UNDERGROUND STREAMS ON ACID IGNEOUS ROCKS IN VICTORIA

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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 of 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.

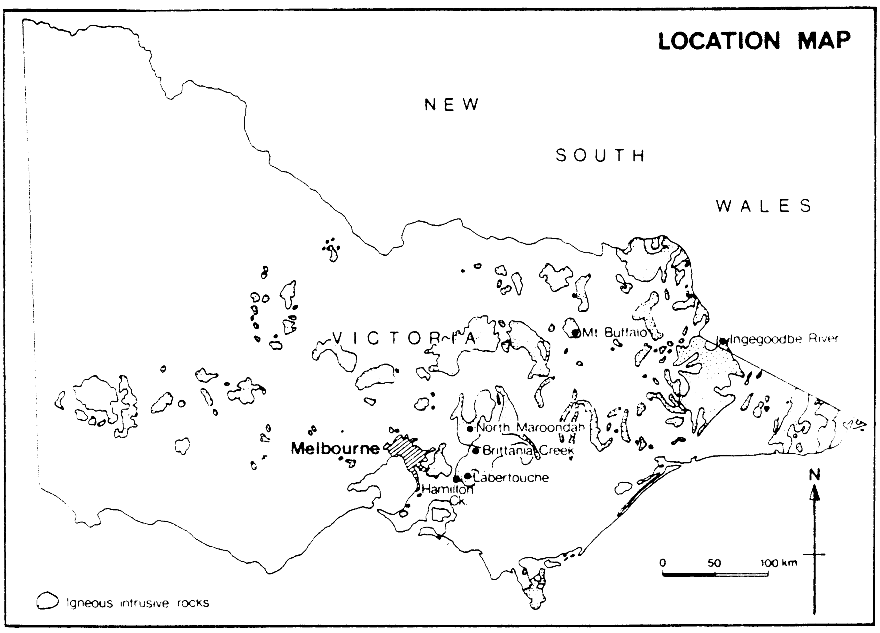

Figure 1: Locations of underground streams on acid igneous rocks in Victoria.

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 100m. 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 46m 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.

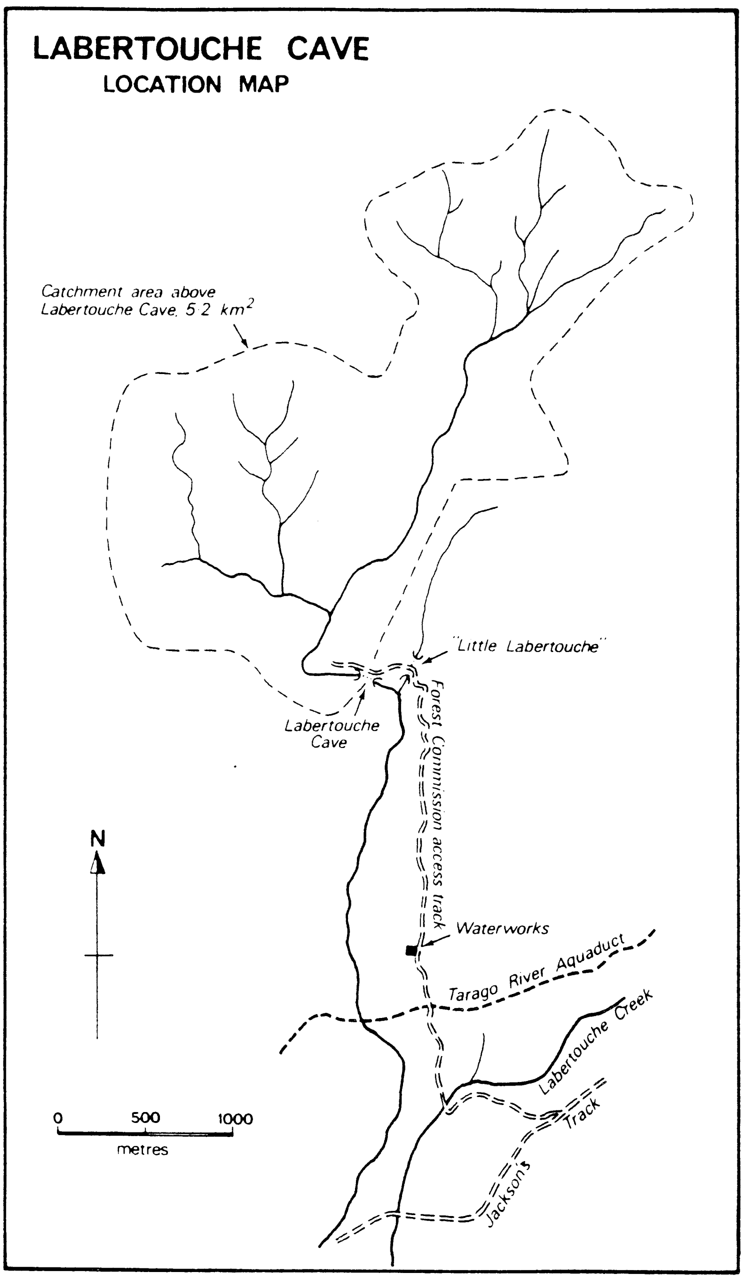

Figure 2: Location map of Labertouche Cave.

