiernan, 1982, 1983, 1984, 1989a). As many as six glaciations may have occurred in some areas where karst is present, the oldest being no younger than early Pleistocene and the most recent having occurred during the late Last Glacial Stage (Kiernan, 1989b). Glaciated karst is rare in southern temperate latitudes. Rapid tectonic uplift and extensive glaciation by geomorphologically very active glaciers has meant that little glaciated alpine karst of pre Last Glacial age escaped effective erasure during the Last Glaciation in New Zealand. Little if any karst occurs at comparable latitudes in South America.

In Tasmania glacigenic deposits that are of at least early Pleistocene and possibly Tertiary age have survived in some karsts that lay just outside the ice limits attained during later glaciations. Old glacial sediments also occur where sediments have survived later glacial erosion through having been deposited in fossil caves or in karren crevices. These Tasmanian glaciated karsts are significant as they probably include the only southern temperate karsts where ample opportunity exists to study the impact on karst evolution of multiple glaciations prior to the late Pleistocene.

Convergent evolution can complicate the interpretation of landforms in glaciated karst. For example, closed depressions may be the product of karst processes, of over-deepening by glacial erosion, of enclosure during the construction of glacial moraines, of subsidence following the post-depositional melting of blocks of ice incorporated within glacigenic sediments, or of suffosion. Depressions of glacial origin may focus subsequent infiltration and promote karst development in the underlying bedrock, a situation that may have occurred in the Farmhouse Creek area in southern Tasmania (Kiernan, 1989b). Preglacial topography may also influence glacial action in such a manner as to emphasise pre-existing karst landforms. For example, Peterson (1966) has proposed that some of the glacial lakes at Frenchmans Cap may have formed at the site of earlier karst depressions. However, a major difficulty is often encountered in answering the "chicken or egg" question as to whether karstification or glaciation came first, and the relative contributions to present morphology of glacial and karstic processes can be difficult to decipher.

LAKE TIMK

Lake Timk occupies an enclosed depression east of the 1423 m high summit of Mt Anne in a small but heavily glaciated massif at 146°25' E longitude and 42°25' S latitude in south-west Tasmania (Figure 1). It is a small lake ≈800 m long and ≈200 m wide (Plate 1). Much of the Lake Timk depression is formed in dolomite and is drained by karst channels on the margin of the lake and in its bed. The karst is formed in carbonate rocks of the upper Precambrian Weld River Group (Calver 1989). These rocks attain a topographic relief of ≈600 m and contain a number of deep cave systems, including Anne-a-Kananda (- 373 m).

Plate 1. View northwards to Lake Timk from the summit of Lots Wife. The location of the negotiable inflow cave is arrowed.

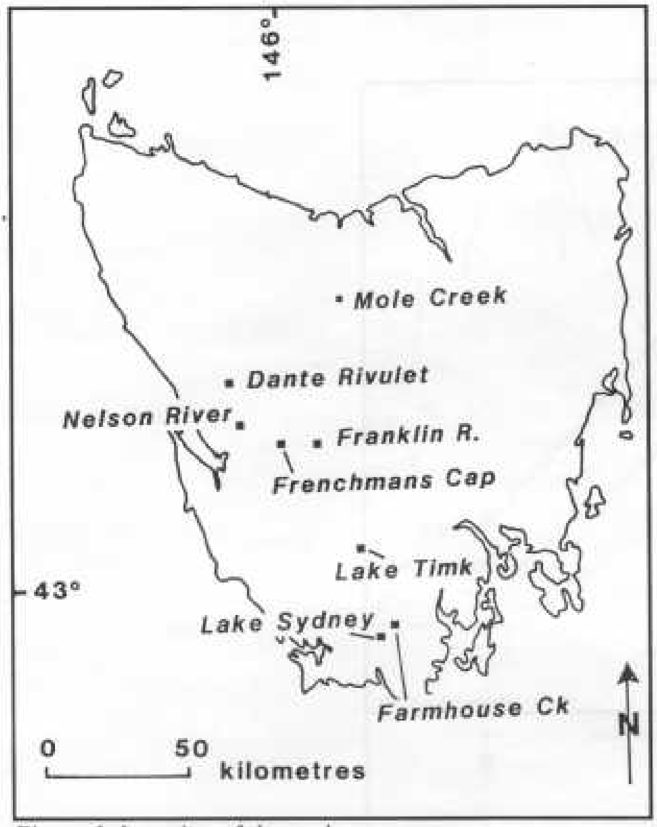

Figure 1. Location of the study area.

