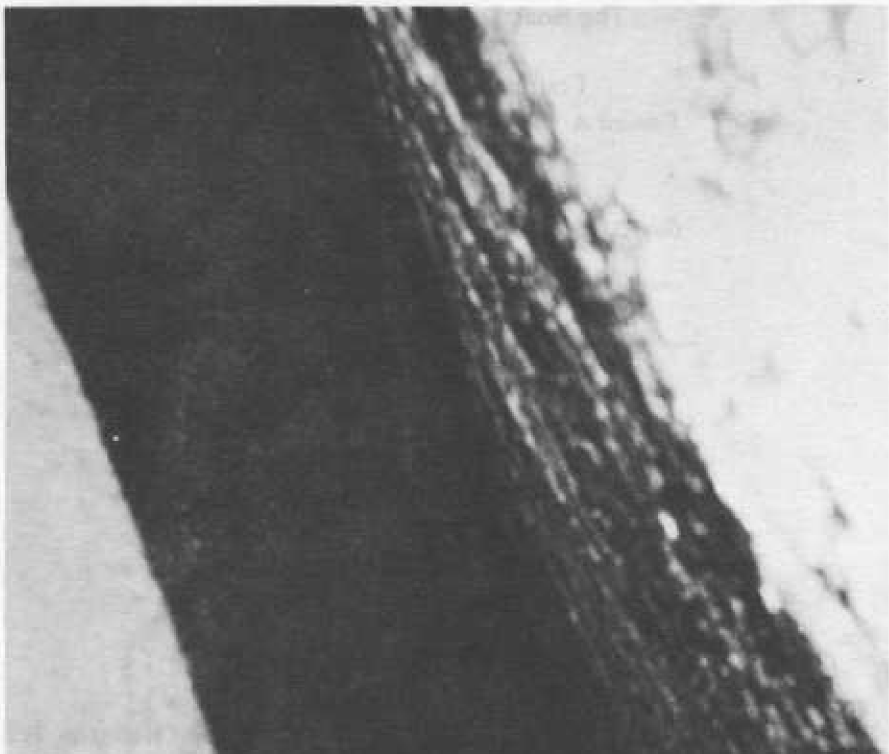
Volume 19(1) 1981

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



Labertouche Cave, Victoria
Photograph by Brian Finlayson

HELICTITE

Helictite was founded by Edward A. Lane and Aola M. Richards in 1962.

This Journal was (and is) intended to be wide ranging in scope from the scientific study of caves and their contents, to the history of caves and cave areas and the technical aspects of cave study and exploration. The territory covered is Australasia in the truest sense – Australia, New Zealand, the near Pacific Islands, New Guinea and surrounding areas, Indonesia and Borneo.

In 1974 the Speleological Research Council Limited agreed to support the Journal with financial assistance and in 1976 took over full responsibility for its production.

Speleological Research Council Limited

The Speleological Research Council Limited, the publisher and owner of Helictite, is a non-profit limited liability company incorporated in May 1964. The aims of the Speleological Research Council Limited are:-

To explore and chart and organize and promote the exploration and charting of caves and cave systems.

To promote, support and assist in the scientific evaluation and investigation of caves and to foster speleology as a science and a sport.

To promote and to assist in the promotion of speleology and speleological Societies and to assist such Societies with grants of money and otherwise.

Other publications by SRC Ltd:

CAVES OF THE NULLARBOR. T.M.L. Wigley and J.R. Dunkley 1968.
- a review of Speleological Investigations in the Nullarbor Plain.

THE EXPLORATION AND SPELEOGEOGRAPHY OF MAMMOTH CAVE, JENOLAN. J.R. Dunkley 1972. - a detailed history and description.

CAVES THROUGH THE AGES. G. Hangay, J.M. James & M. Dorrell 1974.
- a colouring book for children.

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. J.R. Dunkley 1976. - a detailed reference list.

THE CAVES OF JENOLAN, 2: THE NORTHERN LIMESTONE. B.R. Welch (ed) 1976.

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH

VOLUME 19(1) 1981

CONTENTS

"HELICTITE", Volume 19, 1981 consists of two issues. Price per volume Aust. $8.00 post paid. "HELICTITE" is printed and published by the Speleological Research Council Ltd. All correspondence to: P.O. Box 183, Broadway, N.S.W. 2007.

Recent publications from the

Speleological Research Council Limited

CAVES OF THE NULLARBOR
edited by J.R. Dunkley & T.M.L. Wigley
Second Edition. Published December 1978
$6 (post free)

• •

THE CAVES OF JENOLAN –
Volume I : THE EXPLORATION & SPELEOGEOGRAPHY OF MAMMOTH CAVE, JENOLAN
by J.R. Dunkley & E.G. Anderson
Second Edition. Published December 1978
$6 (post free)

• •

THE CAVES OF JENOLAN —
Volume II : THE NORTHERN LIMESTONE
edited by B. Welch
Published 1976
$6 (post free)

• •

Available from :-

Speleological Research Council Limited
P.O. Box 183.
Broadway NSW 2007

REVIEWS

CAVES AND KARST OF THE MULLER RANGE, by J.M. James and H.J. Dyson. Atea 78, in conjunction with the Speleological Research Council, Sydney, 1980. Pp. 150. Price $15.00.

This book is modestly subtitled "Report of the 1978 Speleological Expedition to the Atea Kananda, Southern Highlands, Papua New Guinea". However it is much more than the traditional expedition report on where we went and what we did, with appendices on finance and equipment. So many reports of mountaineering and speleological expeditions seem to be written more with a view to justifying a pleasant jaunt to sponsors than to add to the sum of human knowledge.

Not so with the "Atea Book". By any standards this is an outstanding documentation of an outstandingly well-organized and successful expedition.

Forward planning of Atea 78 took two years and some 20 members of four major speleogical societies in Sydney were involved. The expedition itself included 50 members from five different countries and was in the field from June to August 1978. The expedition was most rewarding, discovering about 50 kilometres of new cave and bringing Atea Kananda itself, at 30 km, to the longest in the southern hemisphere.

However it is in the scientific programme that the expedition has excelled. The first expedition to the Muller Ranges in 1973 (reviewed in Vol. 14 (2) of this journal), while scientific in its intentions, suffered from lack of overall research design and planning. Nevertheless this, and an unashamedly exploratory trip in 1976, provided the background knowledge necessary for the more thorough scientific work of Atea 78. The ambitious programme consisted of two major sections: earth sciences, including investigations of the geology, geomorphology, hydrology and geochemistry, and biology, including flora and fauna surveys both on the surface and underground. This programme was assessed and coordinated by a scientific committee comprising of Professor J.N. Jennings, Professor P. Williams, Dr. G.C. Cox and Dr. J.M. James. The result is a standard of original research considerably higher than normal for such a field expedition.

Some simple statistics give a measure of the scope of the book. The 20 chapters and 9 appendices were contributed by no less than 26 different authors. There are 63 photographs, 53 maps including 4 large foldouts, 17 sketches and 20 tables. A consolidated bibliography lists 127 references.

About half the book documents in some detail Atea Kananda and caves in other parts of the Muller Range. The cave descriptions are precise without being repetitive. Some descriptions are most evocative. The Ship Canal is described thus:

> "The walls seem to loom above like the work-worn sides of great tankers, and ahead the steady motion of a companion's light is the only tangible impression in a cold, black and watery journey."

In addition to the usual cave explorers' colourful appelations such as Ooze Cruise, Pikers Sump and Imperial Mud Standard, Atea Kananda was liberally sprinkled with allusions to the Beatles. Names such as Penny Lane, Primrose Hill, Strawberry Fields, With a Little Help from One's Friends, Winchester and Lucy in the Sky (with Diamonds nearby) might tell future historians something of the age and musical tastes of the explorers.

Following the cave descriptions are 10 chapters on geology, meterology, hydrology, surface geomorphology, water chemistry, clastic sediments, underground geomorphology, botany, vertebrate fauna and biospeleology. The scientific accomplishment is remarkable and reflects highly professional planning. While biological work was necessarily restricted to a broad taxonomy, work on aspects of earth science was of a high standard and some has already been published in this journal and elsewhere.

Finally 9 appendices deal with finance, food, transport, medical, surface equipment, caving equipment, surveying, photography and a glossary.

To conclude, this is a major advance on the already high standard of Australian speleological publications, a model for expedition planning in remote areas and a fine tribute to the authors and editors. As well, in a field dominated by exploration and research in caves and karst of temperate climatic environments, this is a significant addition to our relatively limited knowledge of tropical karst, particularly at high altitudes. It will more than justify the high level of sponsorship, support and faith from within Papua New Guinea, auguring well for future such expeditions.

J.R. Dunkley

AUSTRALIAN CAVES AND CAVING, by Ross Ellis. Western Colour Print, Marrickville, NSW, 1980. Pp. (46). Price $6.95.

This is a picture book of Australian caving, intended for the non-caving public and consisting almost entirely of colour and black-and-white photographs. Text is confined to the first four pages, and consists of an outline introduction to caves and speleology and brief descriptions of the cave areas in each state. A large part of this text is lifted from Wolfgang Kuhrau's book of the same title (Periwinkle Books, Melbourne, 1972), though this is not mentioned. It is not clear whether this is a licensed reprint or wholesale plagiarism, but surely Kuhrau should have been credited?

The remainder of the book is divided into sections, such as "Reaching your Destination", "Surface scenery", "Techniques" and sections devoted to specific areas. There is no contents list, and the pages are not numbered. Many of the photographs are of first-rate quality, and cover a wide range of cave types and activities. The relative proportions devoted to various areas will strike many cavers as strange, but to the general public will be much less important than the overall quality and variety. Much credit to Ross Ellis and the 8 other photographers, all members of Sydney Speleological Society.

The layout is often less happy, with some pictures chopped unnecessarily, others almost swamped by diagonal swatches of colour and some duplication of almost identical shots. For this, presumably, the publishers are to blame. There are a few gaffes, such as Bungonia Gorge captioned as "Kimberleys, W.A." and vice-versa. Some of the pictures captioned as squeezes will make cavers smile.

Inside the front and back covers, details are given of the Sydney Speleological Society. It is a pity, though, in a book covering the whole of Australia, and which will presumably be sold in all states, that the Australian Speleological Federation and its other member societies did not receive a mention.

Overall, a curious book, but one which, through the range and quality of its pictures, will give the general public an idea of what it is that speleologists "see" in caves.

Guy Cox

UNDERGROUND STREAMS ON ACID IGNEOUS ROCKS IN VICTORIA

Brian Finlayson

Abstract

Underground streams occur in valley floors on acid igneous rocks over a wide area of eastern Victoria. In some cases the underground passage is capable of accommodating all streamflow levels so that there is no active surface channel. Three of them contain passages accessible to cavers. The literature contains very few references to features of this kind and there is some confusion as to whether they should be called 'pseudokarst'. Detailed descriptions and diagrams are presented for two of the sites, Labertouche and Brittania Creek. At North Maroondah, sinking streams on dacite have caused complications for hydrological experiments.

Possible origins of these features are discussed and it is obvious that several mechanisms are feasible. One of the difficulties in determining modes of formation is that a variety of processes could lead to very similar end products. Three main theories on the mode of formation are suggested.

INTRODUCTION

Underground streams have been observed over a wide area of eastern Victoria on rocks of granitic composition. In all cases they occur in the floors of valleys and consist of a section of underground stream flowing through boulders. There are no known cases where these streams deviate from the alignment of the surface valley. Some of the underground passages are large enough to cope with all levels of discharge in the stream so that there is now no active stream channel on the surface. In other cases only low flows can be accommodated underground and flood runoff uses a surface channel as well. These features are of particular interest because they are developed on acid igneous rocks.

The literature contains very few references to river caves developed in acid igneous rocks. Wood (1976) has reviewed the literature on caves in volcanic terrain and points out that acid lavas are too viscous to form caves so that his 'vulcanospeleology' deals only with caves in basaltic lavas. Feininger (1969), Ollier (1965, 1969), and Shannon (1975) are the only papers known to the author which discuss river caves in acid igneous rocks. The two works by Ollier deal briefly with one of the caves to be discussed here (Labertouche Cave). Descriptions of the geology of the areas in which these caves are found in Victoria contain no references to them.

Whether these features should be called pseudokarst is of course a matter of debate. Following the usage of Wood (1976) they are pseudokarst because they are "karst-like landforms of non-solutional origin" (p.127). Quinlan (1968) uses pseudokarst in the same sense and has a sub-category 'clastokarst' into which these features would fit. Sweeting (1972) on the other hand, excludes non-solutional features from pseudokarst and follows the usage of Corbel in calling them 'sub-karstic'. Regardless of the complexities of these semantic arguments, a number of these underground stream passages are accessible to cavers and so fall within the legitimate scope of speleology.

SITE DESCRIPTIONS

The locations of all the known underground streams in acid igneous rocks in Victoria are shown in Figure 1. Not all of these sites have been visited by the author. Most of them occur in heavily timbered and inaccessible country and it is possible that there are many similar sites which have not been found yet. The caves at Labertouche and Brittania Creek are the best known and most accessible and are discussed in some detail below. The group of underground streams at North Maroondah include no known accessible caves and are of interest because of their effect on hydrological experiments in the area. The "Underground River" on Mt. Buffalo is marked on the National Parks maps and is visited regularly by tourists. Little reliable information is available for the remainder of the sites and they are referred to only briefly below.

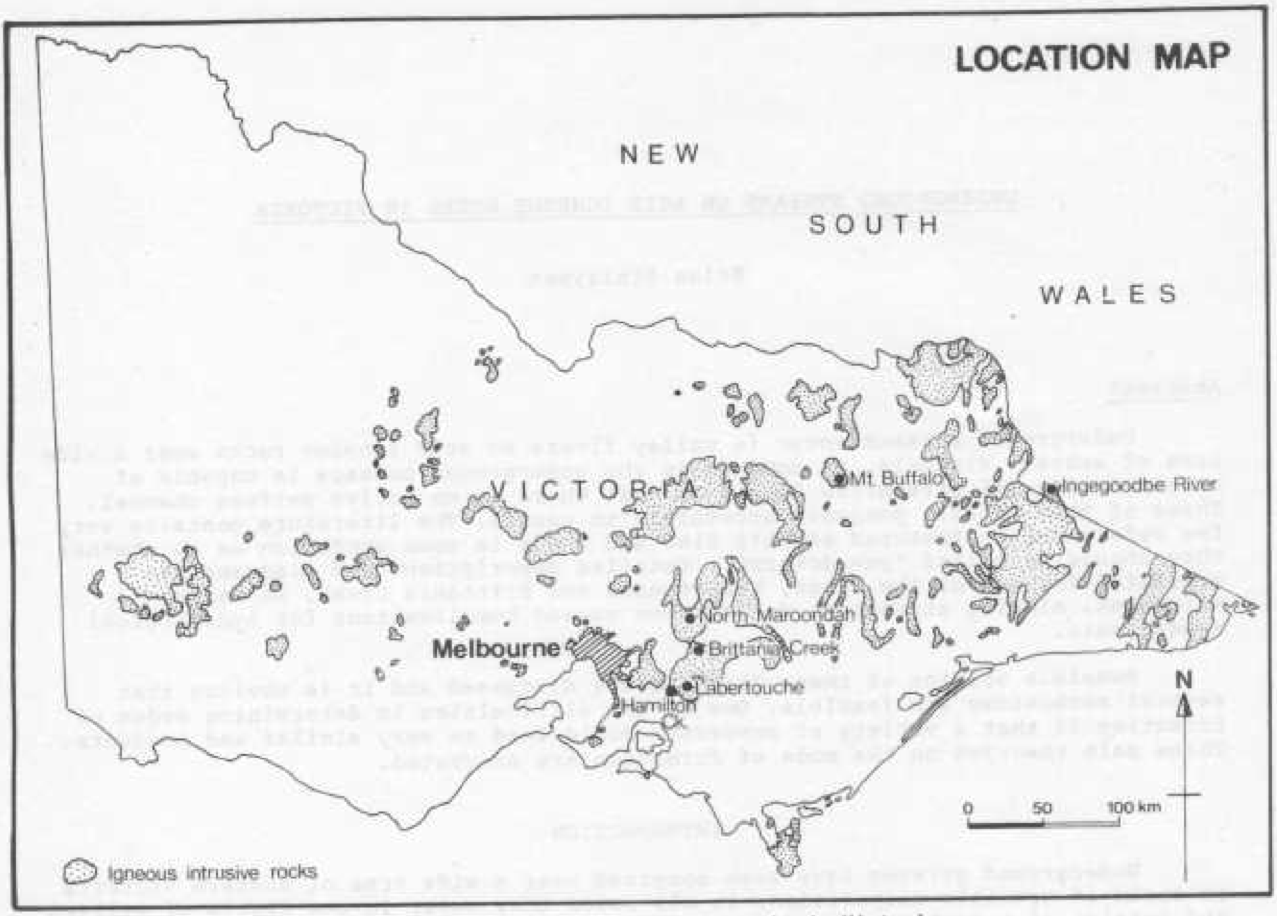


Figure 1. Locations of underground streams on acid igneous rocks in Victoria.