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

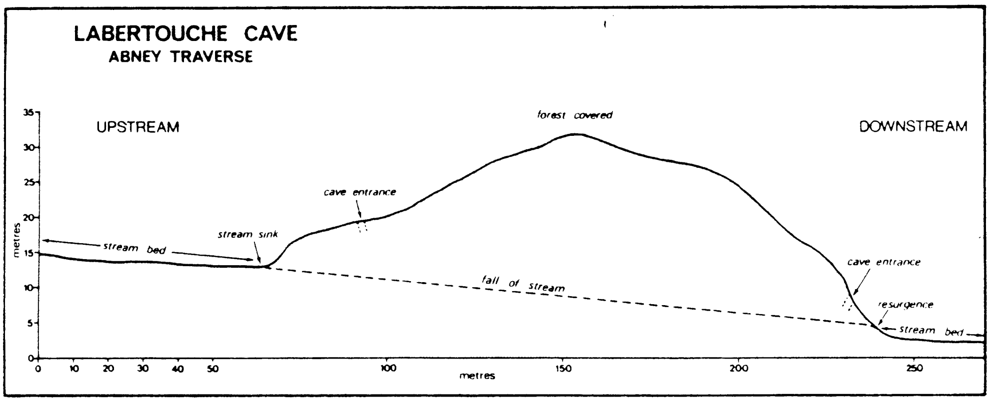

Figure 3: Section along the stream alignment at Labertouche Cave.

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.

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 Warburton Granodiorite are shown in Table I. Descriptions of the geology of the area are given in Junner (1915) and Edwards (1932a, 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.

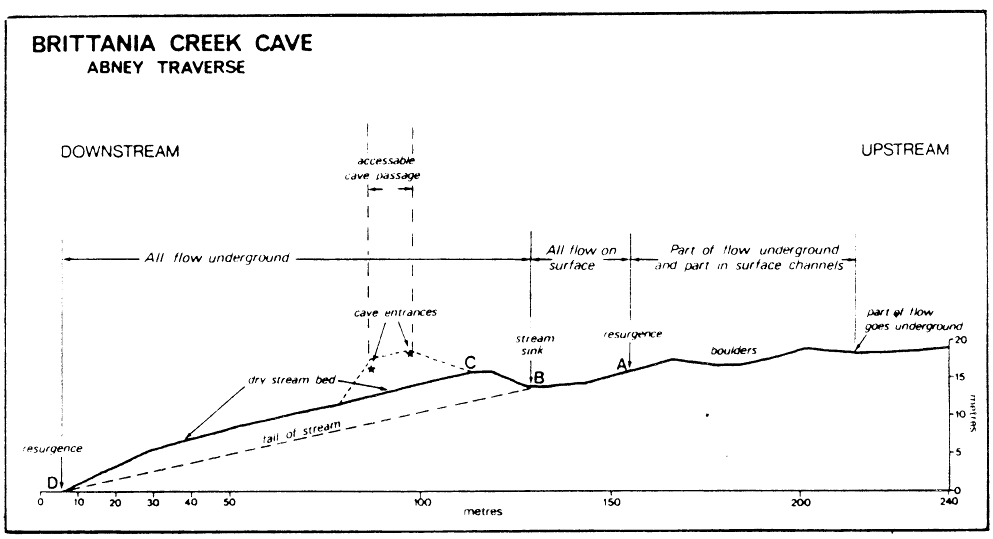

Figure 4: Section along the stream alignment at Brittania Creek Cave.

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.