The most striking karst has formed in the Gomorrah Dolomite, an 800 m thick unit of massive fine-grained dolomite, and in the predominantly bedded Devils Eye Dolomite that overlies it. These rocks are moderately to steeply dipping and strike from NW-SE. Little karst appears to have formed in the late Precambrian fine-grained dolomite and limestone of the preceding Pandani Group that crops out nearby. Lake Timk was originally presumed by Lewis (1924) to be impounded by a moraine but the more recent discovery of underground outlets (Collin, 1970) raised the question as to the extent to which karst processes were involved in its formation. However, Goede (1972) argued that it was probably the result of glacial over-deepening rather than solution.

The glaciers that flowed down the Timk Valley rose from a compound cirque 2.2 km wide. Bedrock benches formed on Permo-Triassic sedimentary rocks occur near the valley head, and another bench formed on Precambrian slate and dolomite occurs at ≈760 m altitude. A broad basin occurs at ≈550 m and there are two large enclosed depressions further downstream, the easternmost of which contains Lake Timk and the westernmost being forested. Both are bounded by moraines at their downstream end. Evidence for at least two and probably four Pleistocene glaciations has been recorded from the Mt Anne massif. At its maximum confirmed extent the Timk Glacier reached ≈9 km downvalley and was ≈400 m thick during a glaciation of middle Pleistocene age. However, the earliest glaciation that occurred in the Mt Anne massif was probably much more extensive than this. The site of Lake Timk was over-ridden during all but the Last Glaciation. At this latter time only a very small glacier developed at the head of the Timk Valley and the basin at ≈550 m formed a sink for much of the proglacial sediment that otherwise might have filled the Lake Timk depression (Kiernan, in press).

Although Lake Timk now has no surface outlet the lake was previously drained via a meltwater channel ≈15 m above present lake level. Several watersinks have formed in the dolomite around the lake margin and in its bed. No water tracing has been conducted, but the underground drainage is presumed to follow the strike of the dolomite beds southeastwards. It probably emerges from a large spring (spring 1 on Figure 2) ≈2.4 km distant on the opposite side of a major drainage divide formed by the Lots Wife ridge that bounds the southern side of the Timk Valley. Drainage from some other localities in the Mt Anne karst may also contribute to the discharge from this spring. Along the southern shore of Lake Timk a fault raises to the surface pebbly dolomitic mudstone and siltstone together with conglomerate and lithic sandstone (Calver, 1989). It is probable that drainage from much of the northeast ridge of Mt Anne also follows the strike of the dolomite southeastwards until it is intercepted by this fault. The water may simply rise into Lake Timk but may flow through a conduit system beneath the lake. If this is the case the linear distance between the presumed resurgence of the Lake Timk water and its most distant sources may be ≈4.8 km. This possibility is given added credence by the fact that one of the water inflow points around Lake Timk gives access to a narrow cave that extends under the lake bed (Plate 2). This has been explored to a depth of ≈20 m below the lake surface, which clearly does not represent the base level of vadose circulation in this part of the Timk Valley (Kiernan, in press b). The presence of a very strong draught suggests that considerable cave passage exists. Despite the immaturity of the inflow cave at Lake Timk the possibility exists that it may connect with an older and better developed conduit system. The water that sinks in the large enclosed depression downstream of Lake Timk is presumed to rise from a smaller spring, spring 2, ≈500 m NE of spring 1 (Figure 2). However, it is possible that spring 2 represents part of the discharge from Lake Timk or even some other system entirely.

