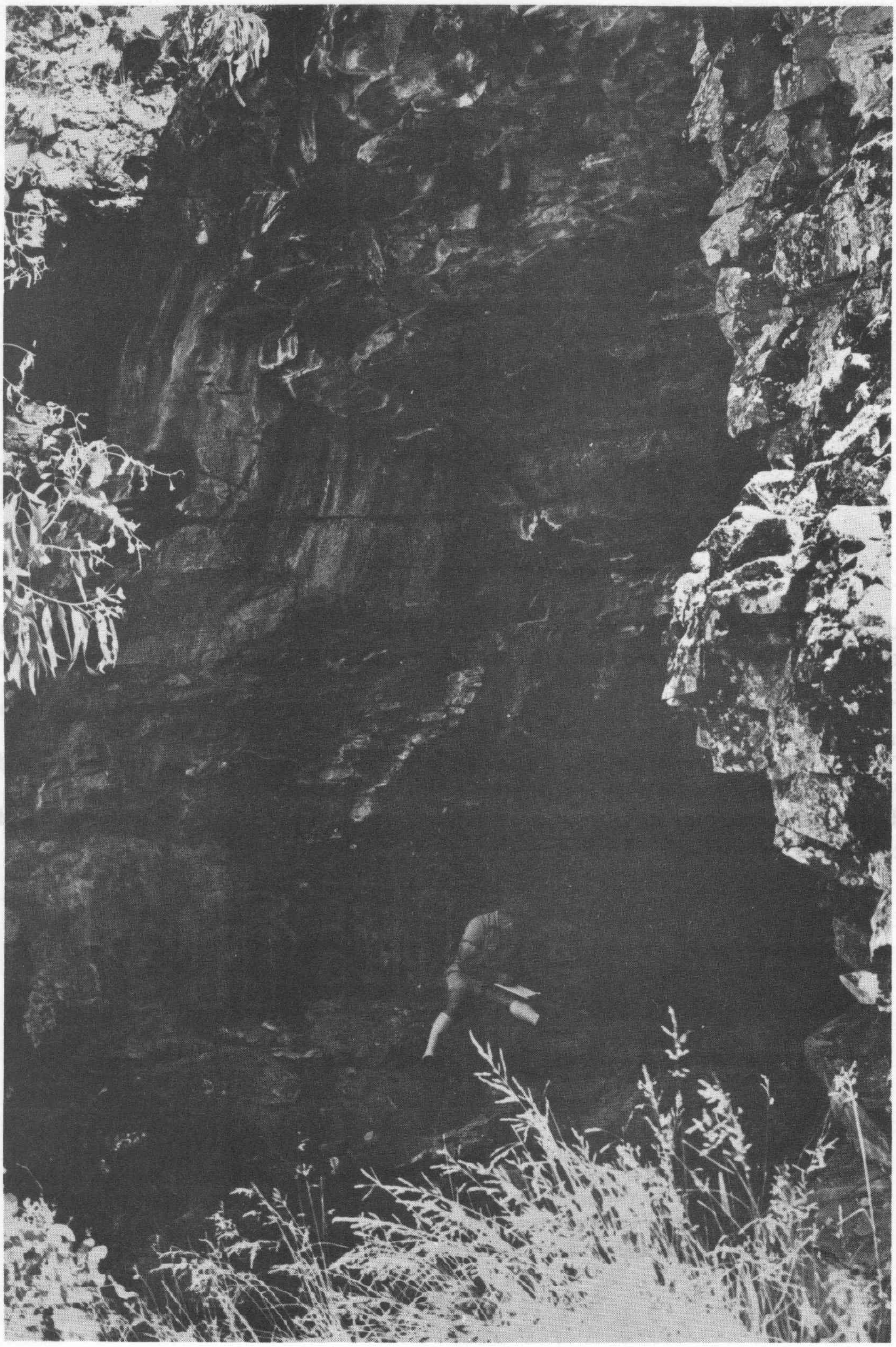
Vol. 17(1) 1979

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



Entrance to Bushranger Cave, Coolah, N.S.W.

photo by R. Schon

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.

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

A BIBLIOGRAPHY OF THE JENOLAN CAVES. PART ONE: SPELEOLOGICAL LITERATURE.
J.R. Dunkley 1976. - a detailed reference list.

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

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REVIEW

KARSTHYDROGEOLOGIE, by J.G. Zötl. Springer, New York and Vienna, 1974. Pp x+291.

Since 1932, Otto Lehmann's "Die Hydrographie des Karstes" has dominated the German language literature of karst hydrology. There can be little doubt that this new book will largely displace it. Lehmann's book was very much a theoretical analysis based on hydrodynamics; Zötl's is empirical and relies on chemical measurements as much as physical ones. Lehmann's failure to heed field observations led him into errors and his physics overimpressed many of us.

Zötl's first section outlines the geological, chemical and climatic factors in karst hydrology. A great deal of matter is covered soundly in short compass here and everything cannot go in. Nevertheless one could have wished for more stress on sheer volume of water in its hydrological and geomorphic effects. More inter-connections between climatic and kinetic controls of solution might have been noted; diffusion increases and viscosity falls off with rising temperature, both relationships rendering solution faster in warm than cold climates. The author takes the quite defensible standpoint that the term "karst" should only be applied where an assemblage of landforms arising from solution and related processes is found. On this basis he accepts granite karst as manifested in some tropical regions but rejects thermokarst in that the latter only comprises one kind of landform - the doline - and it is due to melting, not solution. Moreover no-one in Western Europe regards *Söllen* as karst forms and yet they are relict permafrost melt hollows. However, when he also rejects salt (halite) karst for the same reason, he is taking too narrowly a European view because the evolution of salt domes in arid climates is quite an elaborate affair, even if a neglected study.

The second section on water circulation in karst rocks comprises about two-thirds of the book. It begins with a brief history of karst hydrology, concentrating on the long controversy about karst watertables associated especially with the names of the protagonists, Grund and Katzer, and on critique of O. Lehmann's book. Then follows the most important part of the whole book, a long discussion of modern methods of investigation in karst hydrology in which Zötl has much experience and to which he has contributed greatly. The modern methods allow of the study of the behaviour of entire limestone plateaus and Zötl is right in maintaining that the investigation of particular water connections on their own can be deceiving. The methods are discussed systematically with pertinent practical details where necessary, and their utility demonstrated by many important case studies ranging through Central Europe and the Mediterranean. Temperature surveys, discharge determinations, chemical analyses of spring waters are discussed first; then water tracing by salts, dyes, spores, introduction of radioisotopes and activated substances, bacteria, brighteners, scents and explosive sound waves is dealt with. A series of combined tracing investigations is then treated in some detail. The use of the natural occurrences of isotopes, the so-called "environmental" isotopes - tritium, deuterium, oxygen-18 and carbon-14 - is the next subject, first systematically and then by means of regional investigations from France to Turkey. Various components of spring waters at different seasons have been determined by these means and the nature of storages - long-term or short-term - established.

Interpolated here is an introduction to the use of electronic computers for hydrogeologists by D. Bormann. These 20 pages are too many simply to demonstrate the usefulness of computers in this field and too few to show how to put them to such use.

The section continues with exposition of karst drainage types - in the High Calcareous Alps in Austria, in the scarplands of South Germany, the Grands Causses of central France, the Dinaric-Greek karst, the seamills of Argostoli on the Greek island of Kephallinia, the dolomite karst of the Transvaal and the Danube streamsinks in Baden-Wurtemberg. This is a valuable series of examples where the new methods have yielded valuably in a variety of geological constraints. Zötl pursues in particular the differences between shallow karst (where springs are governed by impervious basements) and deep karst (where the karst rocks extend below the valley floors around them) and also the control exercised by the altitude of the outflows from karst areas ("*Vorflutniveau*"). He uses various instances to support Grund's ideas about watertables in karst and to criticise Lehmann's standpoint. This rings a little hollowly in the Anglo-American speleological world where there is still need to combat too facile a transfer of notions of groundwater and watertables which fit porous sands and gravels to compacted karst rocks where the rock in itself is impervious. Nevertheless there is no doubt that Zötl's water tracing in various Austrian karst plateaus calls for hydrological systems much allied to Grund's scheme; centrally situated streamsinks feed springs around much of the plateau periphery. Zötl's compromise view envisages that the major cave streams act for the rest of the underground water like major surface streams do for their tributaries and the groundwater between. These cave streams are supplied from karst water scattered through the joint systems and lower the surface of these waters more or less strongly according to geological factors. This concept goes back to early papers to Zötl's based on his first major spore drift experiment in the E. Dachstein plateau in 1956 (see Jennings, 1957) but many later investigations confirm it.

This second section is an extremely valuable survey of modern karst hydrologic method and the kind of results which can be obtained now. It is perhaps a fair criticism to say that related modern work on the movement and chemistry of karst waters in Britain and North America is neglected, e.g. the use of flood pulses. This omission is more to be excused than the common ignorance in the English-speaking speleological world of Austrian results.

The third section is really a development of the previous one with a greater emphasis on the practical value of karst water investigations. Firstly three tunnel constructions are discussed; two where proper hydrological investigations were carried out so that the effects of the tunnel could be identified and in one of these cases predicted with success. In the third case, investigations were begun too late and lost their value, though in all cases general information of use for future karst engineering was gathered. Secondly reservoir constructions in karst is taken up. A leaky reservoir, behind a dam which should not have been built and would not have been with adequate prior investigation, is contrasted with a watertight reservoir which fulfilled the expectations of a previous study. Thirdly the relationships between karst waters and neighbouring groundwater in valley fills are discussed and finally the old subject of domestic water supplies in karst regions is looked at again, using Austrian examples where the big cities rely on alpine karsts for water to a great extent. Practical needs have more than ever before provided both the stimulus for scientific progress in karst hydrology and the means whereby this can be achieved.

The final short section summarises the book's content and surveys the present scene in karst hydrology. It ends on the need for synthesis and collaboration - synthesis of results from karst hydrology, karst geomorphology and cave science, collaboration of scientists from a widening range of disciplines now reaching to radiochemistry and of amateurs who climb, cave and dive. Such collaboration has been well exemplified in the Moravian karst in Czechoslovakia.

Zötl's book is an expensive one to buy but an enrichening one to read. Its remarkable dustcover picture strikes a note relevant for Australian speleologists. In it the Cetina River in Dalmatia is seen in furious flood in its canyon near the sea with a waterfall at a rejuvenation head; below the fall, waters pour out from cave mouths in the gorge walls well above the river. This is essentially the situation at Bungonia, though no such spectacular illustration of it is possible unfortunately. In both areas karst development has lagged behind valley deepening.

JENNINGS, J.N., 1957 Water tracing by spore drift and its results. J. Syd. Uni. Spel. Soc. 4 (2): 26-28.

J.N. Jennings

ERRATA

J.M. James, G. Francis and J.N. Jennings, Helictite 16 (2), 1978
page 60, paragraph 3, line 3, for 'km' read 'm'
page 61, paragraph 1, line 2, after 'choke' insert 'at the bottom end of the Slot and the lesser but still large rock fall'.

R. Frank and J.N. Jennings, Helictite 16 (2), 1978
page 76, paragraph 2, line 1, for 'northern' read 'southern'.

CAVE AND LANDSCAPE EVOLUTION AT ISAACS CREEK, NEW SOUTH WALES

M. Connolly and G. Francis

Abstract

Isaacs Creek Caves are situated in the Hunter Valley of New South Wales and form a distinct unit within the Timor karst region. The larger caves such as Main, Helictite and Belfry all show evidence of early development under sluggish phreatic conditions. Nevertheless later phases of dynamic phreatic and vadose development occurred in Belfry and Helictite caves. In the case of Helictite Cave sluggish phreatic, dynamic phreatic and vadose action may have operated simultaneously in different parts of the same cave. After each cave was drained through further valley incision by Isaacs Creek, extensive clay fills derived from surface soil were deposited in it. There has been considerable re-excavation of the fills : in Main Cave younger clay loams have partially filled the resulting cavities and thus underlie the older clays.

The earliest speleogenesis took place in Main Cave which pre-dates the valley of Isaacs Creek. This cave now lies in the summit of Caves Ridge about 100 m above the modern valley floor. Helictite and Shaft Caves formed when the valley had been cut down to within 30 m of its present level and some early phreatic development also took place in Belfry Cave at this time. Later phases of dynamic phreatic and vadose development in Belfry Cave occurred when the valley floor lay about 12 m above its present level and can be correlated with river terraces at this height.

Evidence from cave morphology, isotopic basalt dates and surface geomorphology indicates that Main Cave formed in the Cretaceous and that Helictite Cave, Shaft Cave and the early development in Belfry Cave date from the Palaeogene. Although the dynamic phreatic and vadose action in Belfry Cave is more recent, it may still range back into the Miocene. This is a much more ancient and extended chronology than has hitherto been proposed for limestone caves and is in conflict with widely accepted ideas about cave longevity. Nevertheless evidence from Isaacs Creek and other parts of the Hunter Valley indicates that the caves and landforms are ancient features and thus notions about cave longevity developed in younger geological environments of the northern hemisphere do not apply in the present context.

LOCATION AND GEOLOGICAL SETTING

Isaacs Creek lies 8 km northeast of Timor within the basin of the Isis River, which in this locality flows slightly east of south through a strike valley (Figure 1). Tributaries such as Isaacs Creek and Seckolds Gully flow generally westward through transverse valleys to join the Isis. The area has a general relief of up to 200 m with numerous steep slopes. Further to the north, basalt summits in the Liverpool Range rise up to 600 m above the floor of the Isis Valley. The Isaacs Creek area has largely been cleared for grazing, though steep limestone ridges usually retain forest or woodland cover. Grass trees *(Xanthorrhoea australis)* are often prominent on limestone outcrops. The limestones crop out strongly, whereas other rocks such as mudstones are usually mantled by soil. Along the Isis River and Isaacs Creek the bedrock geology is largely concealed by alluvium.

Geological studies of the area have been carried out by Osborne, Jopling and Lancaster (1948), Manser (1967), Ellenor (1971) and Jones (1978). The dominant regional structure is known as the Timor Anticline, but recent work by Jones (1978) has shown that it is really an anticlinorium with a number of smaller folds present (Figure 2). This structure can be traced northward along strike for about 10 km and in places has a dome and saddle form due to plunge reversals or is disrupted by faulting. Because of these structural complications and the local relief, outcrop patterns are often intricate. Nevertheless outcrop width on the limestone is up to 3 km. This is unusual for the highlands of eastern Australia where most karst areas have developed in narrow strike belts of steeply dipping limestone.