Labertouche Cave

This cave is located on the headwaters of Labertouche Creek, a tributary of the Tarago River about 100 km east of Melbourne via the Princes Highway (G.R. 989929 Warragul 1:100,000 sheet). Bedrock of the area is a late Devonian granite known as the Tynong Granite (Baker, Gordon and Rowe, 1939). The major mineralogical composition of a sample of this granite is shown in Table I.

The cave occurs in steeply dissected and heavily timbered country which is currently being managed as a State Forest. Local relief is in the order of 100 m. The location of the cave is shown in the sketch map in Figure 2. The cave stream sinks in a blind valley and rises 175 m further downstream. A section along the valley axis is shown in Figure 3. The dimensions of the whole system can be judged from the sketch map and the section.

The col which terminates the blind valley is now completely covered with soil supporting a forest cover. The crest of the col is 46 m above the present stream level and is almost certainly higher than the level of the valley floor when the stream first went underground, due to accretions of material from the valley slopes which normally would be transported away by the stream.

The present stream enters the cave through a number of small distributaries flowing between granite boulders. During flood flows the stream level rises and additional entrance passages are used. The cave is capable of accommodating all flow levels and it is apparent that no flow has gone over the col for a considerable time. Above the present stream sink there are remnants of former higher level sinks, one of which serves as an entrance to the cave. It is not possible to enter the cave through the currently active stream passages.

The cave itself is a pile of granite boulders (core stones) with, in places, exposures of in situ granite. The orientations of the boulders indicate that many have been moved and some have been fractured. In the higher levels of the cave there are exposures of what appears to be in situ grus and there are also exposures of stream deposited sediments well above the currently active level. At the stream level there are multiple stream courses, some occupied only during high flows. The present stream is transporting a bed load with particles up to coarse gravel size through the cave. It is quite common to find boulder surfaces which have been polished and scalloped by stream action at all levels and in a variety of orientations. The stream leaves the cave at the base of a steep bouldery slope.

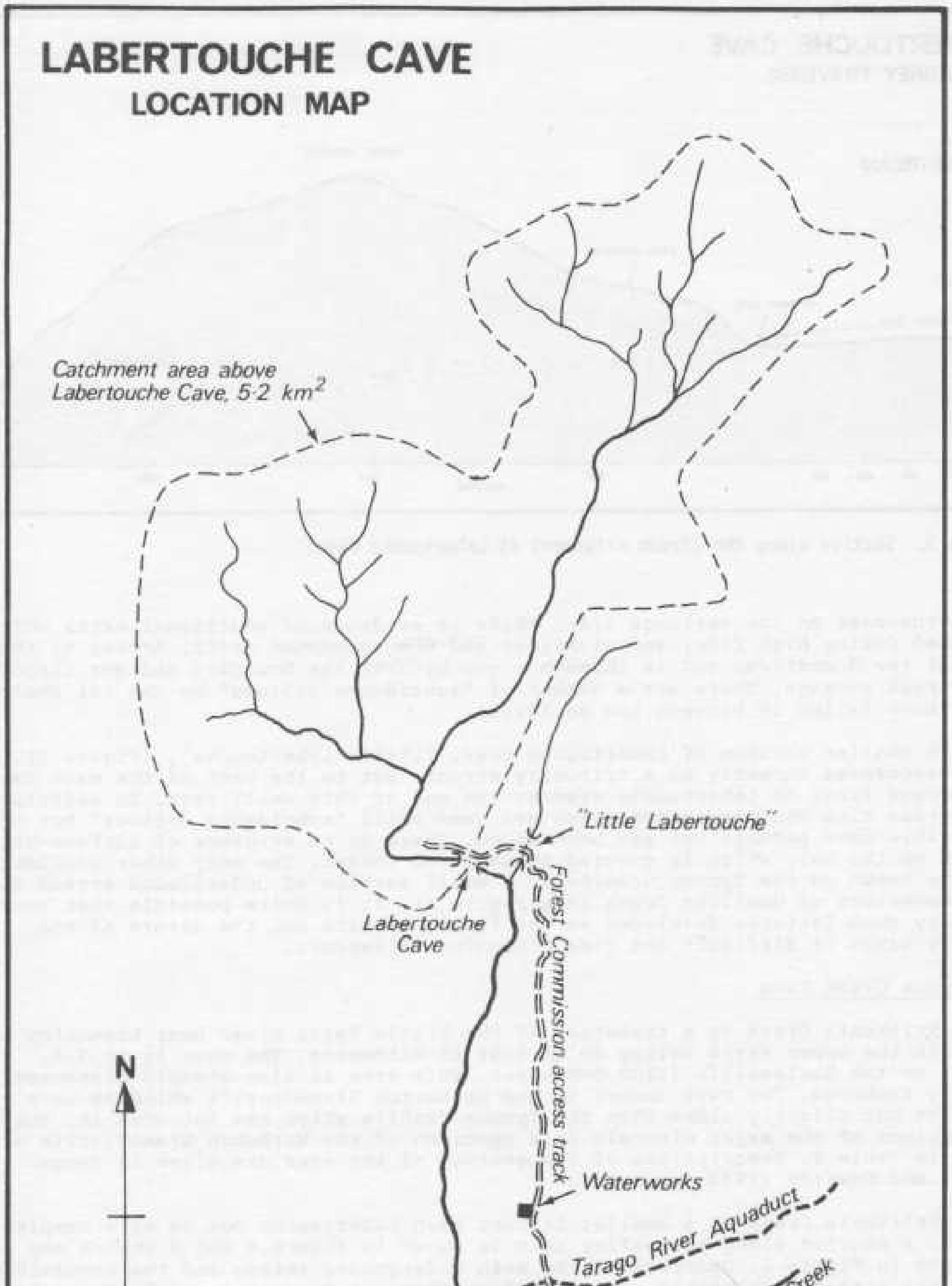


Figure 2. Location map of Labertouche Cave.

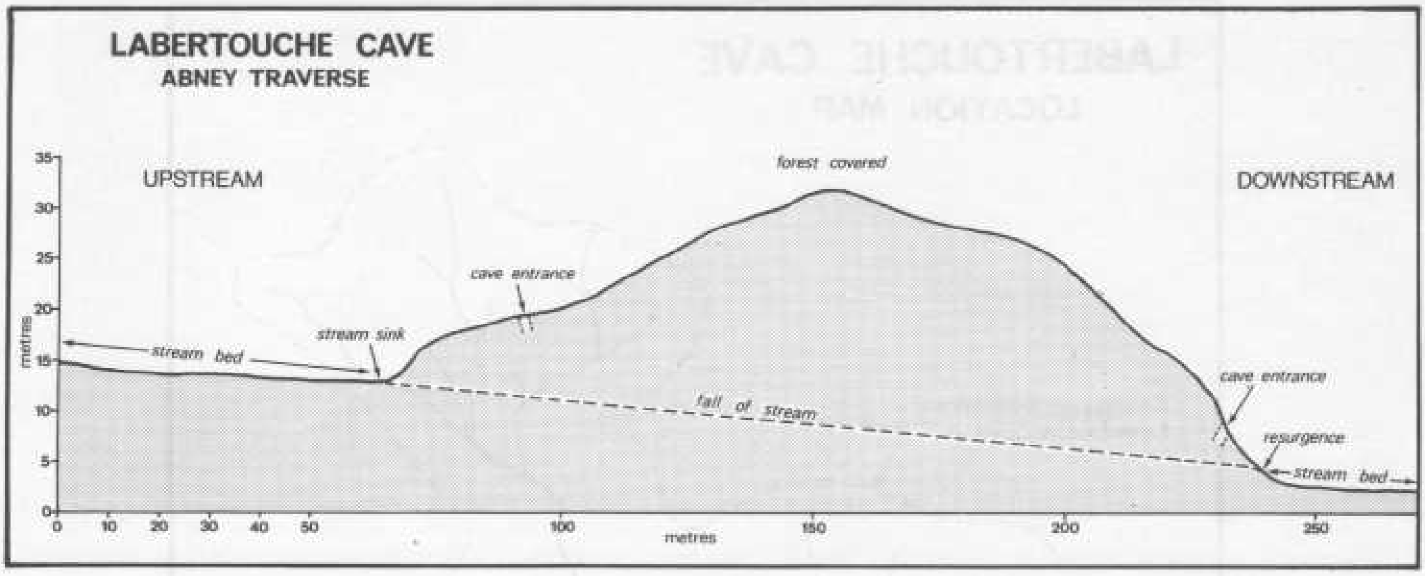


Figure 3. Section along the stream alignment at Labertouche Cave.

As is the case on the entrance side, there is evidence of additional exits which are used during high flow, and of higher and now abandoned exits. Access to the cave at the downstream end is through a gap between the boulders and not through the stream passage. There are a number of "subsidence dolines" on the col where fines have fallen in between the boulders.

A smaller version of Labertouche cave, 'Little Labertouche', (Figure 2), has been discovered recently on a tributary stream just to the east of the main cave. The access track to Labertouche crosses the col of this small cave. In addition to the stream sink and resurgence there are some small "subsidence dolines" but no accessible cave passage has yet been found. There is no evidence of surface stream action on the col, which is covered by soil and forest. The only other similar feature known on the Tynong Granite is a small section of underground stream on the headwaters of Hamilton Creek (see Figure 1). It is quite possible that there are many such features developed on the Tynong Granite but the nature of the country makes it difficult and time consuming to explore.

Brittania Creek Cave

Brittania Creek is a tributary of the Little Yarra River near Launching Place in the upper Yarra Valley 60 km east of Melbourne. The cave is at G.R. 829162 on the Healesville 1:100,000 sheet. This area is also steeply dissected and heavily timbered. The cave occurs in the Warburton Granodiorite which is Late Devonian but slightly older than the Tynong Granite which has intruded it. The proportions of the major minerals in a specimen of the Warbuton Granodiorite are shown in Table I. Descriptions of the geology of the area are given in Junner (1915) and Edwards (1932, a, b, c).

Brittania Creek is a smaller feature than Labertouche but is more complex in detail. A section along the valley axis is shown in Figure 4 and a sketch map of the area in Figure 5. Upstream of the main underground stream and the accessible cave, the stream goes partly underground as shown on Figures 4 and 5. There is a major resurgence at the point marked A on the figures where the surface and the subsurface flows combine to a single stream which then sinks completely at point B. Between point B and point C there is a section of former surface channel which now appears to be completely abandoned. From point C to the low flow resurgence at point D the stream channel shows evidence of occasional surface flows. During higher flows additional resurgences become active as far upstream as point C. The sink at B appears to be capable of accommodating all flows.

The accessible cave passage does not follow the through route of the stream but is in a pile of boulders on the southern side of the stream channel. The boulders are covered with soil and forest. The two entrances to the cave are shown in Figures 4 and 5. Part of the stream flow passes through the cave which, like Labertouche, is simply accessible passageway between boulders. The cave contains both active and abandoned stream sediments and weathering products and humus leached through from the overlying soil.

The subsurface path followed by the water is as shown in Figure 5. The underground flow is deflected to the north by a large exposure of fresh granodiorite without vertical joints and reappears in the resurgence at D from among the boulders forming the northern side of the valley. The underground stream does not follow exactly the surface channel alignment. The stream can be seen through two small dolines shown on Figure 5 and other subsidence dolines occur nearby.

There are no other similar features known on the Warburton Granodiorite.

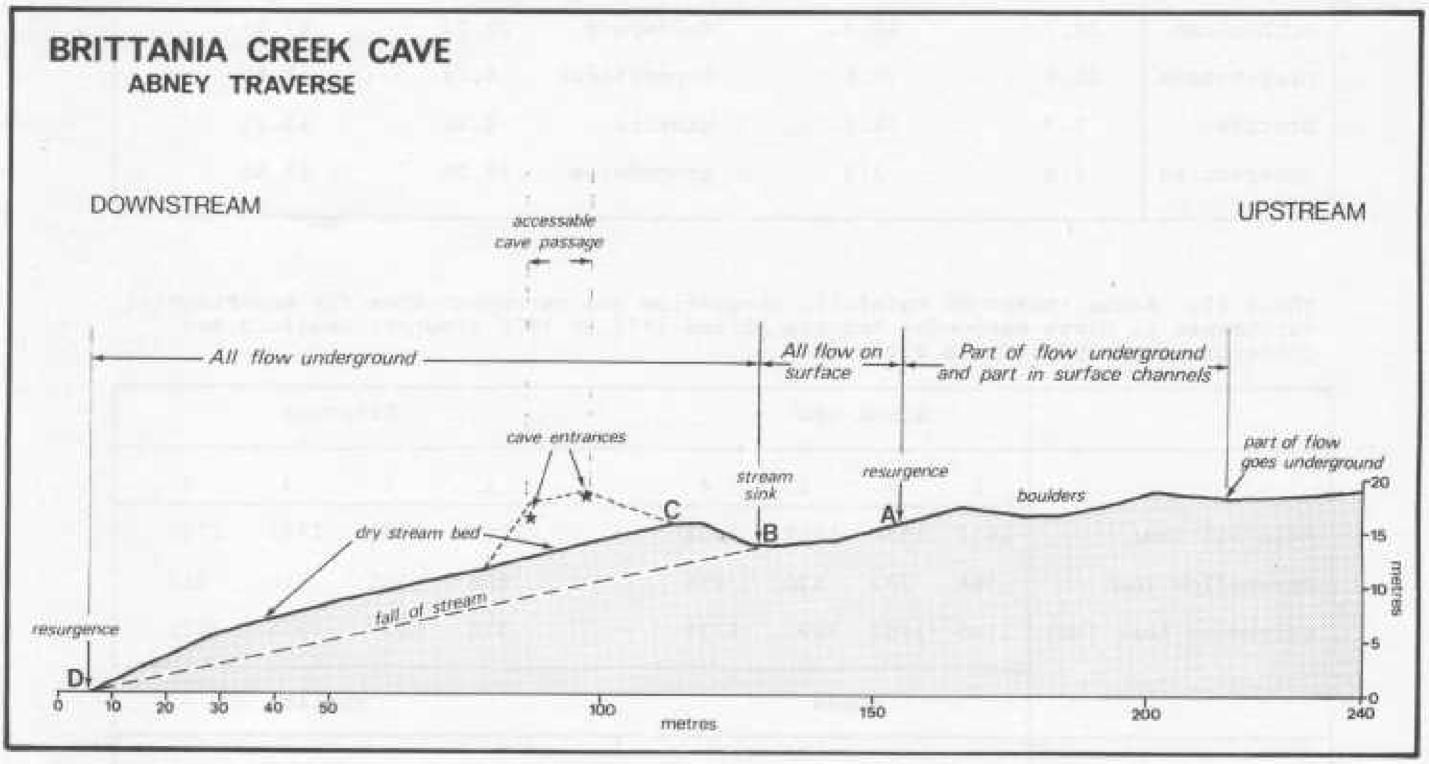


Figure 4. Section along the stream alignment at Brittania Creek Cave.

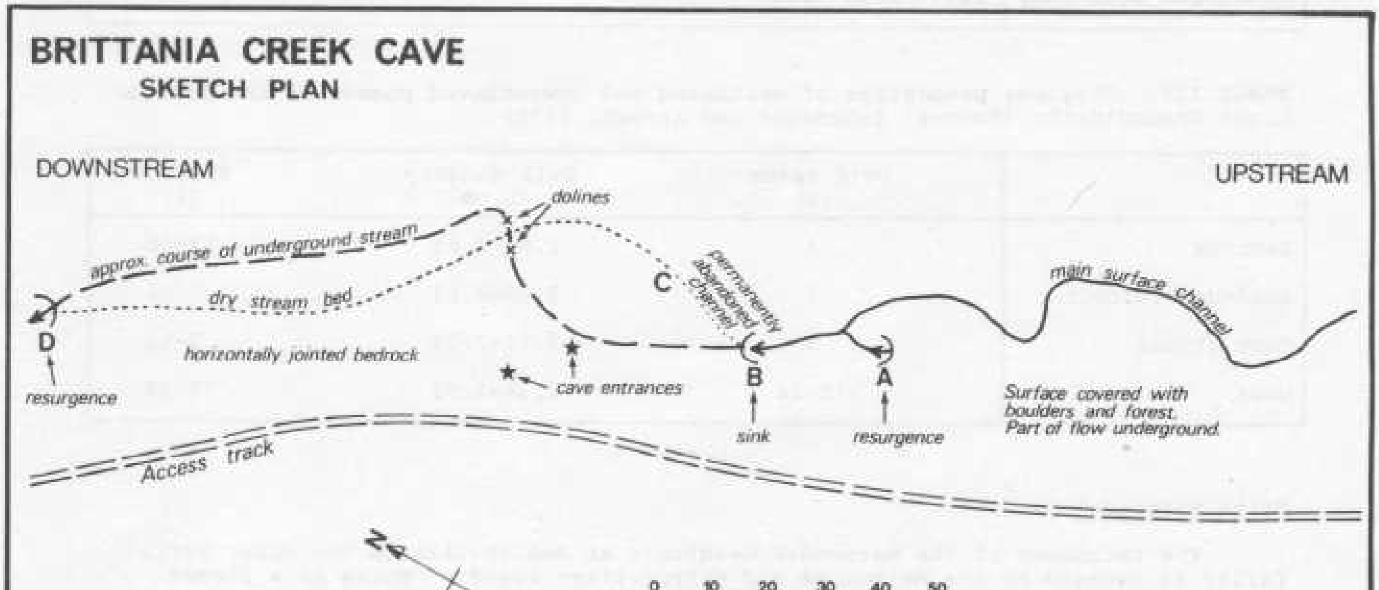


Figure 5. Sketch plan of the area around the Brittania Creek Cave.