The history of the Timk depression has some bearing on the likelihood of a significant integrated cave system existing in the vicinity of Lake Timk. In theory, the bathymetry of the lake might provide some evidence of its principal mode of origin, because different modes of lake basin development may produce different basin morphologies. For instance, if a basin is predominantly the product of glacial over-deepening its deepest parts are likely to lie towards any rock step at its head (in this case the western end of the lake) and on the outside of any bend in the valley (in this case the southern side). Alternatively, if a lake has been formed predominantly by moraine deposition that has dammed a stream its greatest depths may lie towards the downstream end. If a lake is of karst origin the sublacustrine contours may be more symmetrical, or the deepest points may be elongate along structural lineaments such as the strike of the carbonate rocks, or formed at lithological contacts (such as the fault in this case). However, subsequent sedimentation may prevent interpretations of this sort. In an effort to ascertain whether the original form of the Lake Timk basin might still be discernible and shed some light on its origin, a reconnaissance bathymetric sketch was compiled over three days in February 1989. Soundings were made from a floating air mattress using a weighted 30 m fibreglass tape. Sounding positions were estimated and sketched with respect to local features and occasional bearings were taken to prominent landmarks. Later

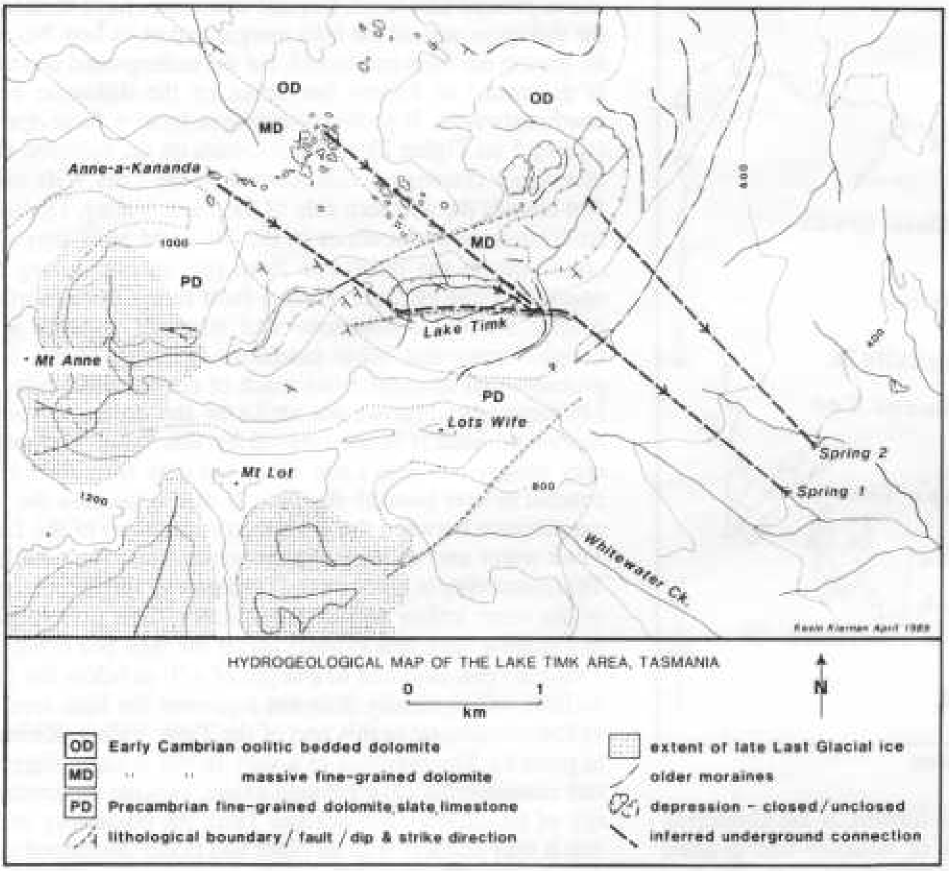

Figure 2. Hydrogeological interpretation of the Lake Timk area.

cross checking was undertaken using coloured air photographs.

The soundings revealed a maximim lake depth of 25 m below the threshold of the inflow cave (Figure 3). Hence, the floor of Lake Timk lies at ≈465 m altitude or some 15 m higher than the even larger "dry" depression further down-valley. The shallow downstream end of Lake Timk suggests that impounding by moraine construction was not responsible for formation of the lake. This is consistent with the presence of a rock bar which may or may not be continuous beneath the moraine at the eastern end of the lake. The morphology of the lake bed is reasonably consistent with its being a rock basin. However, the deepest part of Lake Timk appears to be centrally located rather than being situated at the upstream end where ice descending from the rock step above the western shoreline might have been expected to have most effectively over-deepened the valley. While sedimentation has undoubtedly modified the lake-bed contours at the upstream end, the fact that the deepest part of the lake is not located towards the outside of the slight bend in the valley and close to the lithological boundary also seems unusual if this were solely a glacially over-deepened basin (cf. Derbyshire, 1971). This is despite the fact that the principal sources of postglacial sediment are streams that enter from the western and northern sides of the lake. Depending upon the extent to which sedimentation has confounded the picture, the form of the lake bed seems consistent with a basin of predominantly solutional origin that has been modified by glacial erosion and slightly deepened by the construction of a moraine barrier across its downstream end.