Despite the abundance of limestone in the Timor Anticline, known caves are confined to a few restricted localities. The main group is found in Caves Ridge and adjacent areas along Isaacs Creek (Figure 3). Other caves occur along the Isis River about 6 km to the northwest but do not fall within the scope of this study. Recent geological work by Jones (1978) in the Isaacs Creek area has shown that the limestones can be divided into three distinct units (Figure 2). The oldest unit is the Jepson Lens which consists of thinly interbedded muddy limestone and calcareous siltstone or mudstone. This is overlain by the Timor Limestone Member, a massive to crudely bedded biomicrite, pelsparite and intrasparite which has undergone varying degrees of

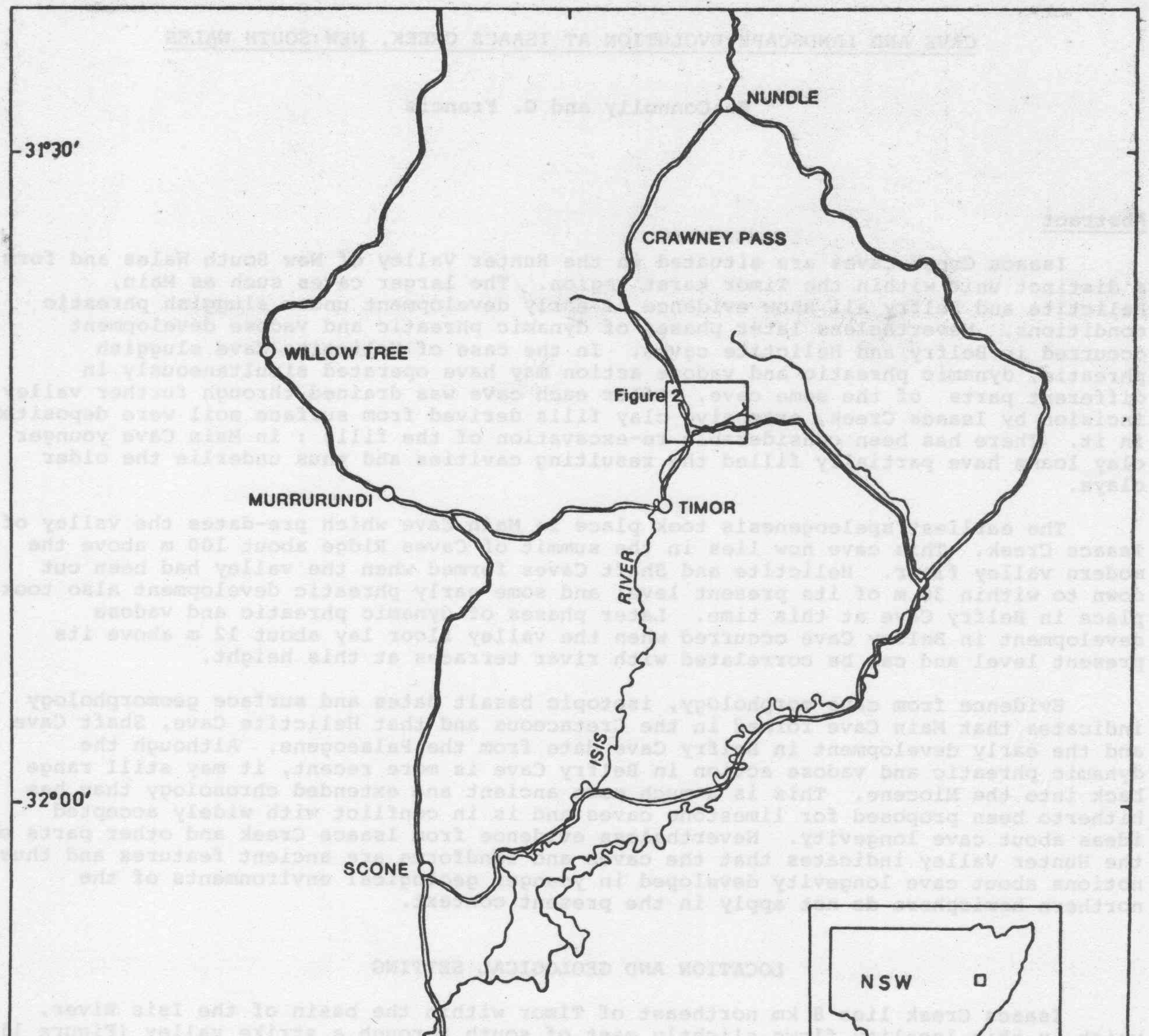
NUNDLE
31°30'
CRAWNEY PASS
WILLOW TREE
Figure 2
MURRURUNDI
TIMOR
ISIS RIVER
32°00'
SCONE
NSW
MN
MUSWELLBROOK
DENMAN
GOULBURN R
HUNTER
BASALT
32°30'
JERRYS PLAINS
SINGLETON
0 10 20 30 40
KILOMETRES
150°30'
151°00'
151°30'

Figure 1.

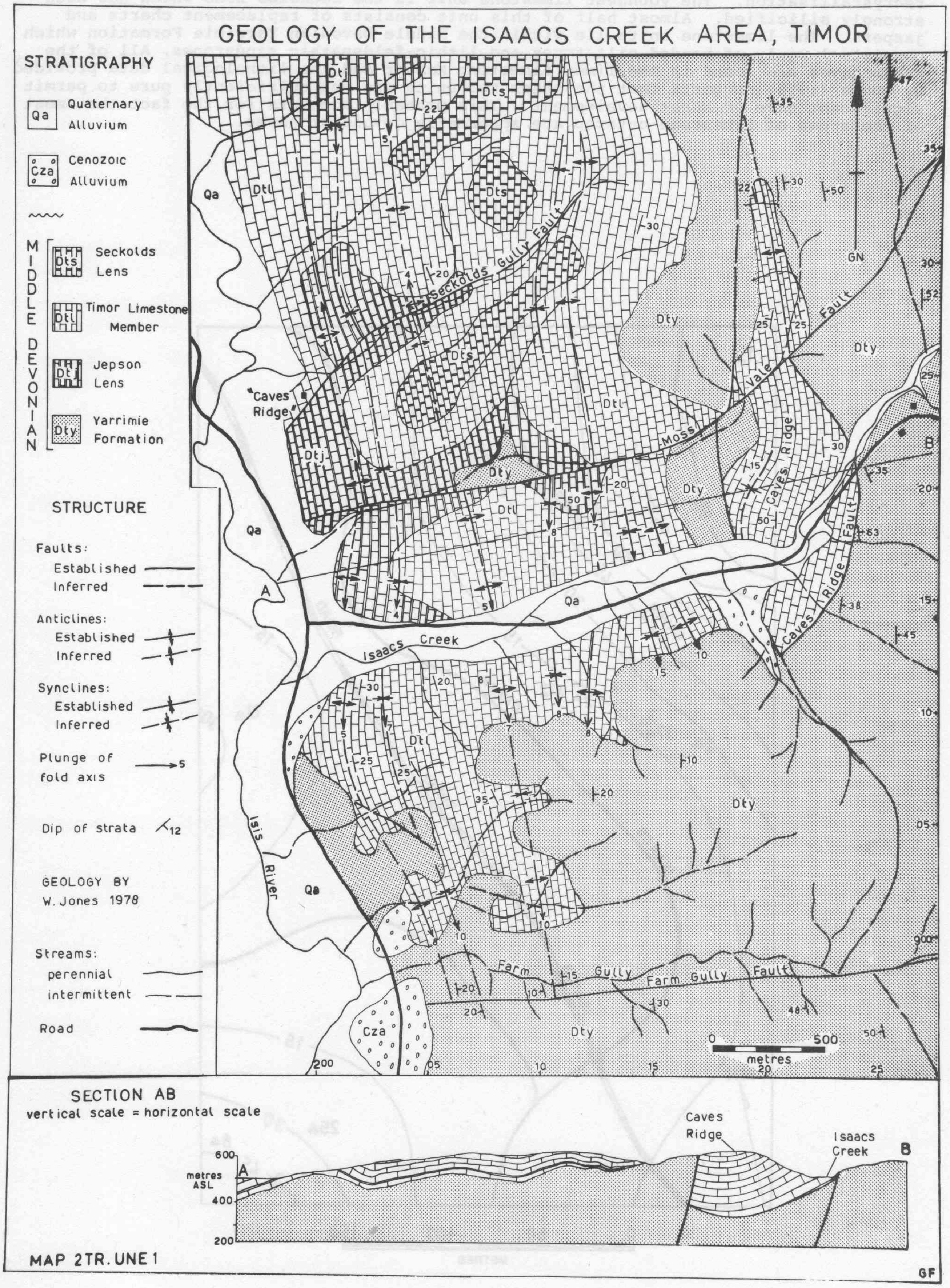
GEOLOGY OF THE ISAACS CREEK AREA, TIMOR
STRATIGRAPHY
Qa Quaternary Alluvium
Cza Cenozoic Alluvium
MIDDLE DEVONIAN
Dts Seckolds Lens
Dtl Timor Limestone Member
Dtj Jepson Lens
Dty Yarrimie Formation
STRUCTURE
Faults: Established Inferred
Anticlines: Established Inferred
Synclines: Established Inferred
Plunge of fold axis
Dip of strata
GEOLOGY BY W. Jones 1978
Streams: perennial intermittent
Road
Seckolds Gully Fault
Moss Vale Fault
Caves Ridge Fault
Farm Gully Fault
"Caves Ridge"
Caves Ridge
Isaacs Creek
Isis River
Farm Gully
GN
metres
SECTION AB
vertical scale = horizontal scale
metres ASL
Caves Ridge
Isaacs Creek
MAP 2TR.UNE 1
GF

Figure 2.

recrystallisation. The youngest limestone unit is the Seckolds Lens which has been strongly silicified. Almost half of this unit consists of replacement cherts and jaspers. The limestone units lie within the Middle Devonian Yarrimie Formation which consists largely of banded siltstones and lithic-feldspathic sandstones. All of the known caves are found in the Timor Limestone Member and the lithological data provided by Jones (1978) suggests that the other two units are not sufficiently pure to permit significant cave or karst development. This probably accounts for the fact that most of the areas of limestone outcrop are apparently devoid of caves.

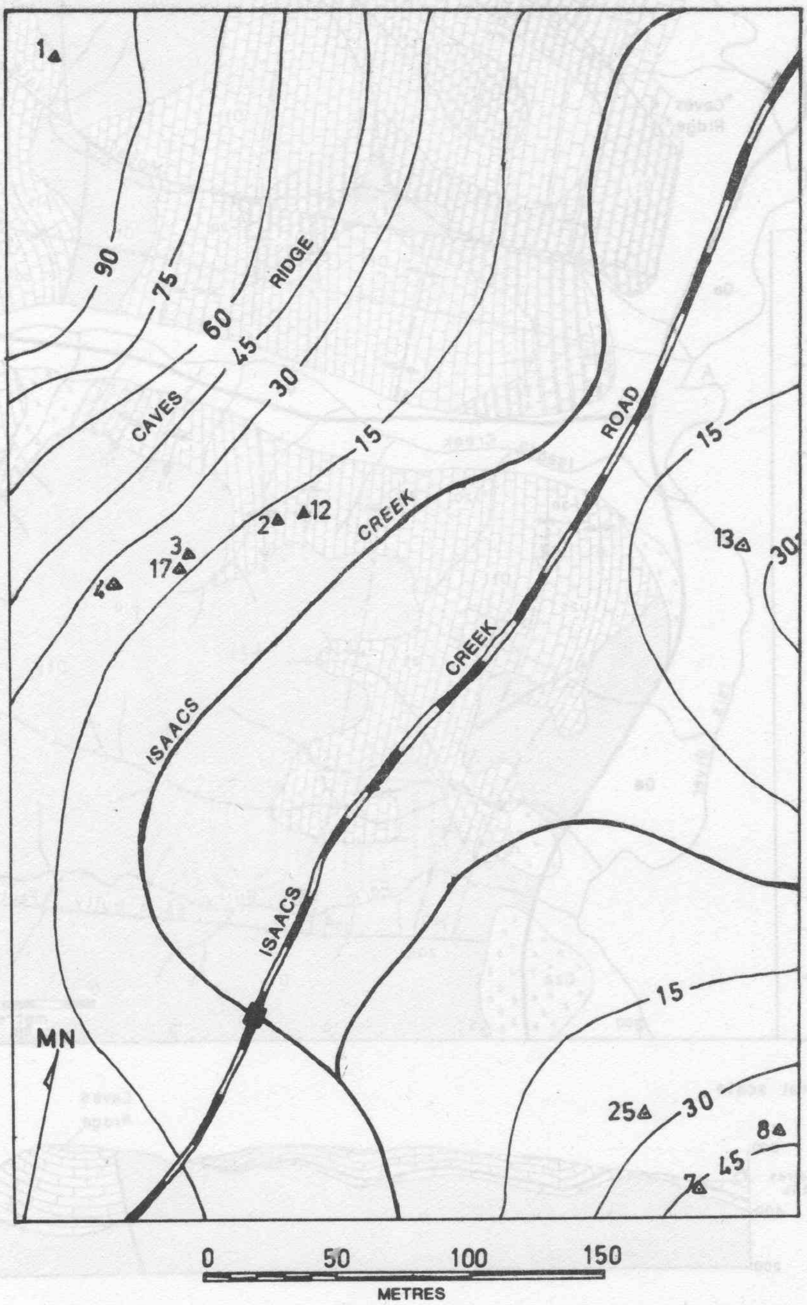

Figure 3. Location of selected caves at Isaacs Creek, N.S.W. 1: Main Cave; 2: Belfry Cave; 3,17: Shaft Cave; 4: Helictite Cave; 7,8: Hill Cave. Contours in metres above a local datum on the floodplain. (after James et al., 1976).

CAVES AT ISAACS CREEK

There are 18 known caves at Isaacs Creek. These caves range from simple shafts or small single chambers to complex systems such as Belfry with several hundred metres of passages. Belfry, Main, Helictite and Hill Caves are the four most extensive. The following discussion of speleogenesis is based largely on Main, Helictite and Belfry Caves since evidence for earlier stages of development is particularly well preserved in these caves.

Main Cave TR1

Main Cave (Figure 5) is located near the crest of Caves Ridge, 100 m above the floodplain of Isaacs Creek (Figure 3). The cave entrance is approximately 640 m above sea level (A.S.L.).

This entrance consists of a 2 m drop and appears to have formed through collapse. The 30° slope wich extends down from the entrance into the Ballroom is littered with angular limestone blocks. The northern wall of the Ballroom consists largely of mud-stained flowstone which exhibits wedge-shaped cross bedding. This probably results from changes in the flow route of water that was depositing the calcite, rather than intervals of erosion between the deposition of successive sets.

Leading off from the southeastern end of the chamber are several small chambers with connecting passages. These have compacted earth floors and lie at a lower level than most other parts of the cave. In these chambers there are prominent lines of stalactites formed by water emerging from joints in the roof. On the eastern side of the Ballroom there are a number of large limestone blocks formed by breakdown and subsequently covered by flowstone.