TABLE I. Percentages of major minerals in acid igneous rocks on which underground streams have formed. (Source: (1) Baker et al., 1939, (2) Edwards 1932a).

	Tynong Granite (1)	Warburton Granodiorite (1)	Quartz-hypersthene biotite-dacite (2)		Quartz-biotite-dacite (2)
quartz	32.0	31.2	quartz	13.18	11.46
orthoclase	34.7	16.3	feldspars	28.92	27.04
plagioclase	25.6	31.6	hypersthene	6.24	1.63
biotite	5.7	18.6	biotite	4.28	13.95
accessories	2.0	2.3	groundmass	48.00	45.65

TABLE II. Annual means of rainfall, streamflow and catchment loss for experimental catchments at North Maroondah for the period 1972 to 1976 (Source: Langford and O'Shaughnessy, 1977, Table 8.2).

	Black Spur				Ettercon			
	1	2	3	4	1	2	3	4
Rainfall (mm)	1652	1634	1612	1606	1787	1784	1731	1728
Streamflow (mm)	504	582	530	276	808	575	416	717
Catchment Loss (mm)	1148	1052	1082	1330	976	1209	1315	1011
	Monda				Myrtle			
	1	2	3	4	1	2		
Rainfall (mm)	1876	1813	1763	1730	1622	1590		
Streamflow (mm)	702	550	632	854	678	852		
Catchment Loss (mm)	1174	1263	1131	876	944	738		

TABLE III. Physical properties of weathered and unweathered phases of the Boulder Creek Granodiorite (Source: Isherwood and Street, 1976).

	Void space (%)	Bulk density (g/cm^3)	Biotite (%)
Bedrock	1	2.67-2.63	13-16
Surface boulders	5	2.57-2.53	7-12
Core Stones	5	2.57-2.53	7-12
Grus	12-26	2.34-1.98	22-29

North Maroondah

The catchment of the Maroondah Reservoir at Healesville in the Upper Yarra Valley is managed by the Melbourne and Metropolitan Board of Works as a closed water supply catchment. The Board established 14 small experimental catchments in this area in 1970/71 (Figure 6). During the surveying and instrumentation of these catchments, sections of underground stream were found in four of them and subsequent analysis of the streamflow records has shown that two of these catchments with underground sections of stream also have atypically low stream flow (Langford and O'Shaughnessy, 1977).

Bedrock in this area is Late Devonian acid volcanics, similar in composition to the Warburton Granodiorite and contemporary with it. In the north of the area the bedrock is quartz-hypersthene-biotite-dacite merging into quartz-biotite-dacite south of Mt. Monda (Figure 6). Analyses of these two groups are shown in

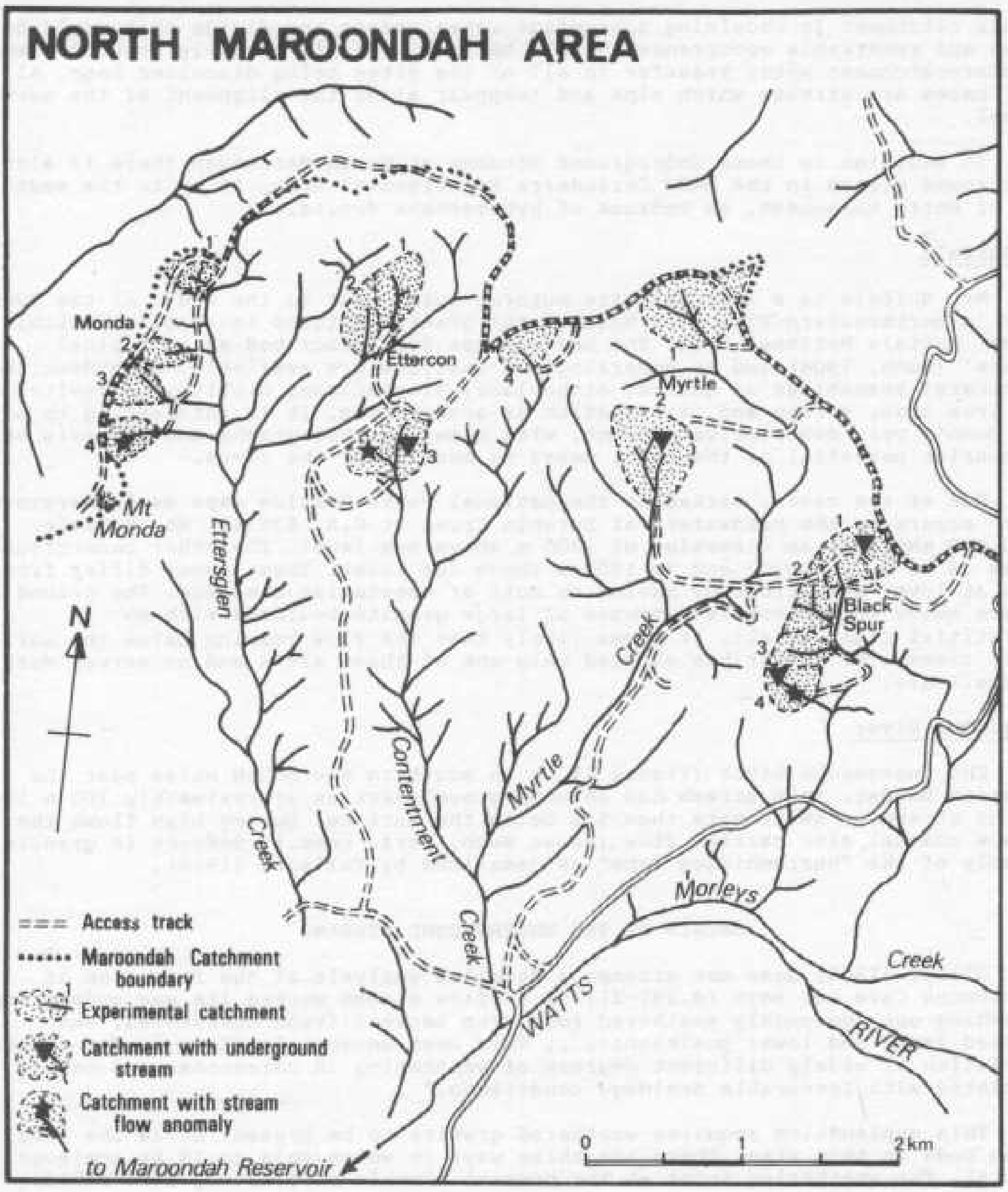


Figure 6. The experimental catchments at North Maroondah. (After Langford and O'Shaughnessy, 1977).

Table I. Edwards (1932a) points out that the quartz-hypersthene-biotite-dacite is a chilled intrusive facies of the quartz-biotite-dacite. All the known underground streams in this area are on the quartz-biotite-dacite side of the geological transition (see Figure 6).

The underground streams at North Maroondah are rarely more than 1 m below the surface. In all cases the surface channels are periodically active. During the construction of the stream gauging sites on the Monda group of catchments a hole was uncovered during excavations in the stream bed through which all of the streamflow disappeared. The gauging site then had to be relocated further downstream.

Two of the catchments with underground streams (Black Spur 4 and Ettercon 3) also have anomalous streamflow records. Annual means of rainfall, streamflow and catchment loss for the period 1972 to 1976 are shown in Table II. Note that Black Spur 4 and Ettercon 3 have high losses and low streamflows indicating that part of the flow is bypassing the gauging structure as either deep seepage or possible underground streamflow. Statistical analyses of these data by Langford and O'Shaughnessy (1977) have shown the differences to be statiscally significant. The streamflow for Monda 4 (See Table III) is significantly higher than the other Monda catchments indicating either accessions to the catchment by subsurface flow from outside the catchment boundary or an incorrectly defined catchment boundary.

If this catchment is receiving subsurface water across the divide that would be a unique and remarkable occurrence on this bedrock. This is the only possible case of inter-catchment water transfer in all of the sites being discussed here. All other cases are streams which sink and reappear along the alignment of the surface channel.

In addition to these underground streams at North Maroondah there is also an underground stream in the MMBW Coranderrk Experimental Area, 12 km to the south east of North Maroondah, on bedrock of hypersthene dacite.

Mt. Buffalo

Mt. Buffalo is a large granite outcrop lying just to the south of the Ovens River in northeastern Victoria. Most of the granite outcrop is contained within the Mt. Buffalo National Park. The bedrock has been described as a 'typical granite' (Dunn, 1908) and no mineralogical analyses are available. Dunn describes the mineral assemblage as quartz, orthoclase, plagioclase, biotite, muscovite, with iron ores, zircon and rare apatite as accessories. It is interesting to note that Dunn's very descriptive account, with numerous photographs and emphasis on the tourist potential of the area, makes no mention of the caves.

One of the caves, marked on the National Parks Service maps as "Underground River" occurs on the headwaters of Eurobin Creek at G.R. 836348, Mt. Buffalo 1:100,000 sheet at an elevation of 1400 m above sea level. The other underground stream is at G.R. 803307 and is 1500 m above sea level. These caves differ from those at lower elevations by having no soil or vegetation coverage. The ground surface above the stream is composed of large granite boulders with no interstitial fines at all. It seems likely that the flow remains below the surface at all times. The author has visited only one of these sites and no survey data are available.

Ingegoodbe River

The Ingegoodbe River (Figure 1) is in southern New South Wales near the Victorian border. This stream has an underground section approximately 100 m long and the stream is never more than 5 m below the surface. During high flows the surface channel also carries flow (Rowan Webb, pers. comm.). Bedrock is granite probably of the "Murrumbidgee Type" as described by Vallance (1969).

ORIGIN OF THE UNDERGROUND STREAMS

Ollier (1965) does not attempt a detailed analysis of the formation of Labertouche Cave but says (p.291-2): "A surface stream worked its way underground by washing out thoroughly weathered rock from between fresh corestones, and occupied lower and lower positions..... This most unusual landform is due to the association of widely different degrees of weathering in corestones and matrix, associated with favourable drainage conditions."

This explanation requires weathered granite to be present below the level of stream beds in this area. There are three ways in which this could be achieved.

a) The weathering front at the present time is progressing more rapidly than stream erosion.

b) The granite mass has been previously weathered to great depth under perhaps different climatic conditions and certainly under a topography of low relief (Ollier, 1960).

c) Weathering at depth in the granite mass was produced by high temperature oxidation or hydrothermal alteration perhaps shortly after the original emplacement.

Given the likely rates of operation of weathering and stream erosion it would appear unlikely that the weathering front would be progressing faster than river erosion in this type of country under the present humid temperature climate. Ollier (1965) points out that in the Labertouche area, weathering under a former peneplain surface would have to have penetrated to over 150 m to explain the observed weathering pattern. The weathering may be hydrothermal alteration but at present it is not possible to distinguish between this and sub-aerial weathering (Ollier, 1965; Isherwood and Street, 1976). It is therefore not possible to determine whether the caves are associated with an early history of high temperature alteration or with a history of deep sub-aerial weathering under a peneplain surface.

While it is not possible at present to adequately test Ollier's hypothesis of the formation of these underground streams, it is possible to elaborate on the mechanism he proposes and to suggest alternatives.

Isherwood and Street (1976) have shown that initial changes during the weathering of rocks of granitic composition involve weathering of biotite which is converted to hydrobiotite by the loss of potassium and the addition of water. The original biotite grains expand and their density is reduced by up to 20%. This leads to a reduction of bulk density in the grus as compared with fresh bedrock and core stones and a corresponding increase in void space (Table III). The weathering of most granitic rocks consists of deep pockets of weathered grus containing core stones and sharp contacts between grus and fresh rock. "The question of why two adjacent masses of rock of the same age, origin, and mineral assemblage should weather at such vastly different rates may lie in comparison of the biotite percentages" (Isherwood and Street, 1976, p.369). Table III shows their analyses of biotite content in bedrock, grus and corestones. Note that the unweathered core stones in a grus matrix contain lower levels of biotite.

This process of 'biotite-induced grussification' and the resulting reduction in bulk density provides a mechanism which allows seepage through otherwise relatively impermeable material, and which could lead to sub-surface piping as described by Feininger (1969). All of the rocks on which underground streams have been observed in Victoria have abundant biotite (Table I). The weathered Tynong Granite is known to flow readily as was discovered during the construction of the Tarago River aqueduct tunnel near Labertouche Cave. "One extensive zone of decomposed material, into which the contractors advanced too far without adequate support, flowed extensively, collapsed the timbering, and eventually filled the tunnel for a distance of 120 feet." (Green and Maver, 1959, p.15). This was the largest of a number of flows of weathered material encountered during tunnel construction.

The underground rivers described in this paper could owe their origin to this type of process and this explanation is supported by the presence of apparently in-situ grus in the higher levels of Labertouche Cave as observed by the author and also Ollier (1965). This explanation would apply equally to material weathered by deep sub-aerial weathering or by hydrothermal alteration.

An alternative theory for the formation of these features is the 'landslide theory'. Mass failure on the valley sides would deposit in the stream bed below a mixture of unweathered core stones and fine-grained weathered material. Since the fines had been relocated their bulk density would be substantially reduced allowing easy movement of water and eventually complete removal of the fines leaving a stream flowing through a pile of core stones. Vegetation litter and colluvial material from the valley side slopes could then collect on top of the core stones and eventually develop a soil profile and a vegetation cover. Once the underground stream passage had been established in this way normal stream bed lowering could continue leaving the cave roof intact. Clearly not all landslides would be successful in establishing a cave in this way. One of the difficulties with this theory is the lack of any recent examples of mass failure which show the initial stages of the process.

Whatever the method by which the stream gets underground, the role of vegetation in establishing the cover over the surface of the boulders is important. On Mt. Buffalo, where the vegetation cover is sparse and less productive than at the lower altitude sites, no soil and vegetation cover has become established across the surface of the boulders covering the stream.

One the the major difficulties in discovering the origin of these underground streams is that regardless of how the stream went underground, the end result would look the same. For example, it has been suggested that the boulders in Labertouche Cave which have been moved and in some cases fractured tend to indicate a landslide but the same effect could be achieved as in-situ boulders settle when the weathered matrix is washed out from between them.

At present nothing is known about the absolute ages of these caves or about their rates of development. Labertouche Cave is apparently the oldest and some indication of its age can be had by considering that the floor of the valley has been lowered by perhaps 30 to 40 metres since the stream first went underground.

CONCLUSIONS

A number of underground streams occur on acid igneous rocks in eastern Victoria. Three of them contain accessible cave passage. The precise mode of origin of the caves is not known though there are three main theories put forward to account for them.

a) The surface stream has eroded weathered material from between corestones to the point where the stream is substantially covered by the corestones. Vegetation assists in trapping colluvial material on the corestones eventually developing a soil on which the local forest becomes established.

b) Sub-surface seepage through weathered material produces sub-surface pipes which enlarge to eventually accommodate all the stream flow leaving an abandoned stream bed in which colluvium accumulates.

c) Rapid mass failure on the valley-side slopes deposits core stones and weathered material in the stream bed. The stream transports the fine grained weathered material away leaving the large core stones. The stream is then flowing through a pile of bouders on top of which vegetation and colluvium collect as described in (a) above.

It is possible that more than one of these mechanisms has been operative since, irrespective of mode of origin, the final result would look the same.