DISCUSSION

The potential impacts of glaciation on karst are variable (Ford, 1979). Glaciers may destroy or derange features by erasure of residuals, may dissect cave systems, may fill sinkholes with sediment or may inject detritus into caves. They may inhibit postglacial solution through mantling of the bedrock by carbonate-rich drift, may preserve karst by sealing and confining epikarstic aquifers with clay-rich sediment, or may stimulate karst development by focussing water inputs and raising the hydraulic head or by lowering spring elevations by glacial entrenchment. The possibility also exists of deep injection of meltwaters during glacigenic flexure of the bedrock (Ford and Williams, 1989). Examples of some of these effects in Tasmania were cited by Kiernan (1982).

Lake Timk was occupied by ice during all but the Last Glaciation and the surface meltwater channel that extends downstream from the lake was probably active up until the Holocene (Kiernan, in press). Taking this into account, and also the fact that the watersinks around the lake margin are immature, the very large size of the spring where the lake waters are presumed to resurge warrants comment. The development of a such a major integrated underground conduit system in the dolomite since the Last Glaciation seems less likely than the existence of at least some components of this drainage system since some considerable time earlier. The situation in this area may warrant comparison with that at Lake Sydney 40 km southeast of Lake Timk, where preglacial karst formed in Devonian limestone was inundated by glacigenic sediment

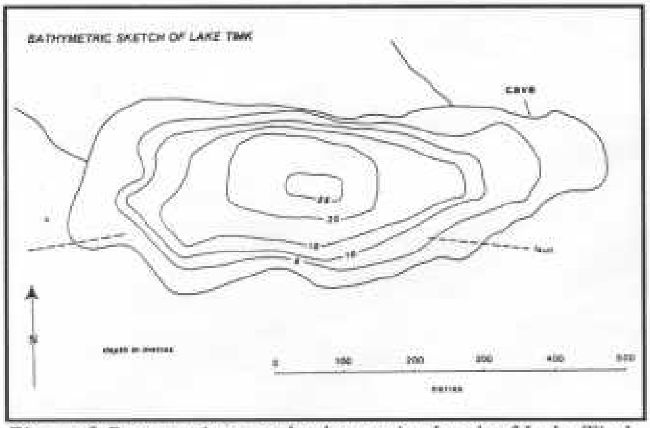

Figure 3 Reconnaissance bathymetric sketch of Lake Timk. The isobaths are approximate only.

during the Last Glaciation and earlier underground conduits may now be undergoing re-excavation following the development of some relatively immature new streamsinks (Kiernan, 1989b).

The cirques, aretes and glacial troughs around the Mt Anne massif attest to intense glacial erosion. It is likely that the most intense erosion occurred during the earliest glaciations. Some karst features were already in existence at this time (Kiernan, in press). Despite the prodigious erosion evident in some glaciated areas, glacial erosion can be highly selective and in some cases have remarkably little impact. Most sinkholes are too deep to be erased during a single glaciation and in many cases even the base of deep grikes can survive a single glaciation and subsequently guide renewed karst activity (Rose and Vincent, 1986; Ford and Williams, 1989). The survival of karren has been reported from the Dante Rivulet in western Tasmania (Kiernan, 1982). In addition, allogenic meltwater may accumulate and facilitate the development of high subglacial water pressures in enclosed depressions (Lauritzen, 1984) where there are no pre-existing karstic outlets (Ford and Williams, 1989) or where any outlets have been sealed by clay or other sediment. This is likely to minimise the degree of thalweg abrasion by ice that occurs. This seems a likely scenario for Lake Timk. Hence, the evidence from this karst area is consistent with the view of Ford and Williams (1989) that most big depressions in glaciated karsts are polygenetic and multiphase features that are the result of many successive karst and glacial episodes.

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Plate 3 Entrance to the inflow cave at Lake Timk. This small entrance is only negotiable when the lake level is low and the cave temporarily becomes very narrow a short distance inside.

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