The Ballroom itself is about 50 m long and 25 m wide, being elongated along a northwest trend parallel to a prominent joint set. The influence of this joint set is most clearly seen on the western wall, parts of which consist of joint faces. At the southern end of this wall is a weathered basaltic dyke which has been emplaced along one of these northwesterly trending joints. The northwestern section of the Ballroom has a flowstone floor developed at a higher level with several passages leading off to the north. One of these passages was formerly earth filled but in places up to 10 m of fill has been re-excavated.

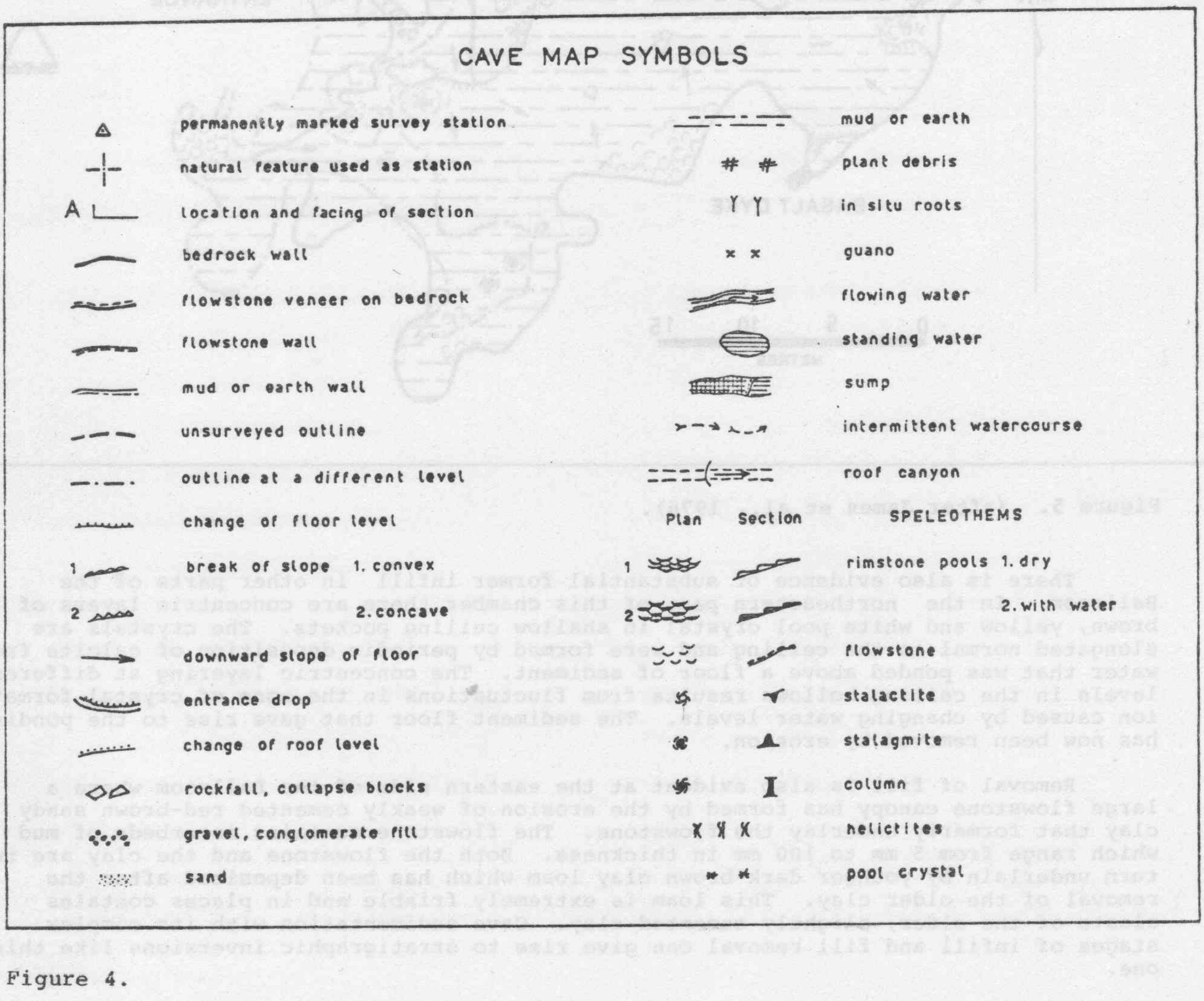

Figure 4.

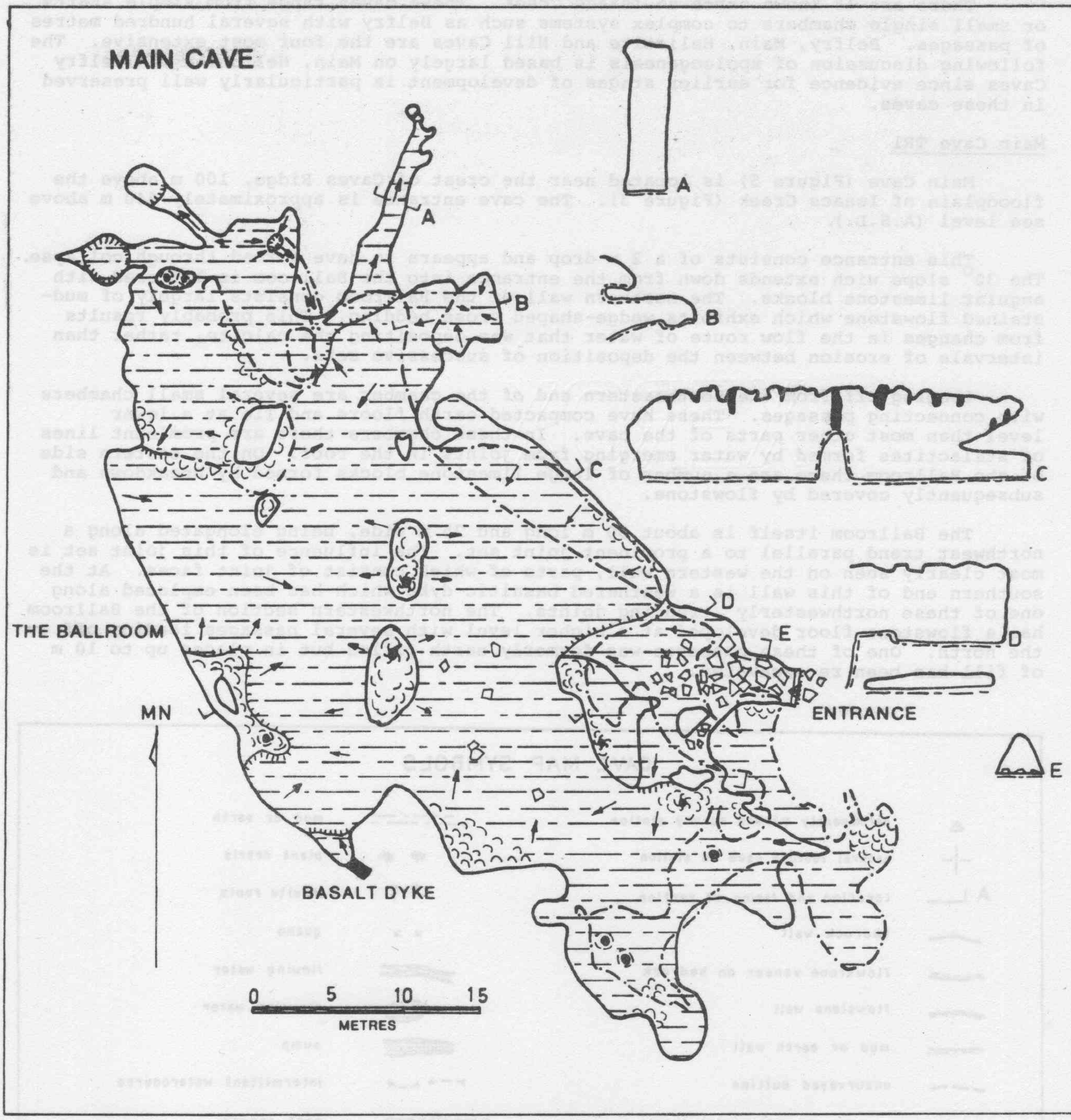

Figure 5. (after James et al., 1976).

There is also evidence of substantial former infill in other parts of the Ballroom. In the northeastern part of this chamber there are concentric layers of brown, yellow and white pool crystal in shallow ceiling pockets. The crystals are elongated normal to the ceiling and were formed by periodic deposition of calcite from water that was ponded above a floor of sediment. The concentric layering at different levels in the ceiling hollows results from fluctuations in the zone of crystal formation caused by changing water levels. The sediment floor that gave rise to the ponding has now been removed by erosion.

Removal of fill is also evident at the eastern side of the Ballroom where a large flowstone canopy has formed by the erosion of weakly cemented red-brown sandy clay that formerly underlay the flowstone. The flowstone contains interbeds of mud which range from 5 mm to 100 mm in thickness. Both the flowstone and the clay are in turn underlain by younger dark-brown clay loam which has been deposited after the removal of the older clay. This loam is extremely friable and in places contains clasts of the older, slightly cemented clay. Cave sedimentation with its complex stages of infill and fill removal can give rise to stratigraphic inversions like this one.

The bedrock solution sculpture is Main Cave consists largely of bellholes and joint ceiling cavities. In the southern part of the Ballroom roof pendants, spongework and large scallops are also evident. The latter features are about 1 m long and 0.5 m deep and do not have any pronounced asymmetry. In some ways these features are transitional between scallops and wall pockets. Spongework is also found in a small cavity at the northern end of the Ballroom but is partly covered by clay fill that contains rounded limestone pebbles.

Main Cave formed almost entirely through solution by sluggish waters in the phreatic zone. Forms such as bellholes, joint ceiling cavities, roof pendants and spongework are typical of solution in parts of the phreatic zone where strong directional currents are lacking (Bretz, 1942; Jennings, 1976). These nothephreatic features indicate theat the cave was located below the watertable during the time that most of its development took place and that limestone solution may have been aided by mixing corrosion along the watertable where vadose seepage came into contact with groundwater (Bögli, 1971).

The validity of watertable concepts in karst studies has been much debated (Jennings, 1976; Smith, Atkinson and Drew, 1976), but evidence from water levels in wells and the locations of springs in the Isaacs Creek area indicates that there is a watertable which lies at or slightly above the levels of the present streams. Assuming a similar relationship between watertable level and valley floor at the time Main Cave was forming, the valley floor at that time must have been about the present summit level of Caves Ridge.

The lack of vadose features in Main Cave indicates that the incision of Isaacs Creek below the level of the cave occurred too quickly for Main Cave to gain lasting evidence of vadose flow. Alternately Isaacs Creek may have been partly diverted into a cave system upstream from Main Cave, in a part of Caves Ridge which has since been eroded. This would have reduced the quantity of water available for vadose flow into Main Cave.

Following the nothephreatic development of Main Cave, several phases of sediment deposition occurred. Evidence of one major depositional phase is provided by the extensive flowstone canopies and by the remnants of earth fill in niches on the walls at the northern end of the cave. The rounded limestone pebbles found in red-brown sandy clays in this part of the cave indicate either vadose inflow transporting clasts, or prior rounding by solution within a surface soil. The lack of allogenic gravels or sedimentary structures such as graded bedding supports the latter interpretation. The rounding may also have occurred through solution within the cave sediment, but this possibility is less likely.

Much of the floor of Main Cave is earth and substantial depths of fill may still be present. The accumulation and subsequent partial removal of this earth fill may indicate changes in climate as well as changes in the level of the watertable. The high initial porosity of the earth fill and the lack of scour and fill structures suggest that the sediment is derived from surface soils which moved down into the cave mainly under the influence of gravity, accompanied by only a little water. The calcite pore fillings and the flowstone cover were deposited during a later period where vadose seepage was dominant over clastic transport. This may have been due to entrance sealing by sediment, or to reduced sediment supply through vegetation and runoff changes.

The partial re-excavation of the earth fill occurred through suffosion caused by aggressive waters migrating along the sediment-bedrock interface. This produced conduits that were large enough to permit vadose flows which removed parts of the older earth fill and formed extensive canopies.

Helictite Cave TR4

Helictite Cave (Figure 6) is situated 26 m above the present level of Isaacs Creek and almost 80 m below Main Cave.

A sloping rockfall leads down from the cave entrance to a chamber which shows evidence of extensive collapse. Nevertheless parts of the roof and walls also display spongework formed under nothephreatic conditions. There is a large flowstone canopy on the western wall. Two main passages lead off from this entrance chamber. The first trends north north west and is littered with large rectangular limestone blocks formed by breakdown along joint planes. Joint ceiling cavities and scallops are found on those parts of the walls and roof which have not undergone breakdown. Further along the passage there are interbedded red-brown clays and flowstones. The individual beds vary from 10 mm to 300 mm in thickness and extend laterally for distances of several metres. This part of the passage has an elliptical cross section (cross section E) and contains asymmetric roof scallops which are steeper on the sides away from the cave entrance. The scallop asymmetry indicates that the former flow was out towards the entrance and the bedrock floor also slopes down in this direction. The passage passes into a vertical fissure developed along a strike joint, which contains roof pendants and weakly developed channel grooves. This fissure is blocked by a flowstone fill.

From the entrance chamber a short, narrow passage leads to the main part of the cave, a northwest trending vertical fissure passage which is about 40 m long. The southern end of this passage is keyhole shaped (cross section D, and Plate 1) and contains large asymmetric scallops, 0.5 m wide, 0.6 m long and 0.1 m deep which are

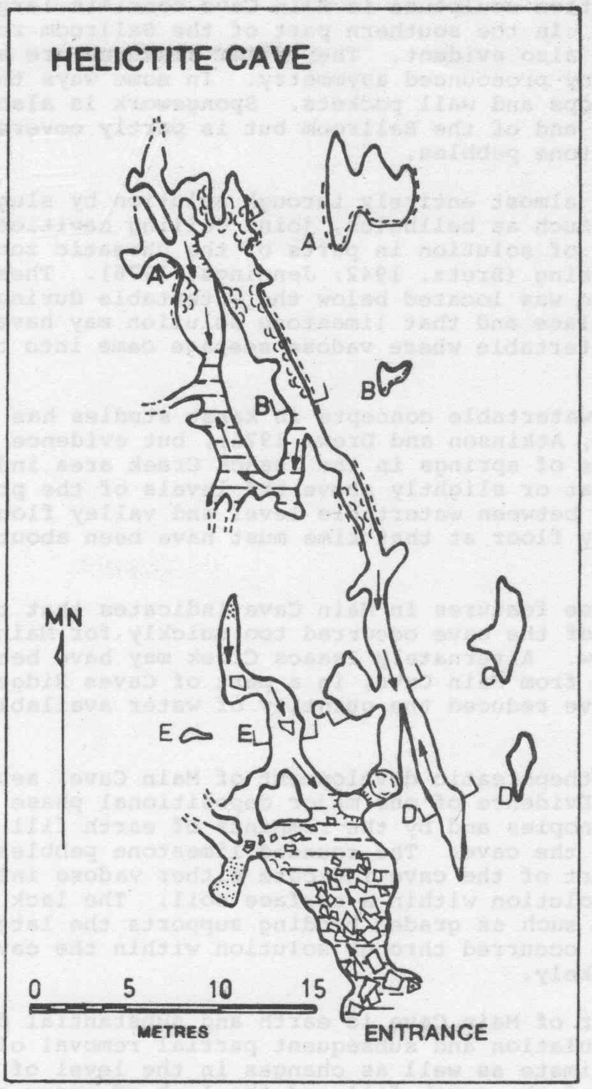

Figure 6. (after James et al., 1976)

most steeply incut on the sides away from the cave entrance, indicating southerly outflow. The slope of the bedrock floor and the presence of minor channel grooves suggest that in places this flow may have been vadose with free air surfaces. On bright days light can be seen under the flowstone which now blocks the southern end of this passage. To the south of cross section C there are interbedded clays and flowstones.