The caves formed this way are quite robust since they do not contain any delicate cave decoration. As such they are useful for introducing people to caving and for satisfying the curiosity of those who simply wish to go underground and are not particularly interested in the finer details of the science of speleology. The caves at Labertouche and Brittania Creek, being close to Melbourne, are visited by large numbers of people who might otherwise be attracted to less robust caves. Unfortunately, many who come bring their paint cans with them.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the assistance of Sue White, Nicholas White, Lloyd Mill and Neville Rosengren in location and survey of these sites; Rowan Webb for information about Ingegoodbe River; and Joe Jennings for helpful advice and discussion.

REFERENCES

BAKER, G., GORDON, A., and ROWE, D.D., 1939 Granite and granodiorite at Powelltown, Victoria, and their relationships. Proc. Roy. Soc. Vict. 51: 31-44.

DUNN, E.J., 1908 The Buffalo Mountains, Mem. Geol. Surv. Vict. 6.

EDWARDS, A.B., 1932a The geology and petrology of the Black Spur area, Healesville, Proc. Roy. Soc. Vict. 44: 49-76.

EDWARDS, A.B., 1932b The geology and petrology of the Warburton area, Victoria. Proc. Roy. Soc. Vict. 44: 163-181.

EDWARDS, A.B., 1932c On the dacite-granodiorite contact relations in the Warburton area. Proc. Roy. Soc. Vict. 44: 182-194.

FEININGER, T., 1969 Pseudokarst on quartz diorite, Columbia. Zeitschr. f. Geomorph. 13(3): 287-296.

GREEN, K.D., and MAVER, J.L., 1959 The Tarago River Aqueduct, J. Inst. Eng., Aust. 31: 1-19.

ISHERWOOD, D., and STREET, F.A., 1976 Biotite-induced grussification of Boulder Creek Granodiorite, Boulder County, Colorado. Geol. Soc. Am. Bull. 87: 366-370.

JUNNER, N.R., 1915 The petrology of the igneous rocks near Healesville and Narbethong. Proc. Roy. Soc. Vict. 27: 261-285.

LANGFORD, K.J. and O'SHAUGHNESSY, P.J. (eds), 1977 First Progress Report, North Maroondah. Melbourne and Metropolitan Board of Works, Report No. MMBW-W-0005.

OLLIER, C.D., 1960 The inselbergs of Uganda. Zeitschr. f. Geomorph. 4: 43-52.

OLLIER, C.D., 1965 Some features of granite weathering in Australia. Zeitschr. f. Geomorph. 9(3): 285-303.

OLLIER, C.D., 1969 Weathering. Longmans, London.

QUINLAN, J.F., 1968 Classification of karst and pseudokarst types: a review and synthesis emphasizing the North American literature, 1941-1966. Special Papers No. 101, Geol. Soc. of America: 448-450.

SHANNON, C.H.C., 1975 Pseudokarst caves in duricrust/granite terrain, Banana Range, Central Queensland. Proc. 10th Bienn. Conf., Aust. Speleo. Fed. Brisbane, 27-29 December, 1976: 20-24.

SWEETING, M.M., 1972 Karst Landforms. Macmillan, London.

VALLANCE, T.G., 1969 Plutonic and metamorphic rocks. In: PACKHAM, G.H. (ed), The Geology of New South Wales. J. Geol. Soc. Aust. 16(1): 180-200.

WOOD, C., 1976 Caves in rocks of volcanic origin. In FORD, T.D., and CULLINGFORD, C.H.D. (eds), The Science of Speleology: 127-150. Academic Press, London.

Address for Correspondence: Department of Geography, University of Melbourne, Parkville 3052, Victoria, Australia.

CHEMISTRY OF A TROPICAL TUFA-DEPOSITING SPRING NEAR MT. ETNA, QUEENSLAND: A PRELIMINARY ANALYSIS

D.L. Dunkerley

Abstract

Water samples taken from a spring and six locations on the stream fed by it were analysed in order to determine the factors responsible for the deposition of tufa along the channel. The spring water, whilst carrying a large quantity of dissolved carbonates, proved to be almost at equilibrium with calcite. The considerable amount of dissolved carbon dioxide necessary for such a load to be carried underwent rapid degassing after emergence of the water. In consequence, about one quarter of the initial load of dissolved carbonate was deposited in the first 430m of subaerial flow. This deposition did not however keep pace with the degassing of CO_2, and calcite supersaturation increased progressively downstream.

INTRODUCTION

Observations of the composition of karst spring waters have been reported often in the literature, generally with temporal fluctuations in composition being the object of study. Such data aid in the investigations of the nature of water movement underground (e.g., Shuster and White, 1971; Paterson, 1979), the possible effects of seasonal variation in respiration of soil organisms and rates of decomposition of organic matter (e.g. Pitty, 1966), and several other areas of concern in karst studies. Relatively few reports document the variation of spring water chemistry at the surface as equilibrium with the free atmosphere is approached. Knowledge of the changes involved in this adjustment may however shed useful light on the rates of such processes as carbon dioxide degassing and the deposition of carbonates as travertine and tufa.

This paper presents the results of a preliminary examination of variation in the composition of a small spring-fed stream during the first 430 metres of subaerial flow. Over this part of its course, the stream has deposited carbonates principally in the form of a series of tufa dams and to a lesser extent as tufa rims along the banks and around boulders protruding above water level. The purposes of the investigation were to discover the levels of carbonate saturation in the stream associated with the tufa deposition, and to examine the rate at which properties of carbonate solution adjusted to conditions at the ground surface subsequent to emergence.

LOCATION AND ENVIRONMENT OF THE SPRING

The spring is located in the karst area bordering The Caves township, about 25 km from Rockhampton in Queensland, and just north of the Tropic of Capricorn (see Figure 1). Here Devonian limestones outcrop discontinuously over an area of 12 km^2, principally along Limestone Ridge and on Mt. Etna. The climate of the area is hot and seasonally wet, with perhaps 60% of the annual rainfall (probably in excess of 1000 mm) falling in the very warm months of December to March. The pale grey limestone is dense and fine-grained, and in places contains many small veins of calcite. Solution where it is exposed appears to be vigorous, with extensive fields of karren all sharply sculptured. A dense cover of forest and vine thicket extends over much of the area of limestone hills; surrounding alluvial plains are largely cleared for pasture.

The point of water exsurgence is located in the bed of a small creek on the north-western edge of the karst area. The creek is generally dry upstream of the spring, but flows briefly after local rain. The spring has been visited on two occasions, and on each the flow was small, estimated at a few tens of litres per minute, and clear. No surface water entered the channel at the time of observation, and the flow appeared constant over the study reach; however, it is possible that there was a small contribution from groundwater entry along the channel. Large pools, 30-40 cm deep, and tens of metres long, created by the tufa dams, occupy most of the channel. In these flow is very sluggish and aeration of the water restricted. Where flow spills over the walls of the tufa dams, some tens of which exist in the study reach, flow velocities increase and mixing and aeration are enhanced. At low flow, overflow typically only occurs at one or two low points along each dam wall (see Plate 1), so that these sites of enhanced mixing are not extensive.

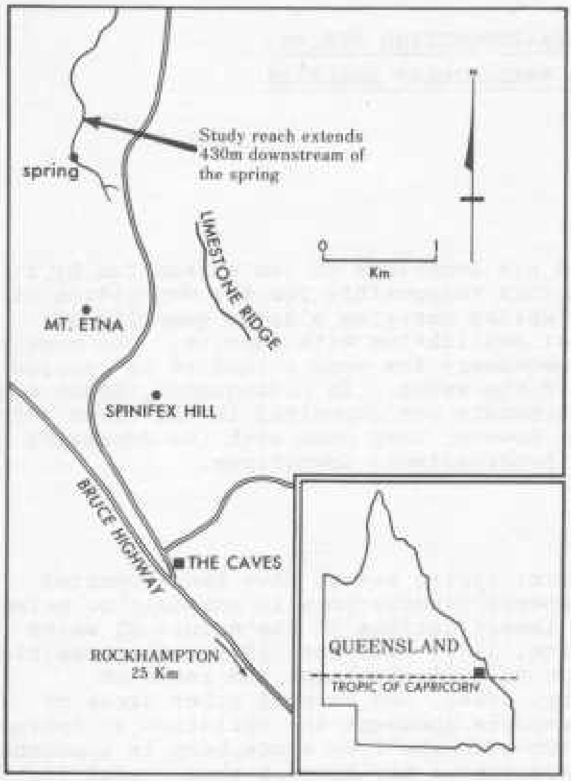


Figure 1. Location of the spring north of Mt. Etna.

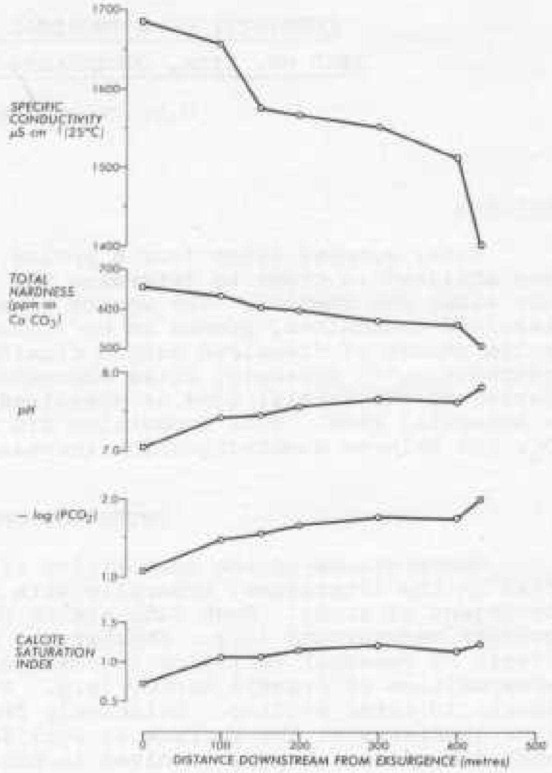


Figure 2. Graphical portrayal of the principal results from Table 1. Distances downstream were paced, and are not exact.

OBSERVATIONS OF WATER CHEMISTRY

During a brief visit to the site on December 1980, water samples were collected at the spring and at six locations downstream. Rinsed polyethylene bottled were used, and each was completely filled to exclude air. The samples were collected where the water was flowing visibly, near tufa dams. They were returned immediately to an air-conditioned room where all chemical analyses were completed within six hours of sample collection. Water temperature was noted at each site in the field. Collection of the seven water samples required approximately 30 minutes, so that for present purposes, they may be regarded as simultaneous samples.

Analyses made subsequent to collection were of pH, electrical conductivity, total hardness and alkalinity, together with calcium hardness at two sites (the exsurgence and the site furthest downstream). Conductivity was measured with a Metrohm model E587 Conductometer, and pH with a Metrohm model E588 pH/mV meter using a Metrohm combination electrode. Buffers of pH 7.0 and 9.2 were used for calibration, which was confirmed both before and after analyses. Hardness titrations were performed on 50 ml aliquots using BDH reagents with EDTA as the complexone. Fresh EDTA was prepared from an ampoule of concentrated reagent and distilled water. Alkalinity was determined by titration of 50 ml aliquots with approximately 0.02M HCl to the methyl orange end-point. All titrations were performed in white porcelain evaporating basins with continuous steady stirring.

Whilst these analyses provide a very incomplete picture of the water composition, especially regarding anion species other than bicarbonate, they are considered adequate for a limited first analysis.

Speciation within the aqueous phase was determined using the WATSPEC program (Wigley, 1977). Mineral saturation indices were calculated as

$$SI_x = \log \left[\frac{IAP}{K_x}\right]$$

where SI_x is the index of saturation with respect to mineral X, IAP is the ion activity product of the dissociation products of X, and K_x is the dissociation constant for the appropriate mineral dissolution reaction. Using this system, a negative SI value indicates under-saturation, while a positive value reflects super-saturation. Also determined was the hypothetical partial pressure of carbon dioxide which would need to exist in a gas phase if the solution were in equilibrium with a gas phase. This is expressed here as $pPCO_2$ (i.e., $-\log (PCO_2)$) in atmospheres. For the free atmosphere $pPCO_2$ is thus about 3.5.

As noted earlier, calcium hardness was analysed at only two sites, the exurgence and the last sample location downstream. Values for the intermediate sites were estimated by interpolation between these two known values. Total hardness was however observed at all sites.

Accuracy of the primary observations

Temperature was read to 0.1°C and is believed accurate to this level. Readings of pH were made to 0.01 unit, but because analyses were made up to three hours after sample collection, accuracy may be no better than ± 0.1 unit. Alkalinity and hardness values are less subject to change in this period, and consideration of reading errors and uncertainty of recognition of end-points suggests that alkalinity, total and calcium hardness results are accurate to ± 15 ppm calcium carbonate equivalent or better.

RESULTS

The results obtained in the field and by computation are summarised in Table 1 and portrayed for easy interpretation in Figure 2. Principal points arising from these results are noted below.

Conditions at the exsurgence

The emerging water is quite warm (24.0°C); 28°C was observed on the previous visit. Such temperatures are very high relative to those of many springs studied elsewhere (e.g. Paterson, 1979). Additionally, the waters are extremely hard, carrying in excess of 650 ppm total carbonates (as $CaCO_3$ equivalent). A high value of the theoretical PCO_2 is also displayed, with $pPCO_2$ being +1.08 at the exsurgence. This corresponds to 8.3% CO_2 or 252 times the level in the free atmosphere. This is consistent with movement of the water through an environment enriched in CO_2 by organic processes, and probably, as suggested by the warmth of the water, at relatively shallow depth. At the exsurgence the water is slightly supersaturated with calcite (calcite saturation index SI_c = +0.73) at a pH close to neutral (7.04).

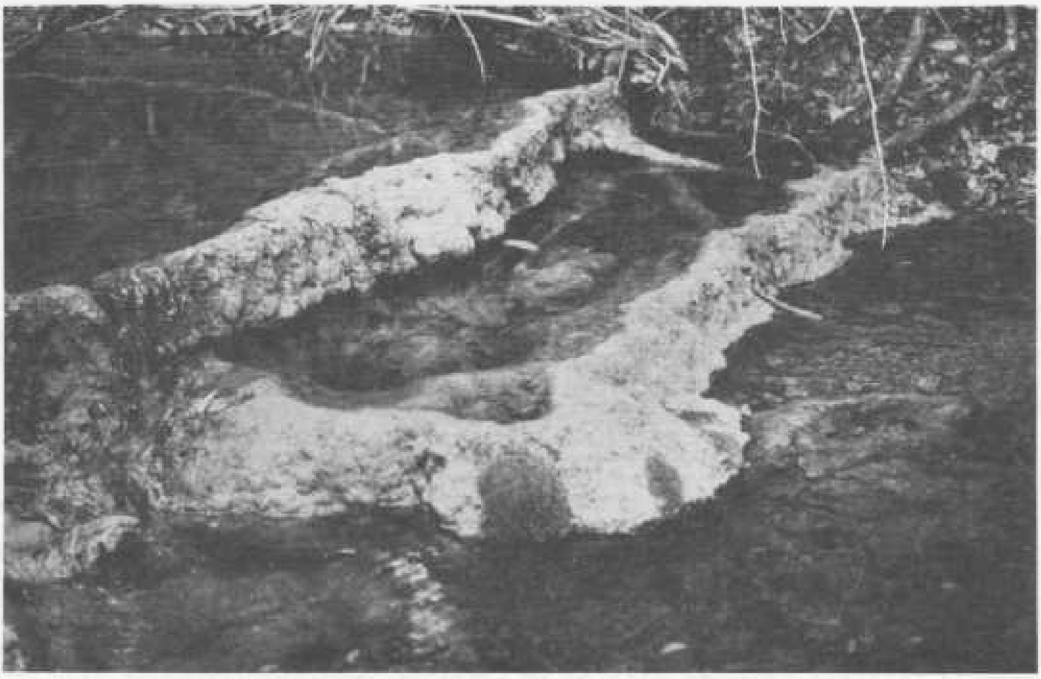


Plate 1. Two typical small tufa dams in the study area. A small overflow from the upper to the middle pool occurs in the centre of the upper dam, and an overflow direct from the upper pool to the lowest occurs at the left of the photo.