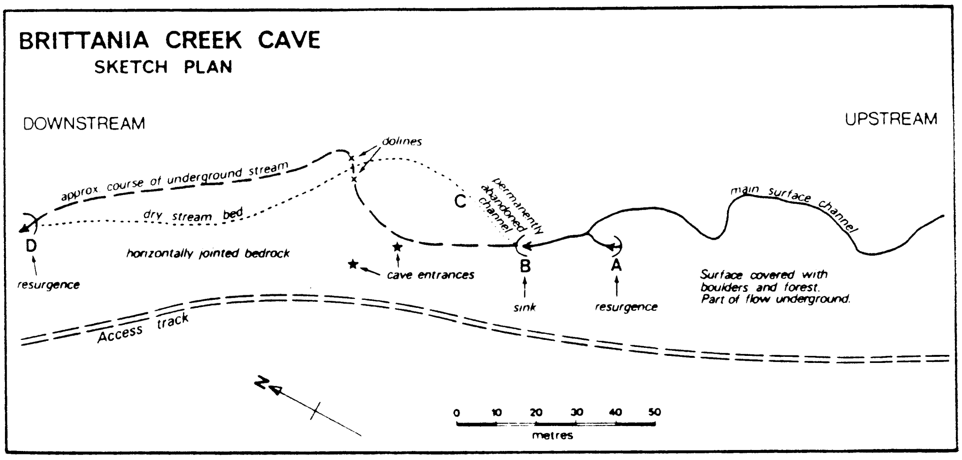

Figure 5: Sketch plan of the area around Brittania Creek Cave.

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

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 Table I. Edwards (1932a) points out that the quartz-hypersthene-biotite-dacite is a chilled intrusive facies of the quartz-

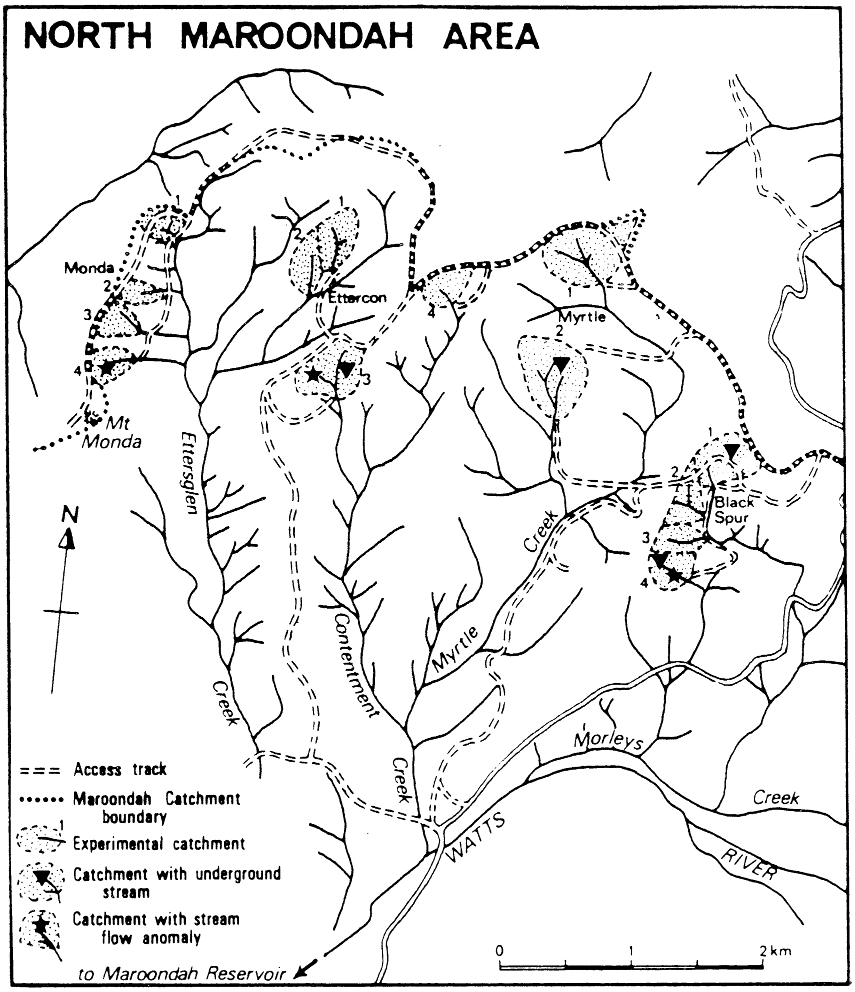

Figure 6: The experimental catchments at North Maroondah. (After Langford and O'Shaughnessy, 1977)

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 1m 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 statistically significant. The streamflow for Monda 4 (see Table II) 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, it 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.

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

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 1400m 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

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

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 gru 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.16). 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 of 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 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

(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 boulders 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 in 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.

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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. für 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. für Geomorph.* **4**: 43-52.

Ollier, C.D. (1965) Some features of granite weathering in Australia. *Zeitschr, für 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. *Geol. Soc. of America Special Papers* **101**: 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, pp. 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.* Academic Press, London, pp. 127-150.