In addition to the northwest trending joints visible along the main passage in Helictite Cave, there are also joints which trend slightly east of north. Mutual offsetting of the two joint sets on a small scale indicates that these are a conjugate pair of shear joints. At the northern end of the main passage, developed on different levels, are two passages which terminate in flowstone fills. In places these passages are separated by narrow rock partitions. Joint ceiling cavities are also present. Much of the walls and floor in Helictite Cave is either flowstone or flowstone-veneered bedrock.

The early development of Helictite Cave was nothephreatic and evidence of this mode of development can be seen in the spongework, pendants, blades and joint ceiling cavities which are common throughout the cave. Following this phase, the cave was modified by dynamic phreatic action which formed cylindrical or elliptical pressure passages with scallops in many parts of the cave. Subsequent vadose incision in these pressure passages gave rise to keyhole passages (Plate 1).

Collectively the solutional features in Helictite Cave indicate that after the nothephreatic phase of development, parts of the cave functioned as a dynamic phreatic and vadose outflow to Isaacs Creek. During the time that Helictite Cave functioned as an outflow the northern section of the cave lay below the watertable, providing a source for the outflow waters. The lack of dynamic phreatic or vadose features in the northern section of the cave suggests that development here was solely due to nothephreatic solution. Therefore it is probable that nothephreatic, dynamic phreatic and vadose development were occurring simultaneously in different parts of Helictite Cave.

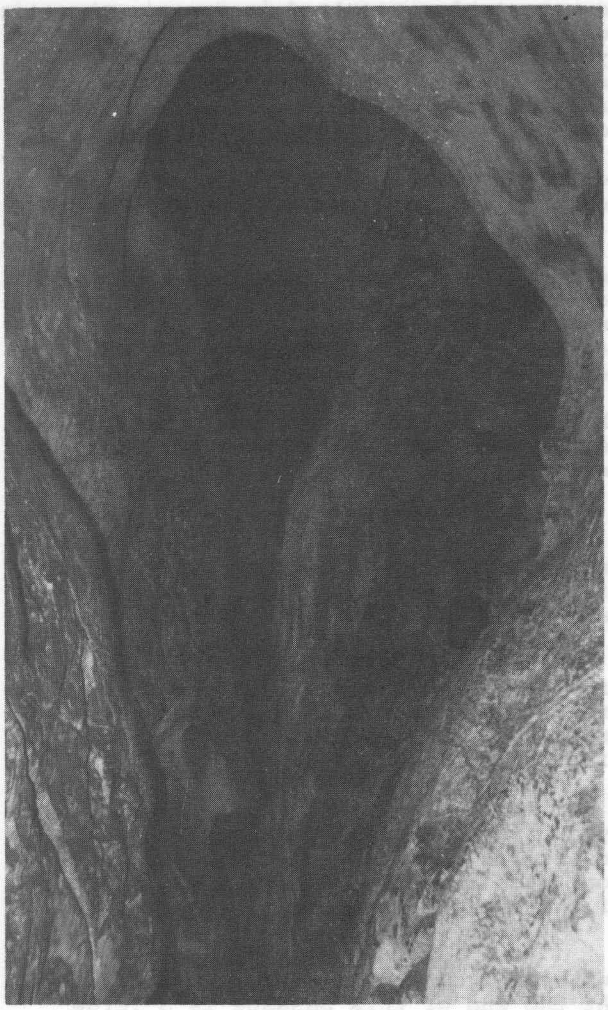

Plate 1. Keyhole passage in Helictite Cave.

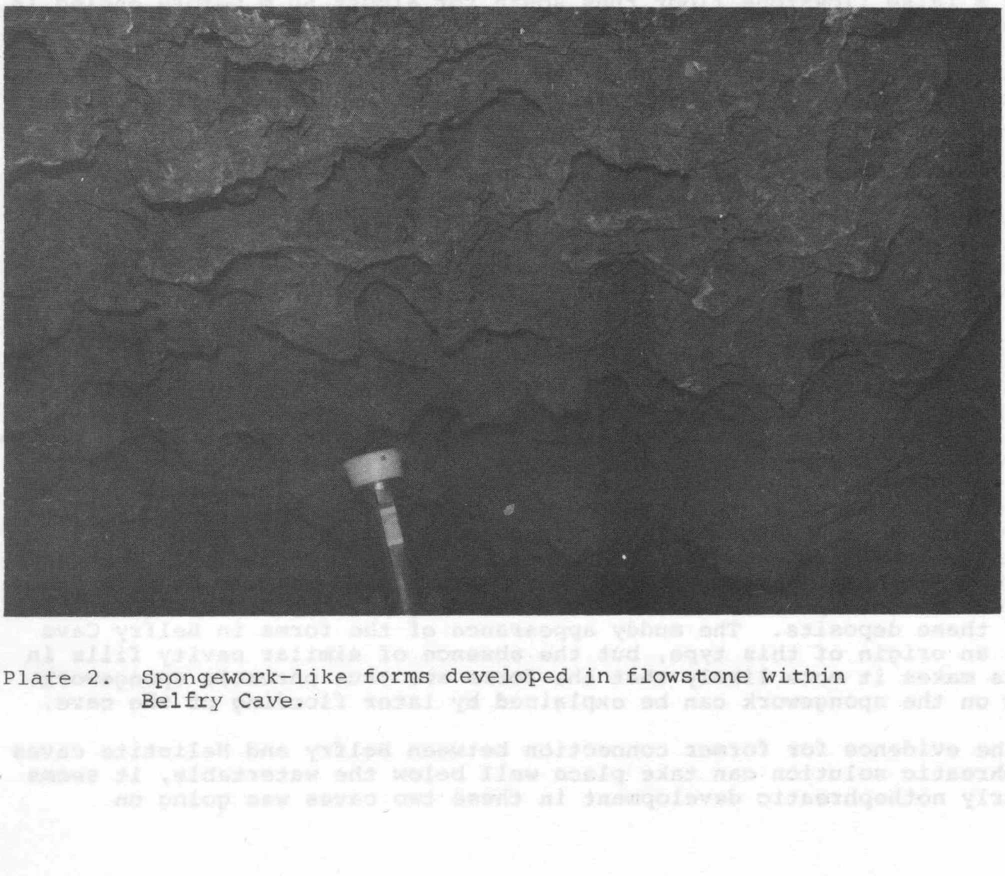

Plate 2. Spongework-like forms developed in flowstone within Belfry Cave.

The presence of keyhole passages implies that continued incision of Isaacs Creek into its valley and consequent lowering of the watertable, resulted in dynamic phreatic development being increasingly replaced by vadose development under lower flow conditions. Helictite Cave finally became dry as hydraulic pressure from the phreas (falling as a result of valley incision) became insufficient to move water towards the cave entrance. Keyhole passages and other features associated with vadose flow only occur in Helictite Cave where the bedrock floors slope downwards towards the entrance, allowing water to flow under the influence of gravity. It seems likely that the functions of Helictite Cave as an outflow were taken over by the Belfry chamber and associated passages which were developing beneath Helictite Cave and were probably connected with it.

Helictite Cave, like Main Cave, contains interbedded clays and flowstones which were deposited after the cave was drained by continued valley incision and which may reflect climatic changes. Since the red-brown clays are similar to those in Main Cave they probably also moved down into the cave largely under the influence of gravity. In this case the flowstone interbeds may represent wetter periods when vadose seepage was dominant over gravity fill (Frank, 1972). Nevertheless the possibility of temporary entrance sealing cannot be excluded and the period of time represented by each bed or lamina is unknown. For these reasons it is not possible to draw specific conclusions about climatic fluctuations during sedimentation.

Belfry Cave TR2

Belfry Cave (Figure 7) is the most extensive cave at Isaacs Creek, with almost 400 m of passages. The entrance to the cave is 12 m above the present level of Isaacs Creek and almost 90 m below the entrance to Main Cave.

From the entrance a boulder slope leads to a chamber 20 m long, which has a planed ceiling and weakly developed channel grooves. Associated with these channel grooves are asymmetric wall scallops which vary in orientation. A chi-square test on the orientations of 102 scallops near cross section H revealed a preferred orientation which is significant at the 0.05 P level and indicates former inflow.

From the entrance chamber passages lead off to the northeast on two levels. In the higher level limestone is intruded by a dyke of amygdaloidal basalt which shows vertical flow banding. This dyke which strikes at 320°, was mistaken for a band of iron-rich shale by James et al. (1976). A second basalt dyke striking at 283° is exposed in the alcove off the northern wall of the entrance chamber, west of cross section A.

A narrow passage runs south and then southeast from the entrance chamber. It contains roof scallops and channel grooves. At the end of this passage is a large mudfloored chamber with a planed ceiling which reflects watertable control (cross section G). There is a connection from here to the CO_2 Hole. Another passage with a large bellhole leads off to the southwest from the entrance chamber and terminates in a flowstone fill.

Through the squeeze to the west of this large bellhole, a passage partly divided into two levels by a false flowstone floor runs south for almost 50 m before ending in a flowstone and boulder choke. This passage contains roof pendants and blades and a planed ceiling north of cross section E. The maze of passages leading from the northern end of this passage to the chamber known as the Belfry also contains roof pendants and blades, as well as spongework-like forms developed in the underside of flowstone canopies (Plate 2).

A passage at the southern end of the Belfry leads through a squeeze (cross section C) to the southwestern end of the cave. The southwesterly trending passage of this section has an earth floor, which is locally covered by flowstone. The passage leads to a T-junction: from here one passage extends south to a flowstone choke and the other passage runs northwest, terminating in earth fill. This section of Belfry Cave contains numerous roof pendants and blades.

Belfry Cave contains many features indicating the operation of nothephreatic processes. These features include roof pendants, blades, and spongework. Some spongework-like features occur in flowstone canopies rather than limestone bedrock. If these are genuine nothephreatic forms then there must have been a period of clastic sedimentation and subsequent flowstone deposition, followed by excavation of the underlying fill and a return to nothephreatic conditions with a rise in the watertable.

Alternately the spongework forms could be the result of the deposition of flowstone in cavities within porous earth fill. Water percolating through porous cave earth may precipitate sizeable coalescing pods of sparry calcite which largely enclose rounded masses of clay (Brain, 1958). Osborne (1978) attributed calcite pods in cave sediments at Cliefden to this process and was able to recognise a genetic sequence in the cementation of these deposits. The muddy appearance of the forms in Belfry Cave is consistent with an origin of this type, but the absence of similar cavity fills in surviving sediments makes it more likely that the forms are true phreatic spongework. The muddy coating on the spongework can be explained by later flooding of the cave.

Because of the evidence for former connection between Belfry and Helictite caves and because nothephreatic solution can take place well below the watertable, it seems likely that the early nothephreatic development in these two caves was going on

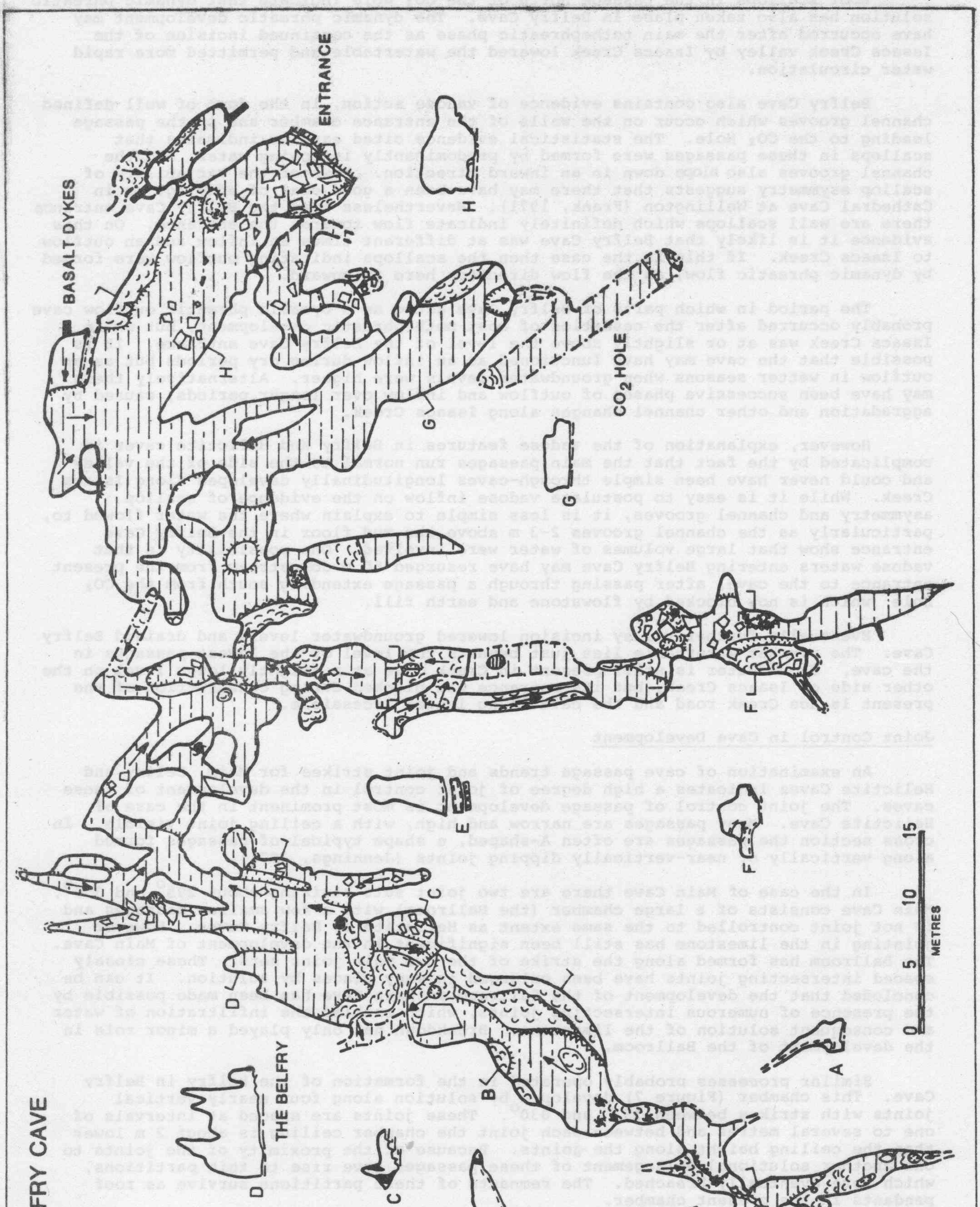

Figure 7. (after Francis, 1978b)

simultaneously. However the respective levels of these caves suggest that nothephreatic conditions persisted in Belfry Cave after Helictite Cave was drained.