TABLE I. RESULTS OF THE WATER CHEMISTRY ANALYSES

Location	Temp (°C)	pH	Ca^{2+} (mMl^{-1})	Mg^{2+}	Alkalinity (m.e. l^{-1})	Specific Conductivity (µS 25°C)	pCO_2 (Bar)	SI_c	SI_d
Spring	24.0	7.04	4.63	2.74	16.08	1685	1.08	0.73	1.31
100m down-stream	24.0	7.41	4.44	2.63	15.51	1655	1.47	1.06	1.99
150m	24.0	7.45	4.24	2.51	14.54	1575	1.54	1.06	1.99
200m "	25.0	7.55	4.19	2.48	14.34	1565	1.65	1.15	2.16
300m "	25.2	7.65	4.01	2.36	13.76	1550	1.76	1.22	2.30
400m "	25.0	7.60	3.93	2.32	13.45	1510	1.73	1.13	2.10
430m "	25.0	7.80	3.39	2.28	11.42	1400	1.99	1.23	2.38

Changes in the downstream direction

In its passage downstream, the water progressively deposits carbonates (principally calcium carbonate), losing 156 ppm $CaCO_3$ equivalent, or about 24% of its original load, over the 430 metres. Since the water temperature remains constant (the creek is well shaded) this deposition is presumably driven by the degassing of CO_2, especially at places of good aeration. The value of $pPCO_2$ rises to 1.99 at 430 metres, corresponding to a fall to 1% CO_2, or about 31 times atmospheric level. Correspondingly, the pH rises downstream to 7.80 at 430 m, through the reactions

$$H_2CO_3 \rightleftharpoons CO_{2(g)} + H_2O \quad \ldots\ldots (1)$$

(equivalent to $CO_{2(aq)} \rightleftharpoons CO_{2(g)}$)

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \quad \ldots\ldots (2)$$

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^- \quad \ldots\ldots (3)$$

and the generalized precipitation reaction

$$Ca^{2+}_{(aq)} + 2HCO_3^- \rightleftharpoons CO_{2(g)} + CaCO_{3(s)} + H_2O_{(1)} \ldots\ldots (4)$$

by which hydrogen ions are lost as the CO_2 is released.

Alkalinity decreases from 16.1 m.e.l^{-1} at the exsurgence to 11.4 m.e.l^{-1} at 430 metres.

Significantly, it appears that the loss of CO_2 to the air, even in this relatively quiet stretch of water, proceeds more rapidly than deposition of carbonates along the channel. Thus SI_c increases steadily from +0.73 at the exsurgence to +1.23 at 430 m, and the solution is further from equilibrium with the solid phase than at the exsurgence.

The same observations apply to saturation with respect to dolomite; SI_d increases from +1.31 at the exsurgence to +2.38 at 430 m. Only 33 ppm magnesium hardness (as $CaCO_3$) or 17% of the original amount, is lost over the 430 m compared with 27% of the calcium carbonate. Here again it appears that loss of CO_2 has proceeded more rapidly than the deposition of carbonates.

The possibility that evaporative loss of water from the channel leads to concentration of the dissolved carbonates and so to carbonate deposition also warrants examination. Evaporative losses over the 430 metres are unlikely to be great, since the channel is sheltered from wind and direct sunlight by riparian vegetation. Further, if significant evaporation was necessary in order to drive the solution into supersaturation, an increase in solute concentrations away from the exsurgence might be expected, extending downstream to the point where precipitation was initiated. Below this point, concentrations might remain steady or continue to rise depending on kinetic effects. In consequence, $pPCO_2$ would either remain steady, or fall. Neither effects is observed; concentrations decline downstream as $pPCO_2$ rises correspondingly. Hence the primary cause of carbonate precipitation must be loss of CO_2, which can cause saturation levels to increase at the same time as solute concentration decline. Limited evaporation may be occurring, but must be assigned a major role because of the observed trends in $pPCO_2$ and solute concentrations.

DISCUSSION

The results presented above indicate that the tufa forming dams and rims at this site is deposited by spring waters only slightly supersaturated with respect to calcite, and that the deposition is probably driven by carbon dioxide loss to the air, the latter reaction proceeding faster than carbonate deposition. Further, the saturation index values given above can be regarded as maxima, since the calculated activity coefficients will be slightly too high owing to under-estimation of the ionic strength from incomplete solute analyses. Uncertainties in pH could, however, act in the opposite direction.

Few other studies are available with which this result may be compared. Barnes (1965) observed the chemistry of Brich Creek, a small travertine-depositing stream in California fed by several springs and seeps. These had $pPCO_2$ values in the range 2.14 - 2.88 or about 15 to 20 times the atmospheric level. Two of the seeps displayed calcite saturation indexes (converted to the form used here) of 0.16 and 0.62, indicating a level of supersaturation similar to that observed in the present study. The data presented by Barnes for several sites downstream of the springs are not from the same dates and hence cannot be strictly compared. Bearing this qualification in mind, his data suggest that SI_c increased downstream to perhaps 1.2 after about 2000 m of flow. Travertine was being deposited in this reach from waters which carried about 80 ppm Ca^{2+} at 10-15°C and pH 7.5-8.2; the travertine became more extensive toward the lower end of the study reach, where a continuous crust existed on the bed. Barnes noted that these data suggest that CO_2 degassing is less sluggish than calcite deposition.

Shuster and White (1971) analysed reactions in the spring-fed Elk Creek in Central Pennsylvania from samples taken at the spring and at 200 m intervals to 1200 m downstream. Their results reveal that calcium ion concentrations remained steady at 40-42 ppm over the entire study reach; bicarbonate ion levels similarly fluctuated less than 2 ppm over the 1200 m. The partial pressure of CO_2, however, dropped from 0.35% at the spring (ten times atmospheric) to 0.06% (less than twice atmosphere) at 800 metres; pH rose from about 7.5 at the spring to about 8.2 at 800 m. SI_c was about -0.55 at the spring, rose steadily to zero at about 600 m, and finally to about +0.25 at 800 m and beyond. This supersaturation did not however, result in any visible carbonate deposition, and the water remained super-saturated.

Loss of carbonates downstream in Gordale Beck in Yorkshire was studied by Pitty (1971). Too few data are presented for a meaningful interpretation, although the observations at two sites along the stream do reveal either no change in pH or else a decrease downstream. In only three of the eleven paired observations does pH increase downstream. However, Smith (1965) and van Everdingen (1969) have both reported rise in pH downstream of springs similar to that found in the present work.

Tufa deposition along a spring-fed stream in the Transvaal was studied by Marker (1973). Analyses of water samples collected from the spring and sites at about 2000 and 4000 m downstream revealed that total carbonate content (as $CaCO_3$) declined from about 85 ppm at the spring to 60 ppm after 4000 m of flow, being a loss of 29% of the original load. Unfortunately, Marker had insufficient data for SI_c or PCO_2 to be calculated.

Clearly, too few studies of tufa deposition yet exist for soundly-based generalisations concerning the controlling factors to be made. In only two studies (the present work and the investigations of Barnes, 1965) has carbonate deposition been related to the degree of supersaturation of the spring and stream waters. Both studies suggest that extensive deposition may occur from water in which SI_c is considerably less than 1.0. Shuster and White (1971) observed no deposition from water displaying SI_c values of around 0.25, but no firm minimum value of SI_c required for deposition can yet be proposed.

The present findings concerning loss of CO_2 to the air are similar to those of Barnes (1965) and Shuster and White (1971). Degassing appears to be quite rapid and the evidence is quite good that it proceeds considerably more rapidly than carbonate deposition. The reactions represented by equations (1), (2) and (3) previously are known to proceed rapidly (see Stumn and Morgan 1970) but the factor or factors which retard the overall deposition reaction (equation 4) are not yet understood.

Plant growth may play some role in the removal of CO_2 from the stream waters. However, few mosses or other plants grow on the tufa dams or along the stream studied in the present investigation, and Marker (1973) considers plant activity to be of little importance in the formation of the Travsvaal tufas. Simple degassing from the water surface alone appears to be capable of driving surface waters into supersaturation, though further data would be valuable on this point.

Climate and carbonate solution and deposition

The waters observed in the present study carry a considerable load of dissolved carbonates, and yet are not far from equilibrium with solid calcite. This situation could only exist if the water had been in contact with a gas phase containing over 50 times the atmospheric level of CO_2. The source of this CO_2 must clearly be the soil air, enriched in CO_2 by the respiration of soil organisms and decay (oxidation) of organic matter. Such processes are invigorated in the warm tropical environment. Thus, despite the inverse relationship between CO_2 solubility and temperature, waters passing through the soil in such an environment are able to collect the requisite carbon dioxide. Further data on this point are provided by Drake and Wigley (1975).

In a study of spring waters at sites from southern Canada to northern Mexico, Harmon, White, Drake and Hess (1975) were able to establish the relationship

$pPCO_2 = -3.16 + 0.070T$....................(5)

between $pPCO_2$ and water temperature in Celsius degrees. This relationship was based on a sample of 305 spring water analyses. However, in this data set, SI_c also correlated well with temperature ($r = 0.84$) suggesting that dynamic effects related to completeness of the dissolution reaction might be involved. Limiting the analysis to samples with SI_c between +0.1 and -0.1 to reduce this effect yielded the relation

$pPCO_2 = -3.42 + 0.77T$....................(6)

based on 63 of the original data sets.

For the spring observed in the present study, this relationship predicts $pPCO_2 = 1.495$; the value calculated from the field data was -1.08. This is quite a close agreement given that only one observation (rather than the mean of several) is used, and is consistent with the existence of a relationship between temperature and soil atmosphere PCO_2 of the kind suggested by Drake and Wigley (1975). Thus, climate may have a major effect on carbonate solution and precipitation through the control exerted by temperature on rates of CO_2 production in the soil. The absence of extensive tufa deposition around springs in the cooler parts of southern Australia (such as Buchan in eastern Victoria) might be explained by this effect. However, local hydrologic and lithologic characteristics may exert an over-riding control on the processes involved, so that the individual sites need to be studied in order to fully understand the reasons for carbonate deposition or lack of deposition from spring waters. In particular, the presence of non-carbonate anions such as Sulphate (Akin and Lagerwerff, 1965) or of small amounts of certain elements such as scandium (Nestaas and Terjesen, 1969) may greatly modify both solution and deposition rates and equilibrium concentrations in karst waters, making the identification of the true role of climiatic variation problematic.

CONCLUSION

The partial chemical analyses used in this investigation do not provide a complete picture of the composition of the spring and stream waters. More thorough analyses might reveal chemical processes additional to those outlined here. Further, the analyses describe the behaviour of the spring water for only one date. Seasonal (and possibly diurnal) fluctuations might also be significant at this site. The results have, however, permitted a first analysis of factors leading to the deposition of the tufa. Increase in water temperature downstream is negligible, and loss of carbon dioxide to the air appears to be the factor driving the solution into supersaturation.

The separate issue of why the tufa is laid down as discrete dams rather than continuously along the channel remains to be examined. Once a dam exists, the enhanced aeration where the water cascades over the barrier would be sufficient to foster its growth. Perhaps an initial roughness in the channel functions in the same way. Numerical modelling will probably be required in order to resolve this aspect of tufa dam construction.

ACKNOWLEDGEMENTS

The author wishes to thank Monash University for financial support and Mandy Kotzman for assistance with the chemical analyses. Mr. S. Johnson kindly permitted access to the spring located on his property.

REFERENCES

AKIN, G.W. and LAGERWERFF, J.V., 1965 Calcium carbonate equilibria in aqueous solutions open to the air. II. Enhanced solubility of $CaCO_3$ in the presence of Mg^{2+} and SO_4^{2-}. Geochim. et Cosmochim. Acta 29: 363-360.

BARNES, I., 1965 Geochemistry of Brich Creek, Inyo County, California: a travertine depositing creek in an arid climate. Geochim. et Cosmochim. Acta 29: 85-112

DRAKE, J.J. and WIGLEY, T.M.L., 1975 The effect of climate on the chemistry of carbonate groundwater. Water Resour. Res. 11: 958-962.

HARMON, R.S., WHITE, W.B., DRAKE, J.J. and HESS, J.W. 1975 Regional hydrochemistry of North American carbonate terrains. Water Resour. Res. 11: 963-967.

MARKER, M.E., 1973 Tufa formation in the Transvaal, South Africa. Z. Geomorph. 17: 460-473.

NESTAAS, I. and TERJESEN, S.G., 1969 The inhibiting effect of Scandium ions upon the dissolution of calcium carbonate. Acta Chem. Scand. 23: 2519-2531.
PATERSON, K., 1979 Limestone springs in the Oxfordshire Scarplands: the significance of spatial and temporal variations in their chemistry. Z. Geormorph., Supp. 32: 44-46.
PITTY, A.F. 1966 An approach to the study of karst water. University of Hull: Occasional Papers in Geography No. 5. Pp 70.
PITTY, A.F. 1971 Observations of tufa deposition. Area 3: 185-189.
SHUSTER, E.T. and WHITE W.B., 1971 Seasonal fluctuations in the chemistry of limestone springs: a possible means for characterising carbonate aquifers. J. Hydrol. 14: 93-128.
SMITH, D.I., 1965 Some aspects of limestone solution in the Bristol region. Geog. J. 131: 44-49
STUMM, W. and MORGAN, J.J., 1970 Acquatic Chemistry. Wiley, New York. Pp 583
VAN EVERDINGEN, R.O., 1969 Degree of saturation with respect to $CaCO_3$, $CaMg(CO_3)$ and $CaSO_4$ for some thermal and mineral springs in the Southern Rocky Mountains, Alberta and British Columbia. Can. J. Earth Sci. 6: 1421-1430
WIGLEY, T.M.L., 1977 WATSPEC: A computer program for determining the equilibrium speciation of aqueous solutions. British Geomorphological Research Group Technical Bulletin 20, Pp 48.

Address for Correspondence: Department of Geography, Monash University, Clayton, Vic. 3168

SCANNING ELECTRON MICROSCOPE STUDIES OF CAVE SEDIMENTS*

David S. Gillieson

Abstract

The microstructure of the surfaces of quartz sand grains can reveal their history prior to their deposition in a cave. The scanning electron microscope is the ideal tool for such studies. This paper presents examples of the sort of information obtainable from such a study, drawing examples from caves in Australia, Papua New Guinea and Norway.

INTRODUCTION

The analysis of cave sediment sequences is a well established methodology for the reconstruction of environmental histories. Reduced temperature and humidity fluctuations within caves and rockshelters reduce the post depositional alteration of sediments (Frank, 1971). Therefore sediment sequences may be preserved intact for Milennia and their analysis has provided information on transport mechanisms and depositional environments for archaeologists, geomorphologists and geologists.

Traditional avenues of approach include particle size analysis, clay mineralology and chemical properties (for an Australian example, see Frank (1975)). A relatively recent method is the analysis of surface features of the quartz sand fraction by means of the scanning electron microscope (S.E.M.). This paper briefly reviews the methodology and methods of this approach and provide some examples from the authors research in Australia, Papua New Guinea and Norway.

BACKGROUND THEORY

The application of the SEM to sedimentology has been developed by Krinsley and his co-workers (Krinsley, 1978) since 1968. The objective was to investigate the surface texture of quartz sand grains as it was considered that quartz, a relatively abundant and resistant mineral with no apparent cleavage, would reflect on its surfaces different palaeoenvironmental features. These features would result from the particular energy conditions characteristic of various transport, depositional and weathering environments. Over the last ten years extensive research involving field and experimental studies has permitted characterisation of certain geomorphic environments. Figure I is based on the authors work and the detailed studies of Krinsley and Doornkamp (1973), Margolis and Krinsley (1974) and Krinsley (1978). It must be stressed that only the identification of certain combinations of surface features in statistically significant percentages permits identification of a sedimentary environment.

Glacial environments, in which sediment transport occurs within and contiguous to the ice mass, involve the sediment being subjected to grinding and sliding action. The consequences of this action is the production of angular grains with characteristic conchoidal fractures, breakage blocks, scratches, step like features and abrasional features termed "chattermarks" (Bull, Calver and Garduer, 1980). Fluvioglacial action tends to round and subdue this suite of surface features producing a distinctive grain form.

Modification of subaqueous transport in streams and currents seems to be dependent on the energy level involved. Early sedimentary petrologists such as Krumbein (1974) noted the rounding and reduced relief of fluvial grains. In turbulent flow regimes the buffeting of suspended grains produces small irregularly oriented impact pits, chipped into the surface. Both Margolis and Kennet (1971) and the author (Gillieson, 1980) suggest that there is a relationship between the density of these pits and different energy levels for subaqueous transport. At high levels of energy, wholesale flaking of the grain surface and abrasional tooling occur. Although abrasion by wind also leads to rounding, upturned plates can be seen exposed on the grain surfaces and represent the ends of the weakly expressed cleavage plates detected by Krinsley and Smalley (1973) and Margolis and Krinsley (1974).

*Paper presented at the 13th Biennial Conference of the Australian Speleological Federation, Melbourne, December 1980.