Roof scallops in the passage north of the CO_2 Hole indicate that dynamic phreatic solution has also taken place in Belfry Cave. The dynamic phreatic development may have occurred after the main nothephreatic phase as the continued incision of the Isaacs Creek valley by Isaacs Creek lowered the watertable and permitted more rapid water circulation.

Belfry Cave also contains evidence of vadose action, in the form of well defined channel grooves which occur on the walls of the entrance chamber and in the passage leading to the CO_2 Hole. The statistical evidence cited earlier indicates that scallops in these passages were formed by predominantly inflowing water, and the channel grooves also slope down in an inward direction. However the variability of scallop asymmetry suggests that there may have been a good deal of eddying, as in Cathedral Cave at Wellington (Frank, 1971). Nevertheless near the Belfry Cave entrance there are wall scallops which definitely indicate flow towards the entrance. On this evidence it is likely that Belfry Cave was at different times an inflow and an outflow to Isaacs Creek. If this is the case then the scallops indicating outflow were formed by dynamic phreatic flow, as the flow direction here is upward.

The period in which parts of Belfry Cave acted as a dynamic phreatic outflow cave probably occurred after the cessation of most nothephreatic development, but while Isaacs Creek was at or slightly above the level of the Belfry Cave entrance. It is possible that the cave may have functioned as an inflow during dry periods but as an outflow in wetter seasons when groundwater levels were higher. Alternatively there may have been successive phases of outflow and inflow over longer periods, caused by aggradation and other channel changes along Isaacs Creek.

However, explanation of the vadose features in Belfry and Helictite caves is complicated by the fact that the main passages run normal to the side of the valley and could never have been simple through-caves longitudinally developed along Isaacs Creek. While it is easy to postulate vadose inflow on the evidence of scallop asymmetry and channel grooves, it is less simple to explain where the water flowed to, particularly as the channel grooves 2-3 m above the mud floor in the Belfry Cave entrance show that large volumes of water were involved. One possibility is that vadose waters entering Belfry Cave may have resurged 50 m downstream from the present entrance to the cave, after passing through a passage extending south from the CO_2 Hole which is now blocked by flowstone and earth fill.

Eventually further valley incision lowered groundwater levels and drained Belfry Cave. The present watertable lies just beneath the level of the lowest passages in the cave. Groundwater is still present in Creek Cave at a slightly lower level on the other side of Isaacs Creek, but its entrance was blocked during construction of the present Isaacs Creek road and the cave is no longer accessible.

Joint Control in Cave Development

An examination of cave passage trends and joint strikes for Main, Belfry and Helictite Caves indicates a high degree of joint control in the development of these caves. The joint control of passage development is most prominent in the case of Helictite Cave. Many passages are narrow and high, with a ceiling joint visible. In cross section the passages are often A-shaped, a shape typical of passages formed along vertically or near-vertically dipping joints (Jennings, 1971).

In the case of Main Cave there are two joint sets striking about 295° and 355°. Main Cave consists of a large chamber (the Ballroom) with a few smaller passages and is not joint controlled to the same extent as Helictite or Belfry Caves. However jointing in the limestone has still been significant in the development of Main Cave. The Ballroom has formed along the strike of the two main joint sets. These closely spaced intersecting joints have been enlarged in many places by solution. It can be concluded that the development of the Ballroom in Main Cave has been made possible by the presence of numerous intersecting joints, which enabled the infiltration of water and consequent solution of the limestone. Breakdown has only played a minor role in the development of the Ballroom.

Similar processes probably operated in the formation of the Belfry in Belfry Cave. This chamber (Figure 7) developed by solution along four nearly vertical joints with strikes between 352° and 030°. These joints are spaced at intervals of one to several metres and between each joint the chamber ceiling is about 2 m lower than the ceiling height along the joints. Because of the proximity of the joints to one another solutional enlargement of these passages gave rise to thin partitions, which were eventually breached. The remnants of these partitions survive as roof pendants in the present chamber.

One noteworthy feature of cave development at Isaacs Creek is the scarcity of passages formed parallel to the valley sides. Such passages are common in cave areas such as Jenolan, Cooleman and Wyanbene. Jennings (1976) has attributed these passages to control of both cave and valley development by the same structural feature or to control of cave orientations by sheeting joints which are genetically related to valley development. Nevertheless the main passages in Belfry and Helictite Caves run normal to the valley walls.

Sheeting joints are absent from Isaacs Creek, but their absence is hardly surprising since three or four closely spaced joint sets formed by stresses associated with Palaeozoic tectonics are present in the cave area. Under these conditions unloading stresses created by later valley incision can easily be relieved by expansion along pre-existing planes of weakness and thus no new joints will be formed.

Moreover cave and valley development at Isaacs Creek is not controlled by the same joint set. The valley follows an arcuate trend, parallel to that to the Moss Vale Fault which lies 500 m to the north. On this basis Jones (1978) has suggested that another fault may lie concealed beneath the alluvium along Isaacs Creek. However there is only minor development of jointing parallel to this suspected fault trend : the master joints for cave development have been shear joints of northerly and north-westerly trend.

Spatial Relationships between Belfry, Shaft and Helictite Caves

Data collected in the survey of Belfry Cave (Francis, 1978b) and in theodolite traverses between the entrances of Belfry, Helictite and Shaft Caves show that Belfry Cave passes beneath Shaft Cave and almost beneath Helictite Cave (Figure 8)

Shaft cave consists of a small single chamber with two entrance shafts, and lies directly above the northern end of the southern branch passage in Belfry Cave. From this point in Belfry Cave a small passage slopes upwards in a southeasterly direction and terminates in a flowstone choke. Since this choke lies only 4 m below the earth floor of Shaft Cave, it seems certain that these two caves were formerly connected.

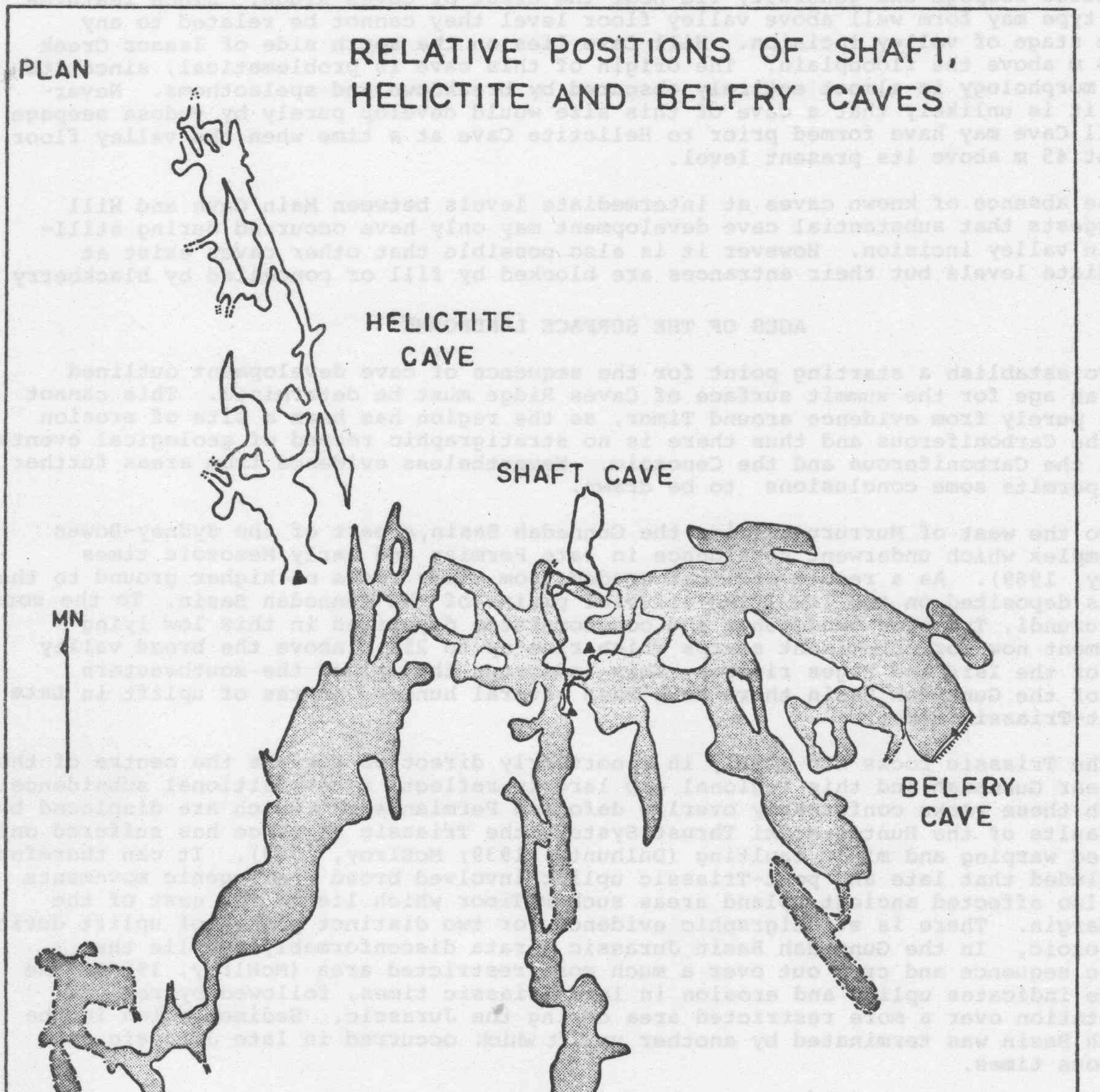

Figure 8.

The entrance of Helictite Cave lies just north of the Belfry chamber. In both caves there are well developed vertical fissure passages which have developed along two conjugate sets of shear joints that trend 020° and 355° respectively. At the southern end of the main fissure passage in Helictite Cave the flowstone floor lies only 8 m above the fissure passage which runs north from the Belfry chamber. In this case it seems likely that the two passages have developed at different levels along the same joint and were formerly connected. This inference is supported by the similar nature of the jointing in both of these passages, in addition to the evidence of passage trends, cross sections and relative positions.

Relative Ages of the Caves

From survey data and cave morphology a relative chronology for cave development can be deduced. The earliest development of the existing caves was in Main Cave, which formed prior to the present Isaacs Creek valley at a time when the valley floor was at the level of Caves Ridge. Helictite Cave and Shaft Cave developed after incision of the present valley had commenced, but at a time when the valley floor lay about 30 m above its present level. The early nothephreatic development in Belfry Cave probably also began at about this time. Phreatic and vadose development continued in Belfry Cave after Helictite Cave was drained by further valley incision. Major episodes of dynamic phreatic and vadose action occurred at a time when the valley floor lay 12 - 15 m above its present level. The youngest phreatic cave at Isaacs Creek is the one that formed in relation to the present valley floor and now lies beneath the road.

In addition to these caves there are simple shafts such at TR19 which were formed by vadose seepage and generally lie near the crest of Caves Ridge. Since features of this type may form well above valley floor level they cannot be related to any specific stage of valley incision. Hill Cave lies on the south side of Isaacs Creek about 45 m above the floodplain. The origin of this cave is problematical, since its bedrock morphology is almost entirely obscured by breakdown and speleothems. Nevertheless it is unlikely that a cave of this size would develop purely by vadose seepage. Thus Hill Cave may have formed prior to Helictite Cave at a time when the valley floor lay about 45 m above its present level.

The absence of known caves at intermediate levels between Main Cave and Hill Cave suggests that substantial cave development may only have occurred during still-stands in valley incision. However it is also possible that other caves exist at intermediate levels but their entrances are blocked by fill or concealed by blackberry bushes.

AGES OF THE SURFACE LANDFORMS

To establish a starting point for the sequence of cave development outlined above, an age for the summit surface of Caves Ridge must be determined. This cannot be done purely from evidence around Timor, as the region has been a site of erosion since the Carboniferous and thus there is no stratigraphic record of geological events between the Carboniferous and the Cenozoic. Nevertheless evidence from areas further afield permits some conclusions to be drawn.

To the west of Murrurundi lies the Gunnedah Basin, a part of the Sydney-Bowen basin complex which underwent subsidence in late Permian and early Mesozoic times (McElroy, 1969). As a result sediment eroded from older rocks on higher ground to the east was deposited on the low lying alluvial plains of the Gunnedah Basin. To the south of Murrurundi, Triassic sandstones and conglomerates deposited in this low lying environment now form prominent scarps which rise up to 250 m above the broad valley floors of the Isis and Pages rivers. This indicates that along the southeastern margin of the Gunnedah Basin there have been several hundred metres of uplift in Late and post-Triassic times.

The Triassic rocks dip gently in a northerly direction towards the centre of the basin near Gunnedah and this regional dip largely reflects syndepositional subsidence. Although these rocks conformably overlie deformed Permian strata which are displaced by major faults of the Hunter-Mooki Thrust System, the Triassic sequence has suffered only localised warping and minor faulting (Dulhunty, 1939; McElroy, 1969). It can therefore be concluded that late and post-Triassic uplift involved broad epeirogenic movements which also affected ancient upland areas such as Timor which lie to the east of the basin margin. There is stratigraphic evidence for two distinct phases of uplift during the Mesozoic. In the Gunnedah Basin Jurassic strata disconformably overlie the Triassic sequence and crop out over a much more restricted area (McElroy, 1969). The evidence indicates uplift and erosion in late Triassic times, followed by renewed sedimentation over a more restricted area during the Jurassic. Sedimentation in the Gunnedah Basin was terminated by another uplift which occurred in late Jurassic or Cretaceous times.

Because the Timor area was a palaeogeographic high during the Triassic and underwent additional uplift towards the end of that period, the summit surface of Caves Ridge which lies only 140 m above the floor of the Isis Valley must have been carved by erosion after the late Triassic uplift. All older surfaces would be situated at much higher levels in the landscape. This means that the summit surface and Main Cave which developed in association with it are no older than Jurassic. The summit surface may also post-date the uplift in late Jurassic or Cretaceous times, but evidence for the magnitude of the two uplifts is not sufficiently precise to allow a firm conclusion on this question.

If the basaltic dykes in Main and Belfry Caves could be dated, this would provide direct evidence of maximum ages for the caves. The dykes were emplaced along shear joints in the limestone rather than within existing caves and thus pre-date the cave development. Unfortunately the dyke rocks are too weathered for isotopic dating or even thin section studies. It might perhaps be argued that these dykes were emplaced in the same phase of magmatic activity as the nearby Tertiary basalts and are thus of Tertiary age. However potassium-argon dating by Dulhunty (1976) has established Mesozoic ages for numerous basaltic intrusions in the Hunter Valley which were formerly regarded as Tertiary on account of their petrographic similarity and proximity to Tertiary extrusives. Consequently the dykes at Isaacs Creek may well be Mesozoic rather than Tertiary.

The Tertiary basalt flows in the vicinity of Isaacs Creek provide a most important reference point in the chronology for cave and landscape development. These alkaline basalts cap the Liverpool Range and associated spurs to the north and east of Isaacs Creek Caves. Wellman and McDougall (1974) obtained a potassium-argon age of 53 m.y. for a flow near the summit of Wombramurra about 7 km north of the caves. These workers also obtained an age of 43 m.y. for flow in the head of the Peel Valley a few hundred metres north of Wombramurra. The flow near the summit of Wombramurra is stratigraphically much higher in the basalt sequence than the one farther to the north and thus must be younger. Consequently it seems likely that the age determined for the flow in the Peel Valley is anomalously young because of radiogenic argon loss (Wellman and McDougall, 1974). The age for the higher flow is thought to be reliable and lies on the Palaeocene/Eocene boundary according to the time scale of Berggren (1972). In the Semphills Creek area 30 km southeast of Timor, isotopic dates obtained by McDougall and Wilkinson (1967), and Wellman, McDougall and McElhinny (1969) suggest that the volcanic activity took place 55-52 m.y. ago. The evidence from isotopic dating indicates that vulcanism in the Timor area occurred in Late Palaeocene to Early Eocene times.

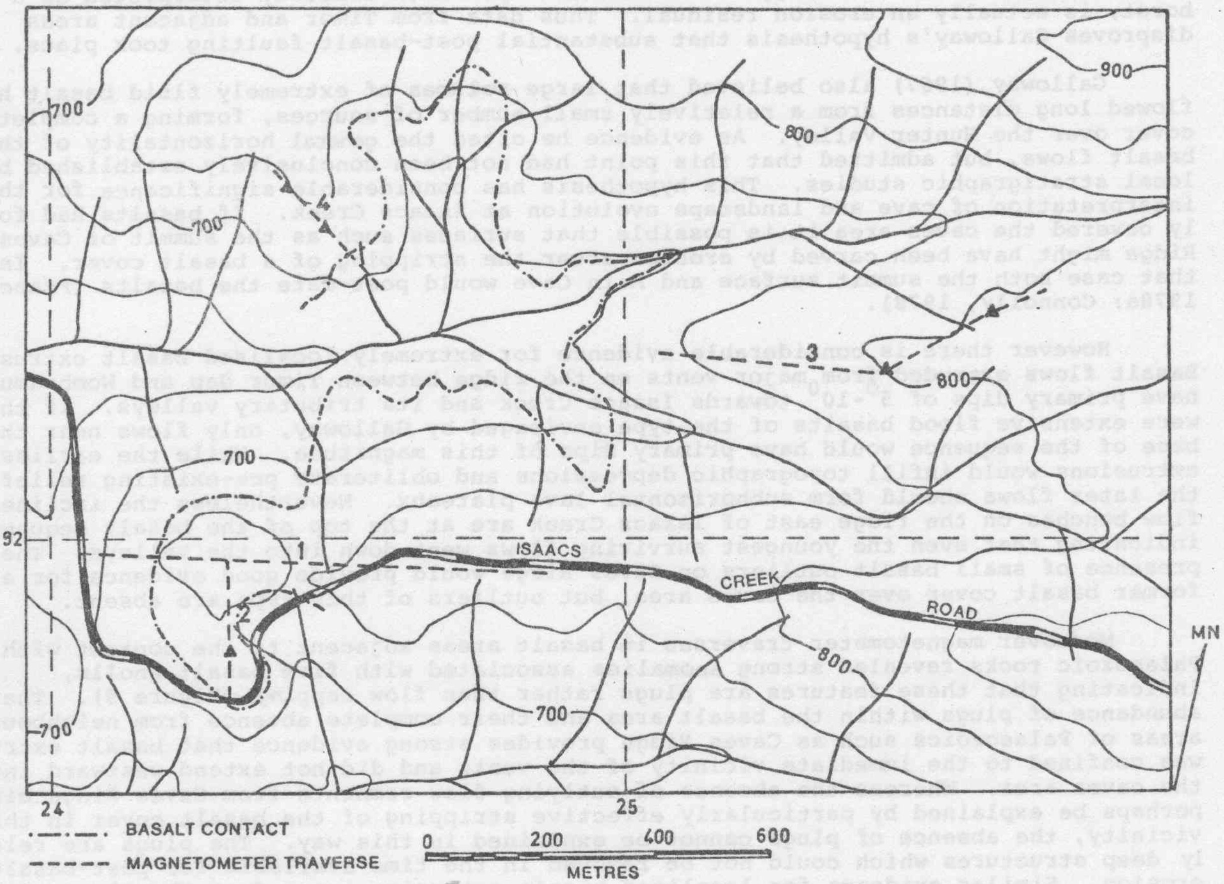

Figure 9. Valley fill basalt to the east of Isaacs Creek Caves

Although the basalts form summits in the Liverpool Range, in places they also extend well down into adjacent valleys. About 9 km northwest of Isaacs Creek basalts extruded from vents to the south of Crawney Pass flowed down into the Isis Valley and now lie at elevations only 40 m above the valley floor. In the area 2 km east of Isaacs Creek Caves, detailed mapping of the basalt contact carried out during the present study (Figure 9) has revealed that the sub-basalt surface is extremely irregular, with a relief of up to 100 m over horizontal distances of less than 1 km. In a broad study of the Hunter Valley, Galloway (1967) found considerable sub-basalt relief and attributed this largely to disruption of the buried surface by post-basalt faulting. Nevertheless good stream bed exposures of the Palaeozoic rocks in small tributaries of Isaacs Creek indicate clearly that the relief on the basalt base is not due to faulting. In places the basalt occurs as a thin veneer on steeply sloping valley sides carved in Palaeozoic rocks. The field evidence shows that basalts were extruded in a landscape of considerable relief and partially infilled small tributary valleys of Isaacs Creek.

Detailed geological mapping by Bayly (1974) about 13 km northeast of Isaacs Creek Caves revealed a similar situation. Bayly found that the basalts had been extruded onto a surface of moderate to high relief and that the faults in the Palaeozoic basement did not extend up into the basaltic cover. The evidence from the Timor area conflicts sharply with the hypothesis proposed by Galloway (1967) that the sub-basalt surface was extensively disturbed by post-basalt faulting. However this hypothesis was not adequately supported by detailed geological studies. The evidence for post-basalt faulting consisted solely of variations in the heights of the basalt base and prominent scarps, together with changes in drainage patterns. Most of these data were collected by air photo interpretation.

Subsequent studies have shown that none of the post-basalt faults postulated by Galloway are actually present. At Stewarts Brook about 30 km south of the Isaacs Creek Caves, Wellman et al. (1969) were able to trace subhorizontal basalt flows across the trend of a major post-basalt fault inferred by Galloway. They concluded that the 500 m variation in the height of the basalt base in the Barrington Tops and adjacent areas reflects pre-basalt relief rather than post-basalt tectonics. Detailed mapping of the Blacktop area about 25 km southwest of Timor by Manser (1967) and by Roberts and Oversby (1972) has shown that the northerly and easterly trending block faults are of northeasterly trend and extend into the Blacktop massif from adjacent lowlands. The prominent scarps to the south and east of Blacktop have developed along an unfaulted contact between the Rossmore Formation and the Isismurra Formation (Manser, 1967). To the west of Blacktop the meridional Wingen Fault coincides in part with one of the Tertiary block faults proposed by Galloway. Nevertheless on the northwestern margin of the massif this fault is overlain by undisturbed Triassic sandstones, indicating that there have been no movements along the fault since the Triassic. Collectively the evidence suggests that Blacktop, which Galloway interpreted as a horst, is actually an erosion residual. Thus data from Timor and adjacent areas disproves Galloway's hypothesis that substantial post-basalt faulting took place.

Galloway (1967) also believed that large volumes of extremely fluid basalt had flowed long distances from a relatively small number of sources, forming a complete cover over the Hunter Valley. As evidence he cited the general horizontality of the basalt flows, but admitted that this point had not been conclusively established by local stratigraphic studies. This hypothesis has considerable significance for the interpretation of cave and landscape evolution at Isaacs Creek. If basalts had formerly covered the caves area it is possible that surfaces such as the summit of Caves Ridge might have been carved by erosion after the stripping of a basalt cover. In that case both the summit surface and Main Cave would post-date the basalts (Francis, 1978a; Connolly, 1978).

However there is considerable evidence for extremely localised basalt extrusion. Basalt flows extruded from major vents on the ridge between Timor Gap and Wombramurra have primary dips of 5^o-10^o towards Isaacs Creek and its tributary valleys. If these were extensive flood basalts of the type envisaged by Galloway, only flows near the base of the sequence would have primary dips of this magnitude. While the earliest extrusions would infill topographic depressions and obliterate pre-existing relief, the later flows should form subhorizontal lava plateaux. Nevertheless the inclined flow benches on the ridge east of Isaacs Creek are at the top of the basalt sequence, indicating that even the youngest surviving flows went down into the valleys. The presence of small basalt outliers on Caves Ridge would provide good evidence for a former basalt cover over the caves area, but outliers of this type are absent.

Moreover magnetometer traverses in basalt areas adjacent to the contact with the Palaeozoic rocks revealed strong anomalies associated with five basalt knolls, indicating that these features are plugs rather than flow cappings (Figure 9). The abundance of plugs within the basalt area and their complete absence from neighbouring areas of Palaeozoics such as Caves Ridge provides strong evidence that basalt extrusion was confined to the immediate vicinity of the vents and did not extend westward into the caves area. Whereas the absence of outlying flow remnants from Caves Ridge might perhaps be explained by particularly effective stripping of the basalt cover in this vicinity, the absence of plugs cannot be explained in this way. The plugs are relatively deep structures which could not be removed in the time available for post-basalt erosion. Similar evidence for localised basalt extrusion comes from the Glenrock area, 13 km northeast of Isaacs Creek, where Bayly (1974) found ten theralite plugs in a 25 km^2 basalt area. Plugs were rare or absent from adjacent areas without basalt. Other stratigraphic studies of alkaline basalts in the New England region to the north of the Hunter Valley have also shown that the volcanic activity was extremely localised. In the Emmaville area the basalts were extruded from numerous local soruces and flows were often confined to drainage lines (David, 1887). Near Armidale the volcanic activity was very localised (Francis and Walker, 1978a; 1978b). In no case do flows lie more than 2 km from the vents through which they were extruded and all isolated basalt outcrops that were formerly regarded as eroded remnants of more extensive flow cappings are now known to contain plugs.

Thus the evidence from Isaacs Creek indicates clearly that the basalt cover did not extend westward over the caves area and this finding is in agreement with results obtained from basalt studies elsewhere in northern New South Wales. Consequently, the proposal that the summit surface of Caves Ridge was carved after exhumation of the Palaeozoics from beneath a Tertiary basalt cover cannot be sustained.

The basalt fill in the tributary valley to the east of the caves shows that this valley existed at the time of basalt extrusion. Although the lowest basalt outcrops lie at an elevation of 660 m, about 15 m above the summit of Caves Ridge, it is not possible that the valley floor of Isaacs Creek could have lain at the summit level of the ridge during the time that the basalts were extruded. The valley fill basalts are about 2.5 km upstream from the caves and the steep, narrow tributary valley has a gradient of 70 m/km. Observations of the heights on the lowest surviving basalt outcrops over a distance of several hundred metres indicate that this valley must have had a gradient of at least 35 m. km^{-1} at the time that the basalts were extruded. This is strictly a minimum estimate since basalts on the valley floor at the lower end of this reach may have been removed by erosion. If the tributary had a gradient of 35 m. km^{-1} and the former gradient of Isaacs Creek was similar to the present one of 20 m. km^{-1}, the valley floor at the caves must have been cut down to within 35 m of its present depth in Late Palaeocene to Early Eocene times. Even if the former gradient of Isaacs Creek was less that the present one, the valley floor would not have lain at a significantly higher level, since the tributary enters Isaacs Creek only 400 m upstream from the caves.

Similar conclusions can be drawn from the valley fill basalts near the head of the Isis River, which lie about 40 m above the valley floor. Since the Isis flows through an alluviated valley with a gradient of little more than 10 m. km^{-1}, it is most unlikely that the former gradient of this valley would have been less than the present gradient. This implies that at the time of basalt extrusion the Isis Valley had been cut down to within 40 m of its present depth near the Isaacs Creek confluence. If the former confluence was accordant like the modern confluence and if the former gradient of Isaacs Creek was similar to the present one, then the valley floor at the caves would have lain no more than 40 m above its present level. Although the precise height of the valley floor at the time of basalt extrusion cannot be known with certainty, the fact that estimates based on heights of basalt in both the Isis Valley and the small tributary of Isaacs Creek are in agreement suggests that these estimates are reasonable.

The valley fill basalts near the head of the Isis River and in the small tributaries of Isaacs Creek indicate that the Isis drainage system already existed at the time that the basalts were extruded, though there may have been some local drainage diversion in areas where basalts were most voluminous. Thus incision of the Isaacs Creek valley must have commenced prior to the Late Palaeocene to Early Eocene vulcanism. Since Main Cave developed under nothephreatic conditions at a time when the valley floor lay at the summit level of Caves Ridge, it must pre-date the basalts and thus be no younger than Early Palaeocene. As the evidence from regional structure and stratigraphy implies that the summit surface and Main Cave are no older than Jurassic, the age of Main Cave lies somewhere between Jurassic and Early Palaeocene with the most probable age being Cretaceous.

Since the evidence indicates that the floor of Isaacs Creek Valley lay about 35-40 m above its present level when the basalts were extruded and since Helictite Cave developed in relation to a former valley floor at approximately this level, the cave must have formed about the time that the basalts were extruded. However the uncertainties about former stream gradients and the variability in rates of valley incision over time prevent the assignment of a specific age to Helictite Cave. Thus the evidence only warrants a generalised Palaeogene age for Helictite Cave, Shaft Cave and the early nothephreatic development in Belfry Cave. Hill Cave probably also dates from this era, though it has been substantially modified by later breakdown.