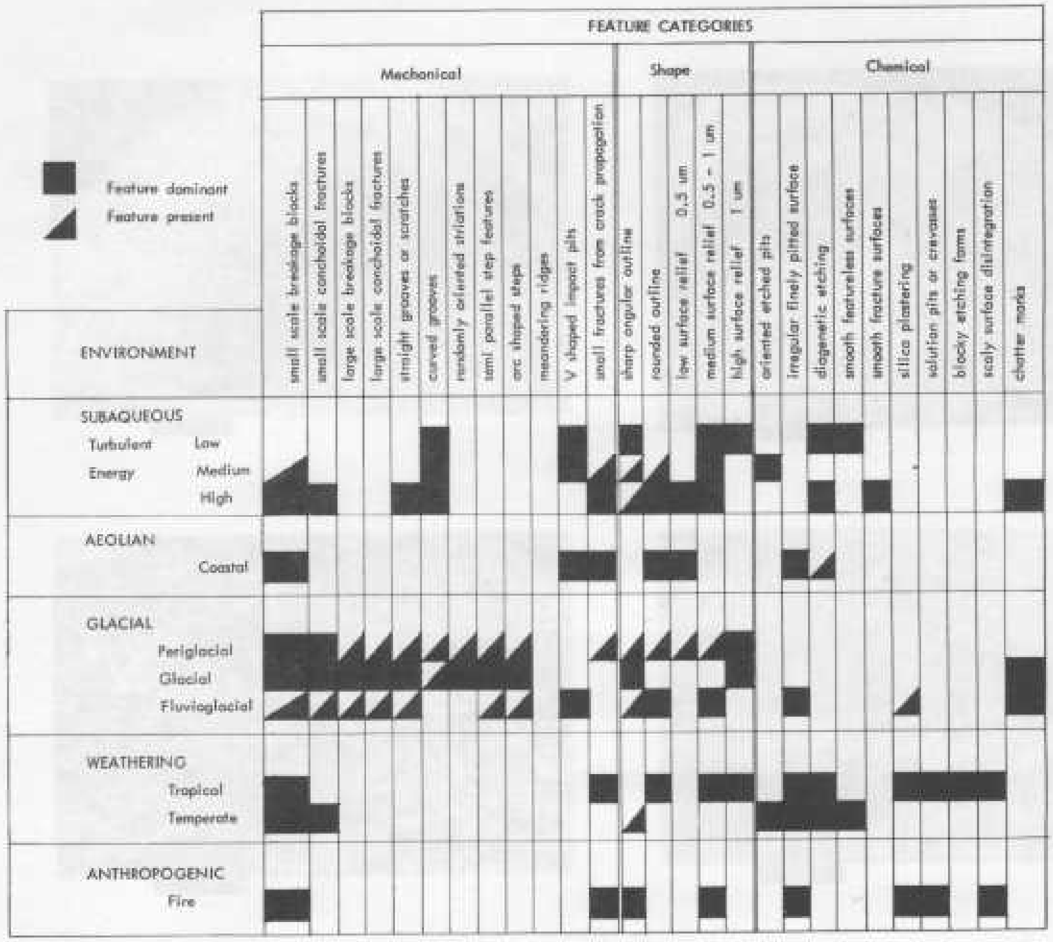


Figure 1. Quartz grain surface features and their environmental occurrence.

Appreciable solution and reprecipitation of silica can occur in environments where silica mobilisation is widespread, for example, in the leached and laterised soils of tropical Australia and New Guinea. Grain surface solution in these high energy chemical environments results in a suite of forms such as etch pits and crevasses. Reprecipitation of silica in alkaline environments results in either amorphous silica plastering or eudhedral crystal growth, depending on the rate of deposition.

Experimental and field studies by the author suggests that strong heating of surface grains in an alkaline chemical environment produces scaly weathering and surface disintegration of grains. Such conditions are found in fire and its resultant ash. Examination of grains from archaeological hearths reveals a dominance of this form which is absent from all other non burnt sediments so far examined.

SEM has several advantages over light microscopy, the principal ones being its finer resolution and extreme depth of field which permits simultaneous viewing of a suite of features of the grain surface.

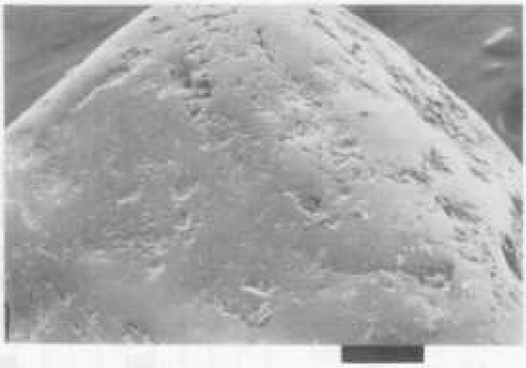
METHODS

Sediment samples are dispersed without agitation and the sieved sand fraction retained. Unicrystalline quartz grains are separated, checked for mineralogy using petrographic techniques, and cleaned using boiling concentrated hydrochloric acid. This treatment does not affect the surface texture (Krinsley and Doornkamp, 1973; Tovey and Wong 1978) but removes furruginous or calcareous coating. The cleaned sample is rinsed, dried and mounted on an aluminium stub for viewing. During SEM examination 20 or more grains are chosen at random and the presence or absence of each of the features in figure 1 noted for each grain. This permits a statistically reliable characterisation of the sample.

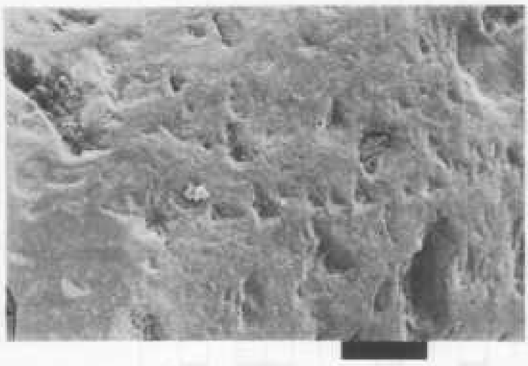
SOME RESULTS FROM CAVE STUDIES

The sedimentary sequences in several large P.N.G. caves have been studied by the author as part of his doctoral research. Two cave systems which bear strong similarity in morphology and geomorphic development are the Atea Kananda and Selminum Tem. Although the latter system is now largely abandoned by the streams that feed it,

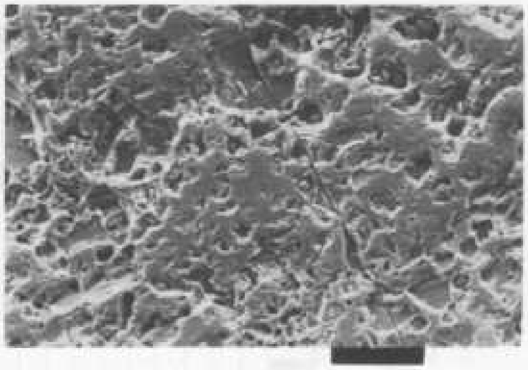
a



b

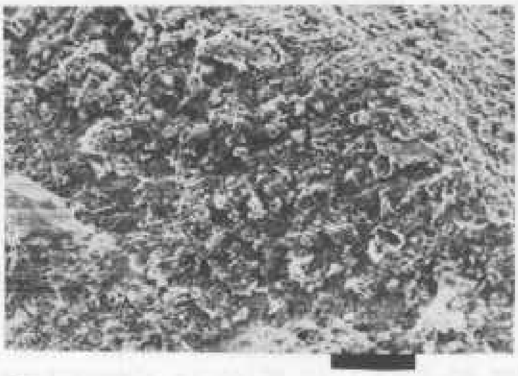


c

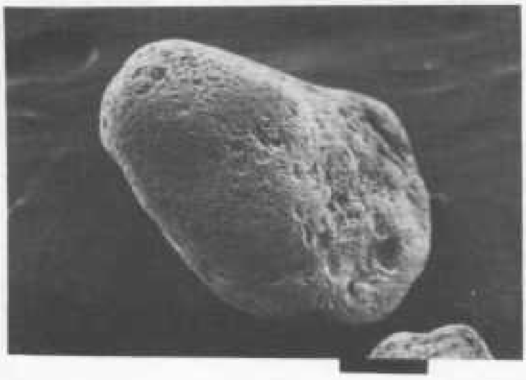


d

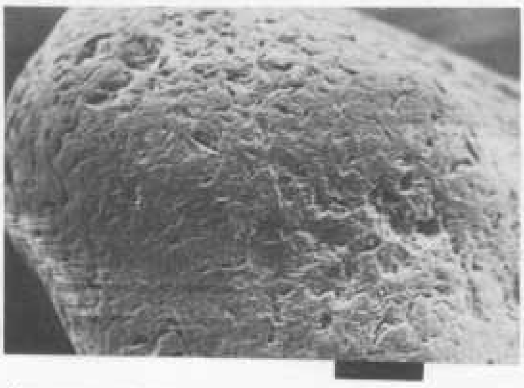
e



f

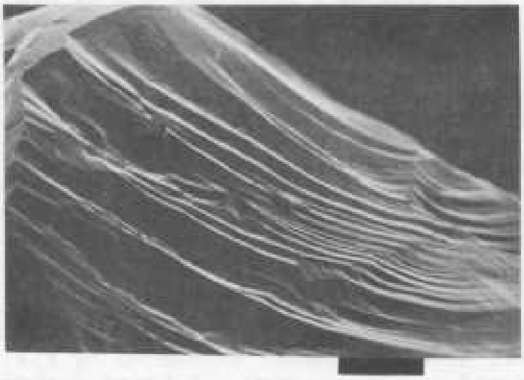


g



h

i



j

Plate I

a Rounded quartz grain from the Fury Tube, Atea Kananda. Note numerous small fractures, curved grooves and incipient chattermarks. Scale 100 µm.

b Grain surface of sand from Ugwapugwa, Atea. showing minor fractures, extensive V pitting, and diagenetic etching of grain ends. Scale 100 µm.

c V pits on a grain from the Fury Tube, Atea. Pits are irregularly spaced and deeply incised. Scale 400 µm.

d Deeply etched grain surface from Rafting Ground. Atea. Surface is completely covered with blocky etching and solution crevasses. Scale 10 µm.

e Grain from the mudflow deposit in Selminum Tem. Note abrasional striations, conchoidal fractures and rounding. Scale 200 µm.

f Scaley weathering of grain from hearth in Aibura cave excavations, P.N.G. Scale 20 µm.

g Whole grain from Ashford Cave, N.S.W. The well rounded quartz sand has extensive diagenetic etching of surface flaws. Scale 100 µm.

h Enlargement of g showing shallow etching forms, crevasses and minor fractures. Scale 40 µm.

i Quartz grain from relict sediments in Greftkjelen pothole, Norway. Highly angular with extensive choncoidal fractures. Scale 200 µm.

j Conchoidal fracture from i showing arc shaped steps, striations and small scale breakage blocks. Scale 40 µm.

the sediments are comparable. Both caves have evolved from early nothephreatic conduits, through a phase of dynamic phreatic enlargement, to their present state of vadose incision. Each cave has several levels which are related to structural and lithological controls, and the successive capture of surface streams, rather than to uplift. The systems have a wide range of sedimentary environments from high energy, turbulent flow to the small feeders which carry storm rainfall underground. Due to the relatively good preservation of cave sediments, it is possible to examine material with little or no diagenetic modification since emplacement.

The source of most of the quartz fraction is either from the erosion of soils derived from the Darai limestones and shale interbeds, directly from rock erosion, or from quartz in volcanic ash (tephra). The surface textures of tephra dervied quartz are generally lacking in mechanical fractures or diagenetic etching, smooth surfaces being characteristic. Grains derived from the Darai limestone are usually angular and fractures, with small scale breakage blocks and minimal diagenetic etching.

Quartz grains from surface soils are subangular with high relief and their surfaces are entirely modified by blocky etching and the development of solution pits and crevasses. This suite of textures is similar to that recorded for other tropical weathering environments (Gillieson, 1980). Silica plastering is minimal suggesting its removal is complete in these leached soils. Plate 1d shows the texture of these soil derived quartz grains. Washing of this material into caves by small, ephemeral surface streams causes little modification apart from rounding of grains and some fracture development. Grains that have been subjected to fluvial transport at higher energy levels are extensively modified. The grains are well rounded (Plate 1a and b) with extensive areas of abraded, featureless surfaces and a suite of fractures, scratches and grooves as well as V pits (Plate 1c). In hollows the etched surface is preserved. At high levels of fluvial energy, wholesale flaking of the grain surface results in numerous fresh fracture surfaces on which abrasional tooling marks - chattermarks - are recorded.

Mass movement processes are of great importance in landsurface reduction in the montane tropics. Mudflow deposits are widespread and may profoundly alter the characteristics of stream channels by infilling. In Selninum Tem a large mudflow has entered the cave conduit and traces are found up to 3 km from the upstream entrance. The quartz fraction of this deposit has surface textures which reflect the fluidised transport of this unsorted, matrix supported clay gravel. The grains have abundant fractures, abrasional tooling and small conchoidal fractures. It is therefore possible to differentiate these deposits from fluvial gravels, whose textures resemble those of the fluvial grains noted above. It is also possible to differentiate fluvial from soil derived material and to rank fluvial deposits in terms of depositional energy. This permits reconstruction of the sedimentary sequence in a cave which may be related to landscape evolution or climatic change.

Ashford Cave is located in a northeastern New South Wales at the headwaters of the McIntyre River. It is a horizontal epiphreatic system with at least three levels of development, evidenced by flat roof sections and accordance of phreatic pendants and spongework. A brief description has been provided by Grimes (1977) and the cave has been mapped by the author. Old stream cliffs near the upstream entrance suggest that the cave may have functioned as a meander cut off cave, and the uppermost level of cave development is accordant with a terrace remnant on nearby Limestone Ck. 3.6 m of sediment stratigraphy were obtained by augering in a infilled phreatic section. The upper part of the sequence is guano derived banded clay sediment. Below 2.9 m the sediments change to orange and reddish brown earths with grey clay modules. It is suggested that this unit represents soil derived sediments washed into the active cave system. Samples were prepared as above for SEM analysis. The quartz grains are sub rounded, supporting water transport, and their surfaces are wholly covered by a complex of solution pits (Plate 1 g and h) and crevasses, suggesting a strong chemical weathering environment. In many respects they are similar to the PNG material but lack the intensity of pitting and features of high energy fluvial sediments. The basal sediment therefore represents fluviatile material, possibly related to the creek terraces, which has been washed into the cave during the period in which it functioned as a meander cut off. The diagenetic modification to the grains may have occurred during one or more phases of reworking and indicates a strong weathering environment not inconsistent with the present humid mild winter climate.

Just north of the Arctic Circle in Norway are found extensive areas of intensely folded Cambro-Silurian limestone. The outcrops tend to occupy narrow zones in the glaciated valleys and dip at between 45 and 80 degrees. The most recent glaciation (Wurm - Wisconsin) resulted in the excavation of the present topography with a relative relief of at least 500 m. Preglacial cave systems would therefore have to be formed at depths of 500 m and would have been nothephreatic. There is however an absence of the forms associated with this hydrologic regime in Norwegian caves, which are dominantly dynamic phreatic or vadose in nature. A more likely explanation is that the caves were developing subglacially and have enlarged in the 10,000 years following glacial retreat. Both water circulation and carbonate solution near the soles of extant glaciers have been noted by Ford, Faller and Drake (1970).

At the northern margin of the Svartisen ice cap two cave systems, Greftkjelen and Greftsprekka, have been mapped to depths of 340 and 325 metres respectively. The caves have developed on several levels and contain pressure tube sections inclined at angles of up to 35 degrees. Relict sediments are found on high level ledges in the caves and are well sorted sands. The surface textures of the quartz fraction show the suite of forms characterising glacial transport. Examples are shown in Plate 1 i and j. This, and the bedrock morphological evidence of extensive frost shatter and glacial mills in the entrance dolines, would support a subglacial origin for the caves. Comparison with till deposits pushed into Setergrotten, a cave near Mo - i - Rana, shows identical surface features.

CONCLUSIONS

Scanning electron microscopy is a useful addition to the methods used by cave geomorphologists in their reconstructions of speleogenesis and palaeoenvironmental change. Used in conjuction with granulometry, it permits differentiation of depositional processes which might yield similarly textured deposits. Although an extensive European literature has provided examples of textures from known geomorphic environments, what is needed in Australasia is a comparative collection from the wide range of climatic and geomorphic regions which comprise our sphere of activity.

REFERENCES

BULL, P.A., CULVER, S.J., and GARDNER, R. 1980 Chattermark trails as palaeoenvironmental indicators. Geology 8 : 318-322.

FORD, D.C., FULLER, P. and DRAKE, J.J. 1970 Calcite precipitates at the soles of temperate glaciers. Nature 226 : 441-442.

FRANK, R.M. 1971 Cave sediments as palaeoenvironmental indicators and the sedimentary sequence in Koonalda Cave. In: MULVANEY, D.J. and GOLSON, J. (eds.) Aboriginal man and Environment in Australia: 94-104. ANU Press Canberra.