After Helictite Cave was drained through further valley incision, nothephreatic solution was replaced by dynamic phreatic and vadose action in parts of Belfry Cave. This later development occurred when the valley floor lay about 12 m above its present level, but there is some evidence from cave morphology that suggests small scale variations in the local base level of Isaacs Creek. Evidence for a former stand of Isaacs Creek and the Isis River at about this level is also provided by lag gravels and terrace remnants which lie 7-13 m above the present floodplains (Figure 2). Two types of terrace can be distinguished. The rock cut terraces are benches cut in bedrock which are often veneered by lag gravels. These gravels are subangular to well rounded and consist almost entirely of allogenic rocks such as olivine basalt, siliceous mudstone and vein quartz. The depositional terraces consist of muds and gravels laid down by the Isis River. The gravels often show well developed imbrication and crude graded bedding. Individual beds are usually lenticular and only extend laterally for a few tens of metres. Near the confluence between the Isis River and Isaacs Creek (201910, Figure 3) a rock cut terrace grades laterally into a depositional terrace.

Associated with these terraces are alluvial fans laid down by tributaries of the Isis River and Isaacs Creeks. Most of these fans lap onto the modern floodplain and are thus younger than the terraces. Nevertheless in a few localities along the Isis River fans are truncated by meander scars at levels above the modern floodplain. This suggests that some fan building may have been going on during the stillstand when the terraces were formed. The variable heights of these terraces are partly due to initial dips of 2^o-4^o towards the valley centre and partly due to later erosional truncation of the depositional terraces.

In studies of coastal basins adjacent to the Hunter Valley, terraces at heights of 7-13 m have usually been assigned to the Late Pleistocene or Holocene even where specific evidence for their age has been lacking (Davis, 1965; Walker, 1969). Evidence from the Hunter Valley shows that assumptions of this type are not reliable. In the Jerrys Plains area 90 km south of Timor, terraces 15 m above the modern Hunter floodplain are overlain by basalts belonging to the Miocene Dubbo Province of Wellman and McDougall (1974). Further to the south similar low basalts are found along Wollombi Brook near Millbrodale. This evidence suggests that the terraces in the Isis Valley may date back to the Miocene. Nevertheless the terraces near Jerrys Plains cannot be reliably correlated with those in the Isis Valley on the basis of height alone, since a retreating knickpoint may have lain between Jerrys Plains and Timor at the time that the basalts were extruded. In this case the terraces on the Isis could be younger than the ones further downstream in the Junter Basin. To resolve this question detailed studies of terraces in the Hunter Basin would be required. Because of the uncertainties about terrace correlation, present evidence only warrants a generalised Neogene age for the terraces near Isaacs Creek Caves.

Since the later phases of dynamic phreatic and vadose development in Belfry Cave took place at the time that the valley floor lay at the level of these terraces, the Neogene age for the terraces can also be applied to the dynamic phreatic and vadose development in this cave. To assign this development to a specific time within the Neogene, evidence such as isotopic dates on speleothems would be required.

CAVE CHRONOLOGY

The evidence from cave morphology, isotopic basalt dates and the geomorphology of the surrounding areas thus indicates that Main Cave formed in the Cretaceous and that Helictite Cave, Shaft Cave and the early nothephreatic development in Belfry Cave date from the Palaeogene. Hill Cave is probably also of Palaeogene age. Although the dynamic phreatic and vadose development in Belfry Cave is more recent, it may still range back into the Miocene.

This is a much more ancient and extended chronology than has hitherto been proposed for caves in Australia or indeed in other parts of the world. Although workers such as Bretz (1950) have described palaeokarst cavities of late Mesozoic or Tertiary age, these exist as infilled relict features exposed along the walls of younger caves or mines. Caves other than exhumed palaeokarst have not previously been attributed to the Cretaceous. Moreover the ages we have assigned to the caves at Isaacs Creek are in conflict with widely accepted ideas about cave longevity. It is commonly held that although a number of extensive cave systems date back to the Early Pleistocene, few if any are older than Middle Miocene (Moore and Nicholas, 1964; Warwick, 1976). For these reasons Jennings et al. (1972) hesitated to assign early Tertiary ages to phreatic passages just below the plateau surface at Bungonia, even though isotopic basalt dates and geomorphic evidence indicated that these caves extended well back into the Tertiary.

It must be remembered that karst research has been dominated by workers in regions such as Europe and North America, where much of the relief has been created by Tertiary orogenies and where many landscapes have been largely sculptured by Pleistocene glacial or periglacial processes. Ideas about cave longevity based on work in these contexts do not necessarily apply to Australia. Ollier (1977) has recently argued that since Australian geological environments are generally older than those in Europe and North America, geomorphologists working in this country must be prepared to think in terms of more extended chronologies for landscape evolution. In support of this contention Ollier cited examples where entire landscapes rather than relict landscape features were inherited from the Tertiary.

Although Ollier was thinking of landscape evolution in general, his point applies with equal force to the development of caves and karst landscapes. In an environment such as the Hunter Valley, where many parts of the region have undergone continuous subaerial denudation since the Carboniferous, where the last orogeny took place in the Permian, where the major valleys were formed no later than the Palaeocene and where Miocene basalts lie on terraces just above the modern valley floors, conditions are ideal for the preservation of ancient landscape features. Thus the survival of Main Cave from the Cretaceous is consistent with other evidence for antiquity in the landscape. The evidence from Isaacs Creek and other parts of the Hunter Valley shows that research workers in Australia should not be constrained by notions about cave longevity derived from work in younger geological environments. Many Australian caves may be considerably older than previous workers have realised. Recent work at Cooleman suggests a Palaeogene age for Clown Cave (Rieder, Jennings and Francis, 1977), whereas Jennings (1972) had previously regarded this cave as a late Tertiary feature.

Isaacs Creek Caves are crucial for the development of new ideas about cave longevity in Australia. Few Australian karst areas have Tertiary basalts only 2 km from the caves and fewer still have isotopic dates on the basalts at sites only 7 km from the caves. The evidence from Isaacs Creek Caves showns clearly that research workers should not hesitate to assign great ages to caves, if evidence from isotopic basalt dates, cave morphology and surface geomorphology indicates that the caves are ancient features.

ACKNOWLEDGEMENTS

Acknowledgement is due to Warren Jones who supplied the geological map (Figure 2) and assisted with fieldwork. Assistance with fieldwork was also given by other members of the University of New England Speleological Society, particularly Nicky Connolly and Charlie Peters. George Rae of 'Caves Ridge' property gave free access to the caves and surrounding area and provided much useful information.

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PRELIMINARY REPORT ; CAVES IN TERTIARY BASALT, COOLAH N.S.W.

R. Armstrong L. Osborne

Abstract

Caves of up to 85 m in length have developed in amygdaloidal bodies within Tertiary basalts. Speleothems are found in some of these caves. The origin and development of these caves is being investigated.

INTRODUCTION

Coolah is located in central N.S.W., 89 km north of Mudgee and 113 km east of Dubbo. The volcanic plateau of the Liverpool Range lies to the north of the town with spurs flanking it to the east and the west. The plateau, which rises to 1,200 m is deeply dissected by gorges containing cliffs with relative heights of 50 m and more.

The caves have formed in amygdaloidal bodies withing the Tertiary basalts of the Liverpool Range.

CAVES

Gorge Cave

This, the largest of the caves yet found in the Coolah area, is located at the base of a 100 m cliff on the north-east side of Rocky Creek Gorge.

The entrance to the cave is approximately 20 m wide and 12 m high. The floor slopes outwards and is strewn with fallen rocks. A tunnel 5 m wide and 1.9 m high leads off from the rear of the entrance area. The roof of this tunnel, composed both of massive amygdaloidal basalt, shows signs of having been formed by collapse. The floor consists mostly of fallen rocks covered by a fine, dry dust composed mainly of wombat faeces. The cave is inhabited by a wombat, bats and fairy martens. The dry faeces dust makes the atmosphere within the cave most unpleasant.

Bushranger Cave

Reputed to have been used as a hide-out by bushrangers (D. Arnott, pers comm), Bushranger cave is located on the western side of a gully leading into the Coolaburra-fundy River.

The entrance is similar to that of Gorge Cave, but smaller, being 9.8 m wide and approximately 9 m high. The large entrance passage leads via a short, narrow passage into a collapse-chamber with a rockpile in its centre. A pool is located on the northern side of the chamber above which small stalactites have developed. Rocks on the floor near these have been cemented together by drip water and small crystal deposits line the pool. Small deposits of cave-coral occur on parts of the roof and areas of cliff near the cave are coated with travertine. A remnant of a former higher floor level on the north side of the entrance passage consists of rubble cemented together by travertine.

Red-back spiders (*Latrodectus sp.*) live among rocks in the entrance.

Airstrip Cave

Airstrip cave is located in an outcrop of amygdaloidal basalt on the south side of State Forest Road near Arnott's airstrip.

The cave consists of a low, wide chamber, 1 m high, with a flat roof and a rubble covered floor. At its northern end smooth walled passages lead off which contain both stalactites and flowstone. Small stalactites have formed along joint traces in the roof and cave-coral has formed on the roof and in places on the walls.

The walls consist of amygdaloidal basalt, often coated with seepage deposits, while the roof consists of relatively unweathered massive basalt. The state of the rubble floor suggests that water flows rapidly over it during wet weather.

Other Caves

Two smaller caves have been investigated. One, directly above Gorge Cave, consists of a collapse-chamber with a narrow cleft-like passage leading off from it.

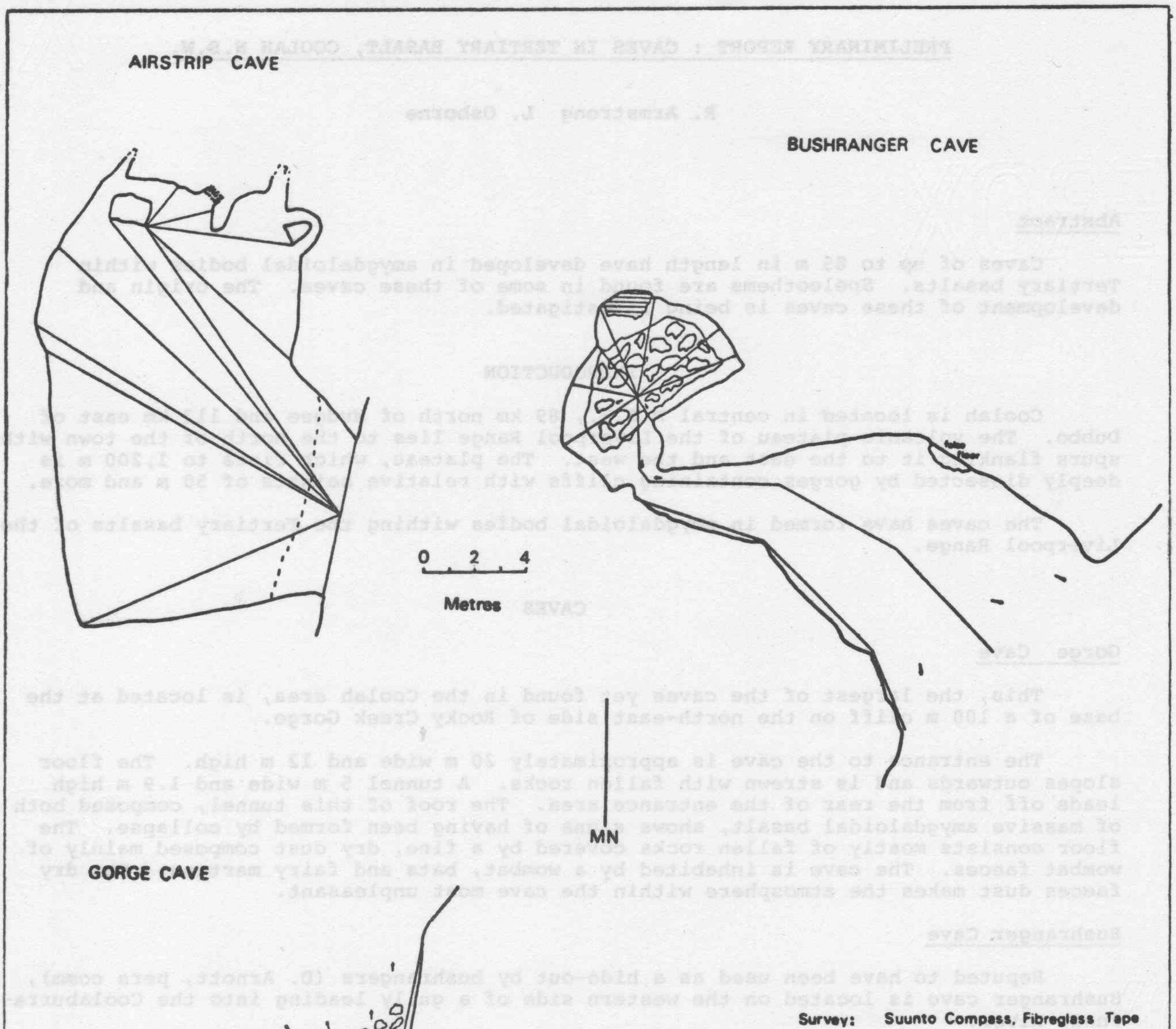

Figure 1. Plans of the three main caves.