FRANK, R.M. 1975 Late Quarternary climatic change: evidence from cave sediments in central eastern New South Wales, Aust. Geogr. Stud. 13 : 154-168.
GILLIESON, D.S. 1980 The clastic sediments of the Atea Kananda. In: JAMES, J.M. and DYSON, H.J. (eds.) Caves and Karst of the Muller Range: 103-109.
GRIMES, K.G. 1977 The border rivers karst region, Queensland and New South Wales Proc. 11th Bienn. Conf. Aust. Speleol. Fedn.: 131-4.
KRINSLEY, D.H. 1978 The present state and future prospects of environmental discrimination by scanning electron microscopy. In: WHALLEY, W.B. (ed.) Scanning electron microscopy in the study of sediments: 169-180. Geo. Abstracts Ltd., Norwich.
KRINSLEY, D.H. and DOORNKAMP, J.G. 1973 Atlas of quartz sand surface textures. Cambridge University Press, Cambridge.
KRINSLEY, D.H. and SMALLEY, I.J. 1973 Shape and nature of small sedimentary quartz particles. Science 180 : 1277-1279.
KRUMBEIN, W.C. 1941 Measurement and geologic significance of shape and roundness of sedimentary particles. J. Sed. Petrol. 11 : 64-72.
MARGOLIS, S.V. and KENNET, J.P. 1971 Cenozoic palaeoglacial history of Antarctica recorded in subantarctic deep-sea cores. Am. J. Sci. 270 : 1-36.
MARGOLIS, S.V. and KRINSLEY, D.H. 1974 Process of formation and environmental occurrence of microfeatures on detrital quartz grains. Am. J. Sci. 274: 449-464.
TOVEY, N.K. and WONG, K.Y. 1978 Preparation, selection and interpretation problems in scanning electron microscope studies of sediments. In: Whalley, W.B. (ed.) Scanning electron microscopy in the study of sediments: 181-200 Geo. Abstracts Ltd., Norwhich.

DAMAWEWE CAVE, ALOTAU, PAPUA NEW GUINEA

C.F. Pain and C.D. Ollier

Abstract

Damawewe is a cave formed in Quaternary limestone near Alotau, Papua New Guinea. It consists of three sets of passages: the uppermost (and oldest) are the largest and the lowermost (active) are the smallest. Although the cave is mainly vadose, there is evidence of enlargement by corrasion and by collapse (in the uppermost level), and the sequence of cave formation has been interrupted by at least one phase of cave fill by clay and gravels.

INTRODUCTION

The area around Alotau, in Milne Bay Province, Papua New Guinea, has a number of small areas of uplifted coral limestone. Caves have been reported in some of these areas. In this paper we describe a cave located at Damawewe. Damawewe is a place in secondary growth forest about 45 minutes walk north of Hagita High School, which is itself about 12 km west of Alotau (Figure 1). The cave is not easy to locate. We contacted the owner, Lage Tede, who lives in Sineada Village, near Hagita and opposite the Sineada Agriculture Station.

We visited the cave in July 1980 and surveyed it with compass and tape. Although many people have visited the cave, as far as we are aware this is the first time it has been surveyed.

GEOLOGICAL BACKGROUND

The geology of the Milne Bay area is mapped at 1:250 000 on the Samaria geological sheet (Smith and Davies, 1973). Middle Eocene submarine basalt (Kutu Volcanics) forms most of the area shown in Figure 1. These rocks underlie ranges that rise to nearly 1000 m to the north and south of Milne Bay. There are two Quaternary rock units mapped in the area. One (Qu - Figure 1) is composed of a whole variety of fluviatile gravels, sands and clays and occurs along the coast and also infilling the depression at the head of Milne Bay. The other (Qc - Figure 1) consists of raised coral limestone and is found along the northern side of the Milne Bay depression. Other areas occur on the northern coast outside the area shown on Figure 1. The limestone is mostly massive biohermal, well crystallised and hard. It is overlain by a stratum of marl (calcareous clay) with some shelly fossils, the contact being more-or-less horizontal and apparently conformable.

Milne Bay has been interpreted as a graben (Jongsma, 1972), but we think it equally likely that it is a fault angle depression, tilted to the south. Smith (1980), and Smith and Simpson (1972) report evidence for two periods of uplift in the area in post-Miocene times, the later period involving some tilting to the southeast. Whatever the tectonic history, the limestone with which we are concerned is almost certainly of Quaternary age, and was uplifted to its present elevation of 150 - 200 m presumably during the second of the two periods of uplift.

THE CAVE

The main entrance to Damawewe Cave is in a doline on a valley side, and there is another entrance at a lower level where the valley side is somewhat steeper. The ground surface is not particularly karstic apart from a few dolines, presumably because of the youth of the limestone. However, cave development in Damawewe is exceptional for such young limestone.

The cave consists of three distinct stream passages (Figure 2). The upper passage is large (see cross sections of Figure 2), with a rounded roof where it is in solid limestone. To the west where the roof is in marl the roof is irregular because of the collapse of large slabs of marl, still present on the cave floor. Some of the collapse appears to be very recent and the passage is evidently still being modified by this collapse mechanism even though it is no longer hydrologically active. The floor is covered by clay and guano, over a metre thick in most places. Flowstone and speleothems are not abundant, but are well formed in a few places.

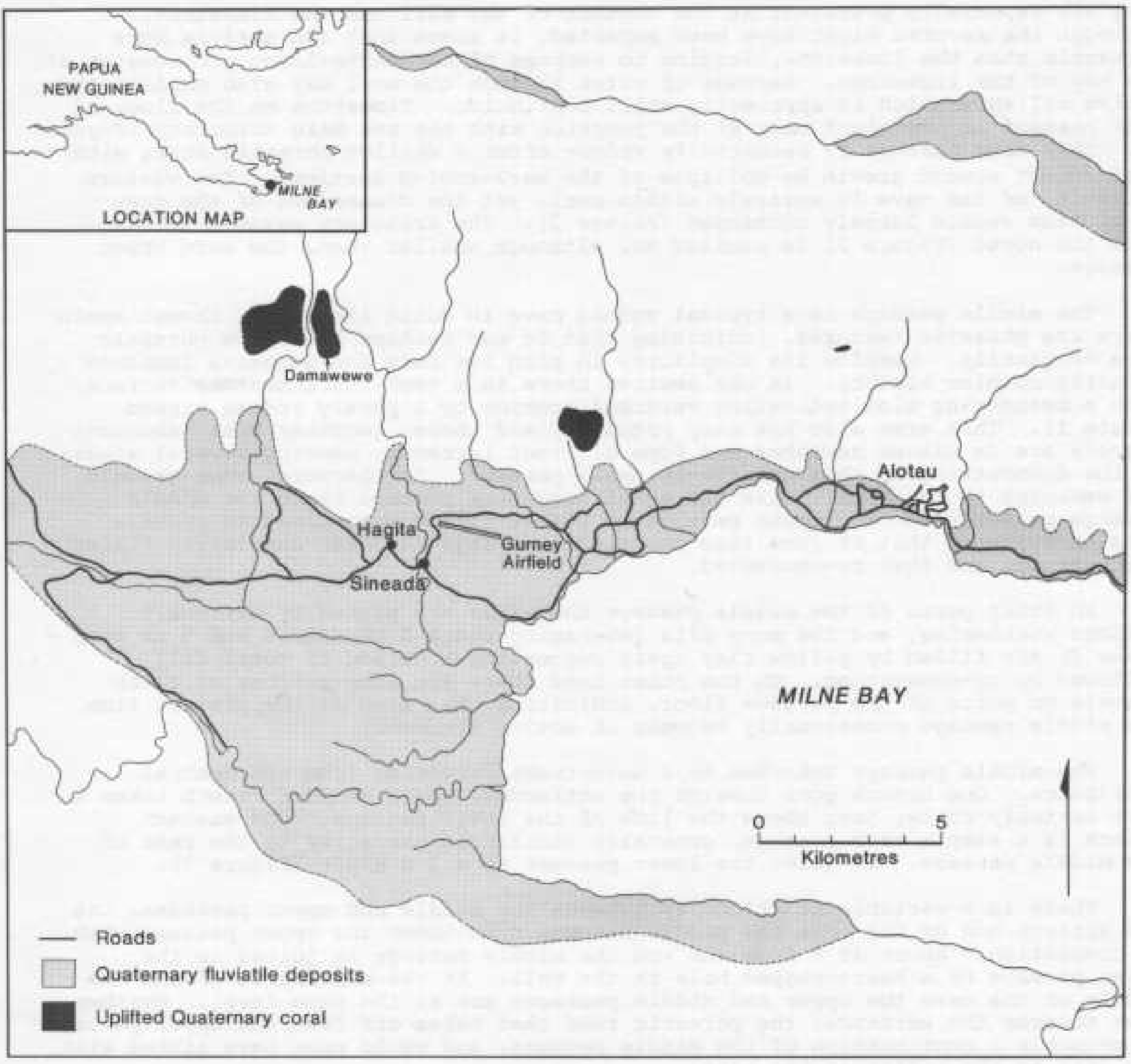


Figure 1. Location of places mentioned in the text, and Quaternary rock units.

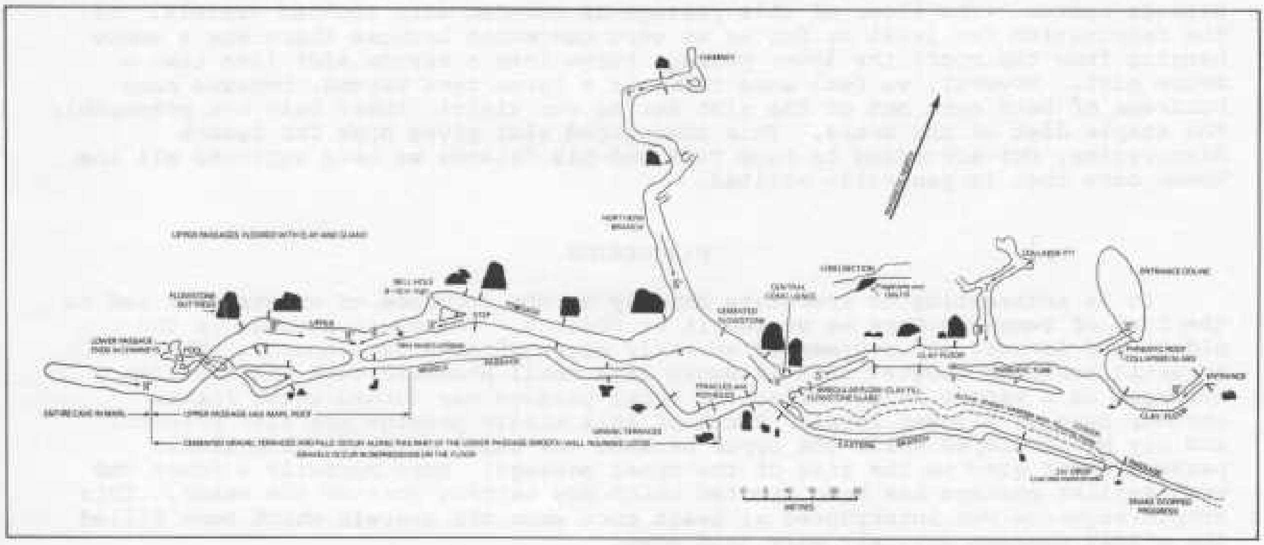


Figure 2. Plan and cross-sections of Damawewe Cave.

They are especially prevalent at the contact of the marl and the limestone. Although the reverse might have been expected, it seems that the marl is more permeable than the limestone, leading to seepage of carbonate-laden groundwater at the top of the limestone. Seepage of water through the marl may also explain the active collapse which is apparently still continuing. Flowstone on the floor of this passage is prevalent only at the junction with the one main tributary (Figure 2). This cave passage is essentially vadose after a shallow phreatic start with more recent upward growth by collapse of the marl-roofed sections. The western extremity of the cave is entirely within marl, yet the dimensions of the cave in section remain largely unchanged (Figure 2). The tributary passage joining from the north (Figure 2) is similar to, although smaller than, the main upper passage.

The middle passage is a typical vadose cave in solid limestone, though again there are phreatic features, indicating that it was perhaps a shallow phreatic cave originally. Despite its simplicity in plan its form and deposits indicate a fairly complex history. In one section there is a rock-cut limestone terrace, with a meandering slot indicating vertical erosion by a purely vadose stream (Plate 1). This area also has many potholes, and these, together with abundant gravels are in places cemented and form distinct terraces, showing several stages in the downcutting of this relatively small passage. Furthermore, some gravels are cemented to the roof, while the small secondary passage where the middle passage passes under the upper passage is almost filled with cemented gravels. This is evidence that at some time the middle passage has been completely filled with gravels and then re-excavated.

In other parts of the middle passage the walls are pitted by extremely carious weathering, and the many pits (averaging about 3 cm across and 5 cm deep - Plate 2) are filled by yellow clay again suggesting a period of total fill followed by re-excavation. On the other hand there are some patches of clean gravels on parts of the passage floor, indicating that even at the present time the middle passage occasionally becomes an active streamway.

The middle passage branches in a downstream direction from the central confluence. One branch goes towards the entrances, and a smaller branch takes a more easterly route, just above the line of the lower passage. The eastern branch is a simple cave passage, generally similar in character to the rest of the middle passage. It joins the lower passage at a 2 m shaft (Figure 2).

There is a variable relationship between the middle and upper passages. At the western end of the cave the middle passage runs under the upper passage with no connection. About 40 m from the end the middle passage is joined to the upper passage by a heart-shaped hole in the wall. At the confluence around the middle of the cave the upper and middle passages are at the same level. Further east towards the entrances the phreatic tube that takes off from the upper passage is probably a continuation of the middle passage, and would once have linked with the exit to the valley at the east.

The lower passage is very small and sinuous, just about big enough to crawl through. It was carrying a small amount of water at the time of our visit, and probably carries much more for most of the time. We could not trace the source of the water, but we have the impression that there is probably a maze of tiny channels at this lower level in an early stage of integration into a simpler cave passage system. The floor of this passage is covered with rounded gravels. At the termination (at least as far as we were concerned because there was a snake hanging from the roof) the lower passage turns into a narrow slot less than a metre high. However, we feel sure there is a large cave beyond, because many hundreds of bats came out of the slot during our visit; these bats are presumably the staple diet of the snake. This unexplored slot gives hope for future discoveries, but according to Lage Tede and his friends we have explored all the known cave that is generally visited.

DISCUSSION

It is interesting to speculate briefly on the sequence of events that led to the form of Damawewe Cave as we see it at present. The upper passage is the oldest and largest and represents an early stage of cave development. The phreatic sections suggest that it began as a small phreatic cave and was then enlarged as a vadose cave. After the upper passage was formed water formed another cave at a lower level. Parts of this middle passage are also phreatic and may be developed while the upper passage was still active. This middle passage never grew to the size of the upper passage. More recently a lower and even smaller passage has been created which now carries most of the water. This simple sequence was interrupted at least once when the gravels which once filled the middle passage entirely were laid down.

It is tempting to attribute the lowering of the cave activity to base level lowering that accompanied the uplift of the coral. However, we have no evidence for this, and down cutting of the adjacent valley is an alternative hypothesis. Further work is required to work out the history of the cave in detail.

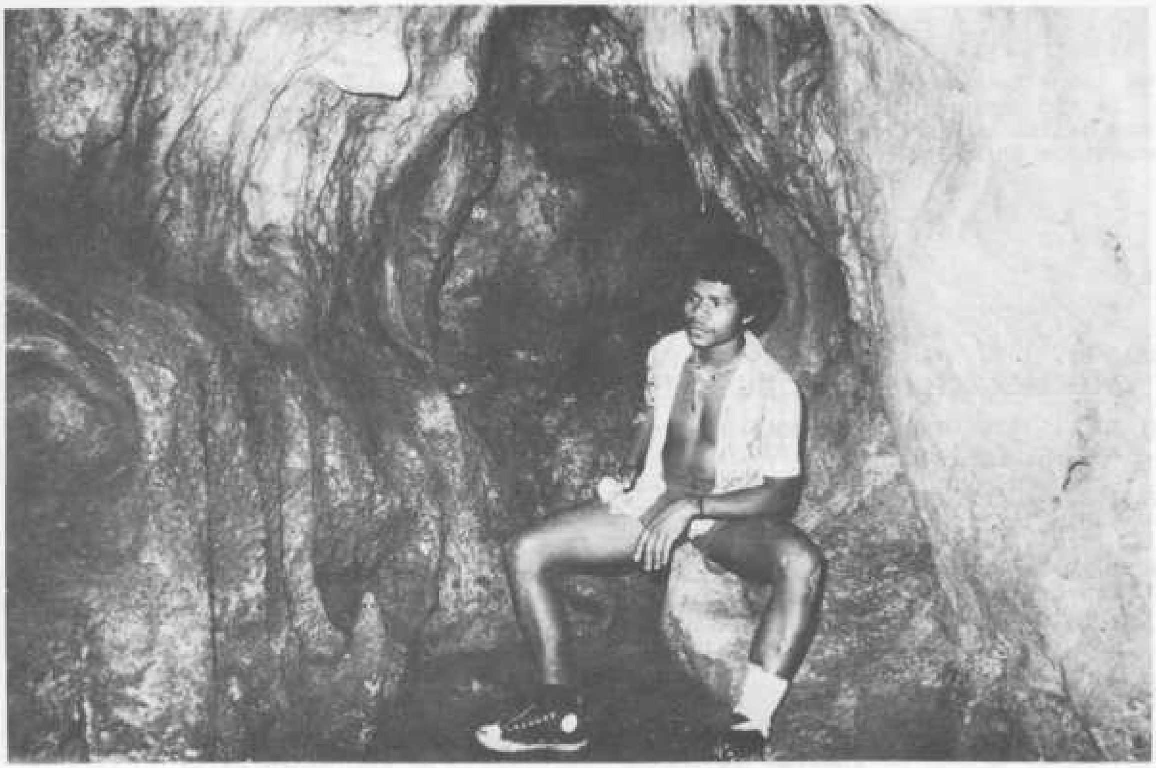


Plate 1. Part of the section of Damawewe Cave with a limestone terrace. The Cave in this section shows clear evidence of mechanical erosion.

Plate 2. Carious weathering pits partially filled with clay, in the middle passage of Damawewe Cave.

ACKNOWLEDGEMENTS

We thank Lage Tede of Sineada Village for giving us permission to visit the cave; he and members of his family and friends guided and accompanied us in the cave and on the walks from Hagita. John Standing and his wife provided us with accommodation in Alotau; to them we extend our thanks.

REFERENCES

JONGSMA, D., 1972 Marine geology and Recent sediments of Milne Bay, New Guinea. Bur. Min. Resour. Aust. Bull. 125: 35-54.

SMITH, I.E., 1970 Late Cainozoic uplift and geomorphology in south-eastern Papua. Search 1: 222-225.

SMITH, I.E. and DAVIES, H.L., 1973 Samarai, Papua New Guinea - 1:250 000 Geological Series. Bur. Min. Resour. Aust. Explan. Notes SC/56 - 9.

SMITH, I.E. and SIMPSON, C.J., 1972 Late Cainozoic uplift in the Milne Bay area, eastern Papua. Bur. Min. Resour. Aust. Bull. 125: 29-34.

Address for correspondence:

Dr. C.F. Pain, School of Applied Geography, University of New South Wales, P.O. Box 1, Kensington 2033, Australia.

C.D. Ollier, Geography Department, University of New England, Armidale 2351, Australia.

GULEMWAWAYA: A CAVE IN WELDED TUFF AT BUDOYA, FERGUSSON ISLAND, PAPUA NEW GUINEA

C.D. Ollier

Abstract

A 30 m cave in pyroclastic deposits on the flank of a volcano is thought to be made by eluviation and fluvial erosion, and possible supported mechanically by welded tuffs above.

This note is to record a small but significant cave that deserves further attention. I visited the cave for about half an hour in July 1980 and had no facilities for survey or photography.

Budoya is about two kilometres from the southern tip of Fergusson Island, north of Dobu Island and Esa'ala on Normanby. Salamo town and airstrip is about five kilometres north west across Gomwa Bay. Budoya is a small township, with a mission station and boarding school located on the coast on the flanks of Deidei Volcano (365 m). The most recent 1 : 100 000 map labels the volcano Deidei, but according to Fisher (1975) Deidei strictly refers to some solfataric areas near the base and the actual volcano is called Oiau.

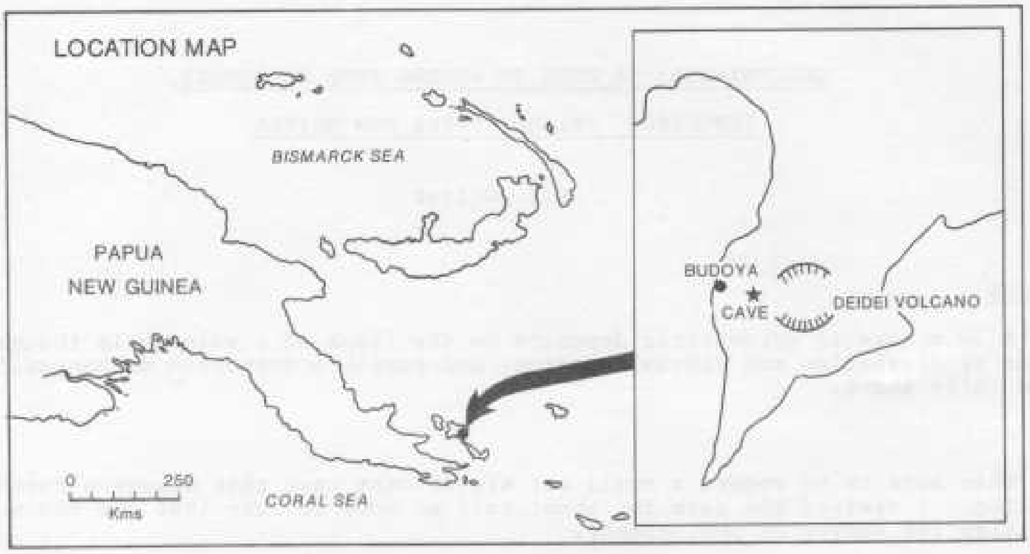
The rocks of the Deidei area consist mainly of ash, pitchstone, and obsidian, and include some grey vesicular lavas as well as pyroclastics. Composition is generally trachytic. In the area of the cave the rocks are greyish-white pumice (in very irregular and angular fragments) and black volcanic glass. The glass fragments are flattened into roughly lenticular shape, and the largest ones which are about a metre across are about 10 cm thick. The angular pumice fragments interlock and hang together well, but can be prised out by hand. The whole assemblage of pumice and flattened glass fragments suggests a pyroclastic flow deposit (ignimbrite).

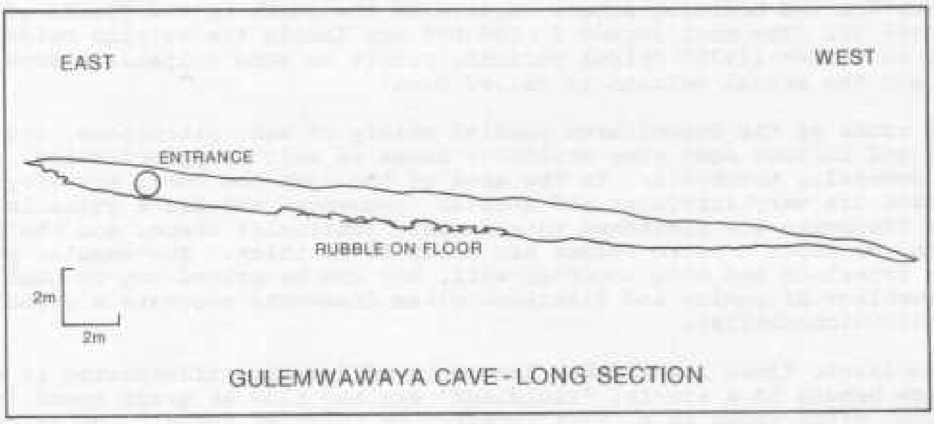
Pyroclastic flows result when fragments of lava are transported in hot gases which behave in a special 'fluidised' way and flow at great speed downhill, a phenomenon often known as a '*nueé ardente*' or 'glowing cloud'. Deposits from such flows typically consist of thick layers of uniform pumice, but lenses of glass are not uncommon. Some pyroclastic flows develop welded, more solid layers after the flow has come to rest, and the welded band is always somewhere in the middle of the flow with more rapidly cooled and unwelded pumice above and below.

From Budoya Mission a rough track runs eastwards up a long valley. This is followed for about half an hour (estimated to be about 800 m), and then a climb of about 20 m on the south side of the valley leads to a round cave entrance about a metre across. This leads in for about 5 m in a southerly direction and joins the main cave, Gulemwawaya, which is a simple east-west passage about 30 m long, 2 to 3 m wide, and about 1 m high, sloping down to the west at about 5°.

The cave roof is fairly flat and consists of pumice and flattened obsidian fragments up to a metre across. This appears to be pyroclastic flow deposit (ignimbrite) in place. Fragments can be plucked out by hand (though I was not keen to try much of this) but it seems possible that the amount of glass and the degree of welding could be greater just above the actual cave roof. The cave floor is debris covered. Some of the larger fragments on the floor have simply fallen from the roof and proved too heavy to be moved, but signs of flowing water are evident, and to some extent the floor (and the cave) are formed by water erosion and transport.

The cave must have an unusual mode of origin, for ignimbrites are not soluble like limestone, nor do they have primary caves like lava tubes in basalt. It seems that water percolation may have slowly moved particles downhill (eluviation) to create the cave in the first place. After initiation of a cave it would grow by water erosion of the floor in exceptionally wet times. Normally pumice is exceptionally porous, so there may be an impermeable layer beneath the cave (welded? blocked with clay?) to enable water to flow through the cave. Nevertheless the cave is blind, and at the lower end water evidently simply seeps away through the rock. Pumice can support steep slopes (Ollier, 1969, p.130 and Figure 27) but I doubt if it could support a flat topped cave, and therefore suspect that more welded tuff may be present above the cave to provide mechanical strength.





The mechanism suggested to create this cave, eluviation and some fluvial erosion, is rather like the mechanism invoked to form a cave in fractured gneiss on Misima Island (Ollier and Pain, 1978) except that the cave entrance at Gulemwawaya cannot serve to evacuate the debris, and it is indeed difficult to see where the eroded material can go. So far as I know this is the first cave of its kind described from ignimbrite and although small it warrants a more detailed study.

REFERENCES

FISHER, N.H., 1957 Catalogue of the Active Volcanoes of the World. Part V, Melanesia: 59-62. International Volcanological Association, Naples.

OLLIER, C.D., 1969 Volcanoes. A.N.U. Press, Canberra.

OLLIER, C.D. and PAIN, C.F., 1978 Caves and karst on Misima Island, Papua New Guinea. Helictite 16: 40-49.

Address for correspondence: Department of Geography, University of New England, Armidale, N.S.W. 2351.

ABSTRACT

DARWIN AND DIPROTODON: THE WELLINGTON CAVES FOSSILS AND THE LAW OF SUCCESSION, by Kathleen G. Dugan. Proceedings of the Linnean Society of New South Wales 104, 1980 for 1979:265-272.

The fossils from Wellington Caves, some of them 'giant', are well known to Australian speleologists, finds of importance for the study of Australian fauna from early discovered caves. What I think we did not appreciate was that the Wellington 'bones' have a place in the world history of science of significance also, the theme of this paper.

Many will have watched the BBC-TV series on 'The Voyage of the Beagle'; much was made of the importance to Darwin in developing his theory of evolution of the fossils he found in southern South America. There fossils of giant relatives of sloths, llamas and armadillos helped to make clear to him the notion of the geological succession of life, a basic part of his theory along with the idea of natural selection to which the finches and tortoises of the Galapagos Islands proved crucial.

However it seems that Darwin was previously aware of the similar significance of the Wellington Caves bones for the law of succession from Charles Lyell's Principles of Geology which quotes William Clift's identifications of dasyures, wombats and kangaroos amongst them. The fact that these recently extinct animals were closely related to the distinctive modern marsupial fauna of Australia counted much against earlier conceptions such as Cuvier's catastrophic theory or Buckland's ideas of successive divine creations within a short time span.

Watchers of the TV series will remember the devious role played by the palaeontologist, Sir Richard Owen, in organising public opposition to Darwin at the famous Oxford meeting of the British Association for the Advancement of Science. This article relates the series of rearguard actions of Owen to maintain that there was a fossil elephant component in the ancient Australian fauna, damaging to Darwinism. But the growing evidence from Australia, not all of it from caves, of course, finally extinguished this red herring, started by that doctrinaire N.S.W. colonial, the Reverend John Dunmore Lang.

Joe Jennings.

CAVES AND KARST OF THE MULLER RANGE: EXPLORATION IN PAPUA NEW GUINEA. Editors J.M. James and H.J. Dyson.

Report of Atea-78, Australasian Speleological Expedition.

160 pages, with full colour cover, 71 plates, 69 figures and maps, and three large loose-leaf maps. Published by Atea 78 in conjunction with Speleological Research Council Ltd.

Available from: SRC Ltd., P.O. Box 183, Broadway, NSW 2007

ATEA 1978

Speleological Research Council Limited

INFORMATION FOR CONTRIBUTORS

SCOPE

Contributions from all fields of study related to speleology will be considered for publication. Suitable fields include Earth Sciences, Speleochemistry, Hydrology, Meteorology, Conservation, Biospeleology, History, Major Exploration (Expedition) Reports, Equipment and Techniques, Surveying and Cartography, Photography and Documentation. Comprehensive descriptive accounts of the exploration and morphology of individual caves will be welcomed, but simple trip reports and brief cave descriptions are not adequate. Papers overall should not exceed 20 printed pages in length. Contributors intending to write at greater length or requiring any advice on details of preparation are invited to correspond with the Editors. All manuscripts will be read by referees. Short 'Letters to the Editor', expressing a personal view or giving a preliminary report of interesting findings, are welcomed, and will be given preference for speedy publication.

MANUSCRIPTS

Submitted manuscripts should be in a final form ready for publication. As proofs are not normally sent to authors particular care should be taken to check for typing errors. Manuscripts should be typed, double spaced, on one side of the paper. The title should be uppercase and underlined, and the authors' names should follow. A brief and explicit summary of the notable aspects of the paper, headed Abstract, should precede the main text.

Throughout the main text major headings should be in upper case, centred and not underlined, while subheadings should use lower case, underlined and aligned with the left hand margin. Acknowledgements should be placed at the end of the text before the references, and the authors' addresses for correspondence should follow the references.

Authors with access to an IBM Golfball typewriter may wish to submit their papers in 'camera-ready' form. They should request our leaflet "Helictite Typographic Style". Papers should still be submitted in the above form in the first instance.

REFERENCES

References should be listed alphabetically at the end of the manuscript and cited in the text by the author's name and the year of publication (e.g. "(Grey, 1973)"). Where there is more than one reference to the same author in one year the letters a,b, c, etc. should be added. If there are more than two authors, they should all be named at the first citation and in the reference list, but the first name followed by 'et al.' should be used in subsequent citations. References should be checked particularly carefully for accuracy. Journal titles should be abbreviated following the "World List of Scientific Periodicals", which is available in most large libraries. The following examples illustrate the style:

GRAY, M.R., 1973 Cavernicolous spiders from the Nullarbor Plain and south-west Australia. J. Aust. ent. Soc. 12: 207-221.

VANDEL, A., 1965 Biospeleology. The Biology of the Cavernicolous Animals. Pergamon, London. Pp. xxiv, 524.

WIGLEY, T.M.L. and WOOD, I.D., 1967 Meteorology of the Nullarbor Plain caves. In: J.R. DUNKLEY and T.M.L. WIGLEY (eds), Caves of the Nullarbor. A Review of Speleological Investigations in the Nullarbor Plain. Southern Australia: 32-34. Speleological Research Council, Sydney.

ILLUSTRATIONS

Figures and photographs should be kept to a minimum and generally should not duplicate information in tables or other material. Photographs should be clear black and white prints with sharp focus. Where several photographs are to form one plate they should be mounted together on white card. Any lettering required on photographs should be applied with 'Letraset'. Figures should be drawn in Indian ink on white card, heavy paper or tracing material and lettered using stencils or 'Letraset'.

All illustrations should be drawn to fit a print area of 153 x 260 mm. They may be larger provided that these proportions are maintained, but allowance for reduction must be made when choosing letter sizes and line thickness. Several diagrams or photographs can only be included in one page if they all require the same reduction. Diagrams for inclusion in the text must be drawn to a width of either 153 mm (to appear at the same size) or 210 mm (for reduction); they must be clear and simple as they will be reproduced by a lower-quality process.

Figures and plates should each be numbered consecutively and specifically referred to in the text. The numbers should be marked lightly in pencil on the margin or back of each illustration. Captions should be typed on a separate sheet.

UNITS

The S.I. system (Australian Standard AS 1000) should be used unless citing historical data, in which case the original units should be quoted and appropriately rounded metric equivalents added; e.g. "100 feet (30 m)".

OFFPRINTS

Offprints of papers will be supplied after publication, at the author's expense. The number required should be stated when submitting the manuscript.

HELICTITE

Journal of Australasian Cave Research

VOLUME 19(1) 1981

CONTENTS

Speleological Research Council Limited