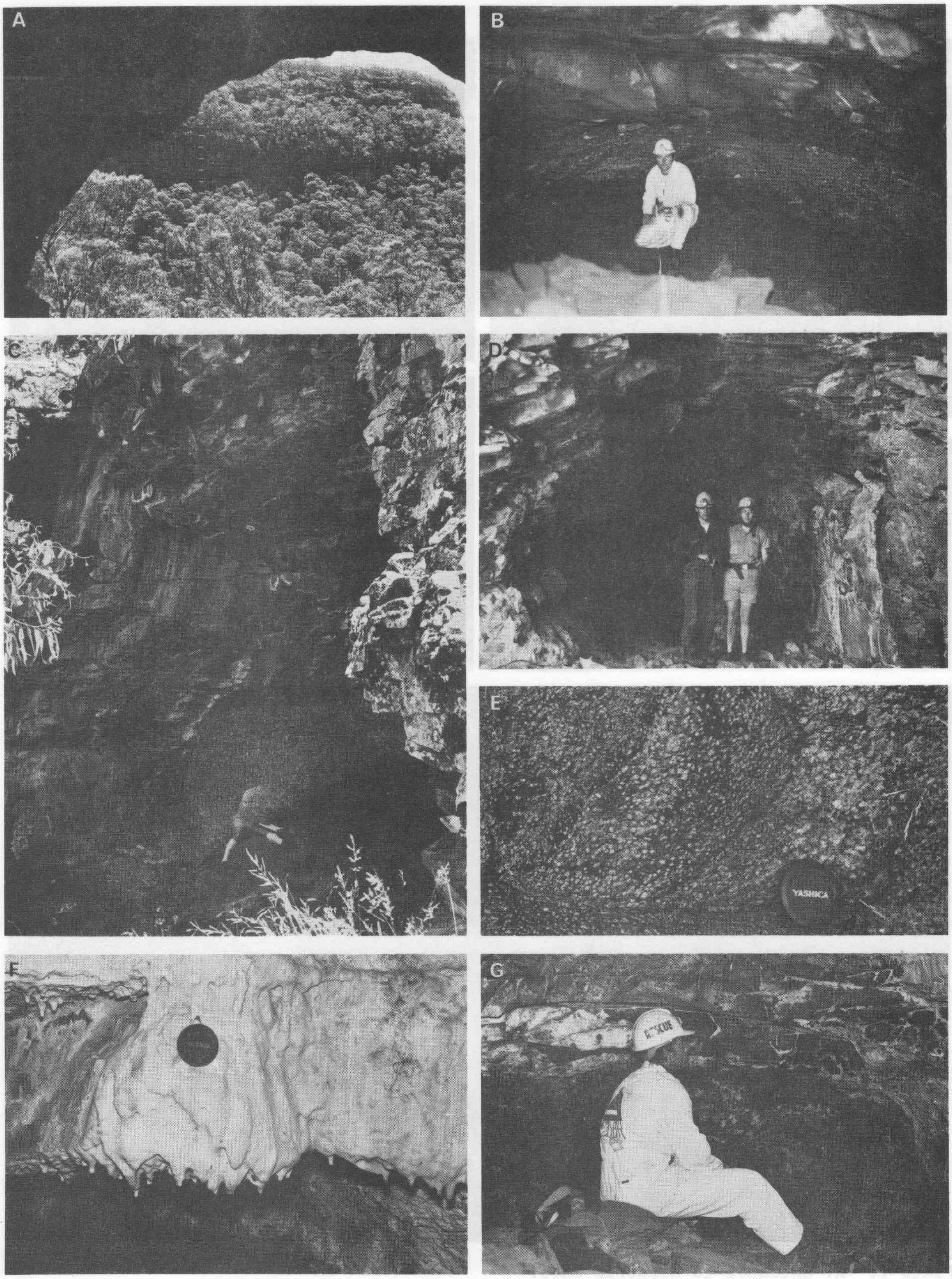

Plate 1. A: Looking out from the entrance of Gorge Cave. Note ladder for scale
B: Inside Gorge Cave. Note both amygdaloidal and massive basalt in roof.
C: Entrance to Bushranger Cave. (Photo R. Schon)
D: Entrance passage of Bushranger Cave. Note collapse along joints concentric to passage. (Photo R. Schon)
E: Travertine on rocks of cliff near Bushranger Cave. (Photo R. Schon)
F: Speleothems in Bushranger Cave. (Photo R. Schon)
G: Chamber of Bushranger Cave. Figure is seated on pile of collapse debris. (Photo R. Schon)

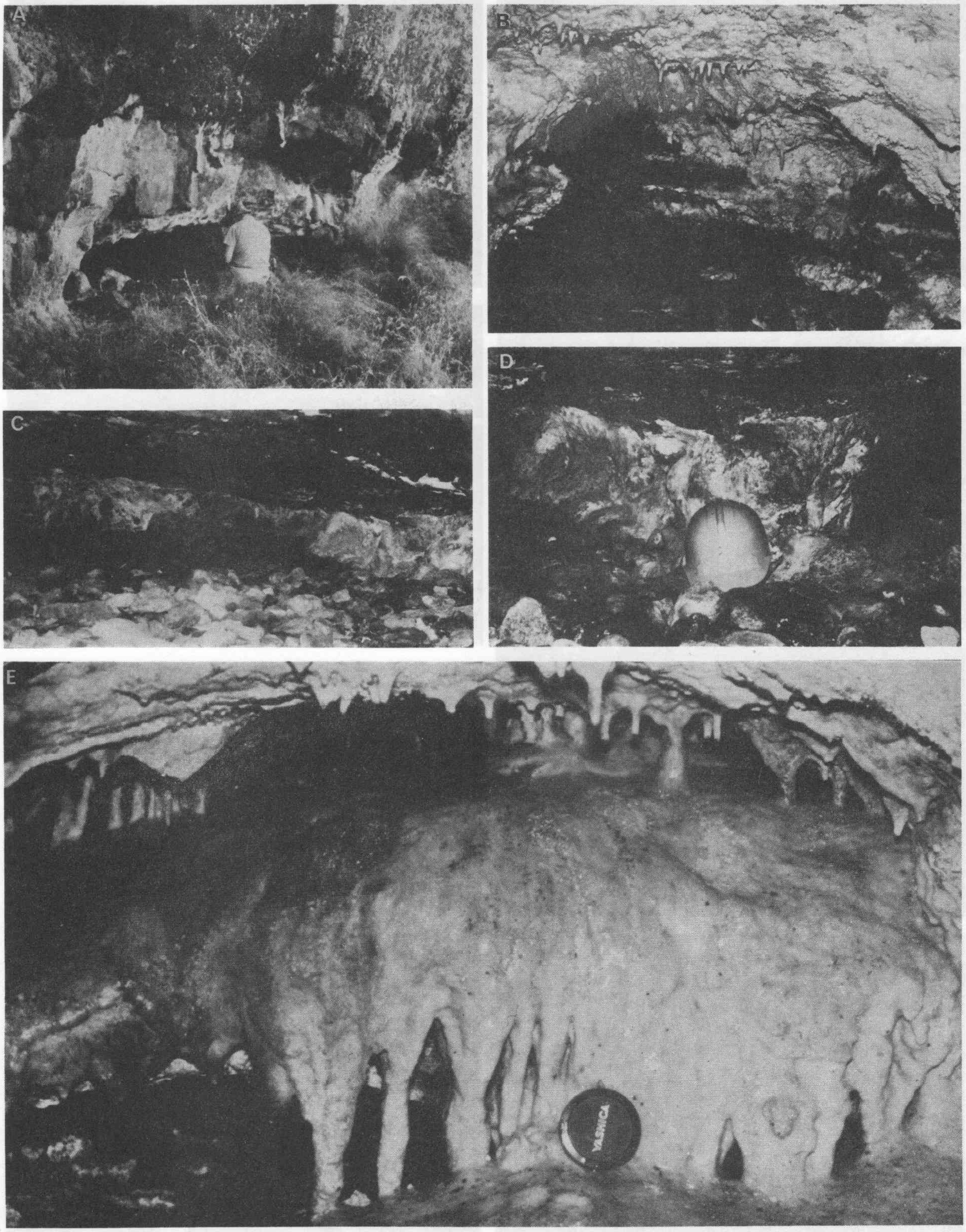

Plate 2. A: Entrance to Airstrip Cave.
B: Speleothems in northern end of cave.
C: General view of Cavern, note flat roof and debris on floor.
D: Column of material removed to form cave.
E: Flowstone in Airstrip Cave (light yellow colour). (Photos R. Schon)

Another cave is located in the cliff behind Cunninghams Camp Monument. It is a small collapse-chamber that can only be entered for a short distance.

Reconnaissance of the area has indicated that caves of the Airstrip Cave type may be fairly common. A number of these have been noted in the cliffs below Pulpit Rock and await investigation.

DISCUSSION

Speleogenesis

The caves examined fall into two quite distinct classes, those of tubular shape; Gorge Cave and Bushranger Cave and low flat cavities like Airstrip Cave.

Airstrip cave has formed by the weathering and removal of amygdaloidal basalt where an overlying horizon of massive basalt has been strong enough to form a roof. Where such a layer does not exist the amygdaloidal basalt crumbles away as cliff faces recede. Groundwater would be the main agent of this weathering. This is well illustrated at Norfolk Falls where springs rising in amygdaloidal basalt are closely related to the development of small overhang caves.

Gorge Cave and Bushranger Cave belong to a different class of cavities to Airstrip Cave. Both contain remnants of an original structure of circular cross-section and seem to form the centre of concentric joints developed in the surrounding massive basalt. Features usually associated with lava tubes; a lining, flow features, clinkery floor and lava stalactites (Wood, 1976) are absent while the occurrence of both amygdaloidal and massive basalt in the caves indicate that they are secondary erosional features. Dissolution of a zeolite zone to produce a cave in dolerite has been reported by Hale and Spry (1964). It would seem that these caves probably result from a similar dissolution of circular, elongate bodies of zeolite rich amygdaloidal basalt by groundwater.

Speleothems

The presence of stalactites and travertine in creeks and springs of the Liverpool Ranges was first reported by Leichhardt (1867). Speleothems are prolific in Airstrip Cave and developed to a lesser degree in Bushranger Cave. Groundwater seeping into these caves passes through the amygdaloidal basalt whose secondary minerals are the likely source of the deposited minerals. The chemistry and mineralogy of these deposits is being investigated.

Research

A study of the petrology of the Liverpool Range basalts is presently being undertaken by R. Schön. The author is investigating the development of the caves and the speleothems. Collation of local information at Coolah by R. Cameron and further field reconnaissance of the area should result in the documentation of further caves.

ACKNOWLEDGEMENTS

Reports of possible lava tube caves in the Coolah area came to light during recording of the Geological Heritage of N.S.W. by the Geological Society of Australia.

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HARDNESS CONTROLS OF CAVE DRIPS, MURRAY CAVE, COOLEMAN PLAIN, KOSCIUSKO NATIONAL PARK

J.N. Jennings

Abstract

Drips in the forward part of Murray Cave between 5 and 50 m below the surface were sampled about once a month for 2 years, carbon dioxide in the soil above and in the cave air being measured also. Mean soil CO_2 content was 15 times atmospheric, summer yielding higher values than winter though the dry 1972-3 summer had low values. Greater depths in the soil had more CO_2 than shallower ones. Cave air had on the average little more CO_2 than the atmosphere but river flooding of the cave was followed by large CO_2 fluctuations.

There was a slight tendency for drips to be warmer and to vary less in temperature inwards. Drip pH was greater in summer than winter because of higher CO_2 production. The (Ca+Mg)/(Na+K) ratio of the drips was nearly 10 times that of the Blue Waterholes, showing that igneous rock weathering around the Plain supplies more of the Na and K in the spring output than was envisaged before. The drip Mg/Ca ratio lies close to that of the Blue Waterholes, underlining the dominance of the limestone in the output hydrochemistry.

The mean total hardness of 141 $mg.l^{-1}$, not significantly different from earlier Murray Cave drip measurements, sustains the previous estimate that the superficial zone provides about 2/3 of the limestone solution. The summer value (149 $mg.l^{-1}$) is significantly greater than the winter mean (132 $mg.l^{-1}$), including high values in the dry 1972-3 summer when CO_2 values were low. Lagged correlation on a weekly and 3 weekly basis of individual drip hardnesses on air temperature and precipitation yielded few significant results. Only a weak case for dominance of hardness by temperature through rhizosphere CO_2 was evident but neither was the conflicting hypothesis of antecedent precipitation dominance supported. Temperature and precipitation control hardness in such contradictory ways that more detailed observations over equally long time periods are necessary to elucidate their influence.

INTRODUCTION

Various karst studies have shown that a high proportion of limestone solution takes place at or near the surface. The hardness of drips in shallow caves provides integrals of the various components of solution in this superficial karst zone.

The factors governing the hardness of such drips are several and complex in operation. Nevertheless Pitty (1966, 1968) made a good case from lagged linear correlation of the drip hardnesses of Derbyshire and Yorkshire caves with air temperature and precipitation that the most important single control appeared to be increased solar radiation and consequential air temperature in spring and summer, which promote plant growth and microbial activity. In turn these induce higher partial pressure of carbon dioxide in soil air. Infiltrating water dissolving this 'rhizosphere carbon dioxide' is then able to dissolve more limestone in a given time and so to increase the hardness of drips in caves below. In the climate of the Pennines, soil moisture is more or less permanently available; Pitty (1966) points out that his observations at Poole's Cavern, Derbyshire, were made over a well-watered summer and he felt able therefore to neglect evapotranspirational effects.

By contrast, study (Jennings, 1972) of the Blue Waterholes, the major springs of the small Cooleman Plain karst in southern New South Wales, suggested that water availability might well override the thermal factor in control of solution there (cf. Nicod, 1975; Rossi, 1974). The mean annual air temperatures and mean summer air temperatures of the two areas are close, though the available Cooleman Plain record is short (Jennings, 1979). The mean annual precipitation is somewhat greater at Cooleman Plain than at Buxton in Derbyshire and better distributed through the year. Nevertheless periods of water deficit are more likely to occur at Cooleman Plain and consequently soils dry out for long periods there. The behaviour of the cave drips in the area therefore warrants measurement to test the hypothesis that they may respond more markedly to precipitation than to temperature in their hardness.

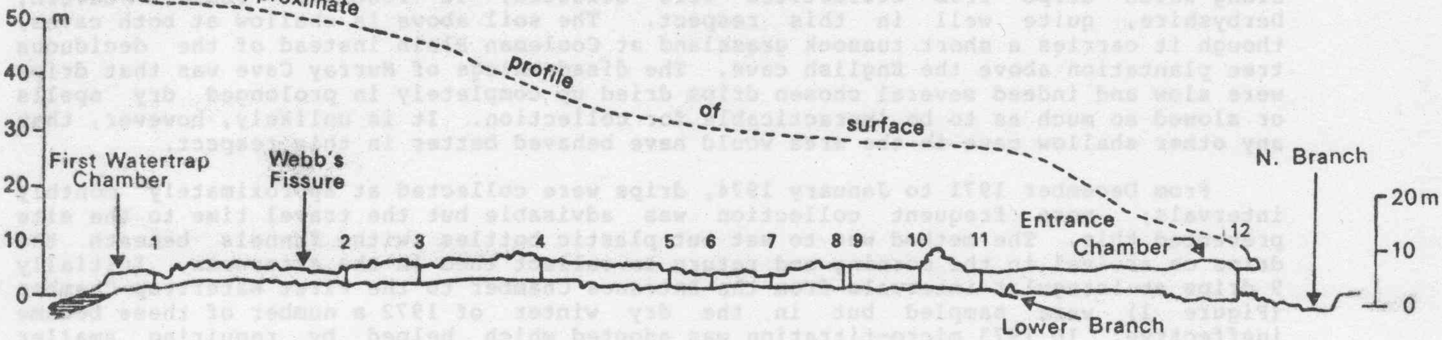

Figure 1 Long profile of Murray Cave to First Watertrap showing drip sites.

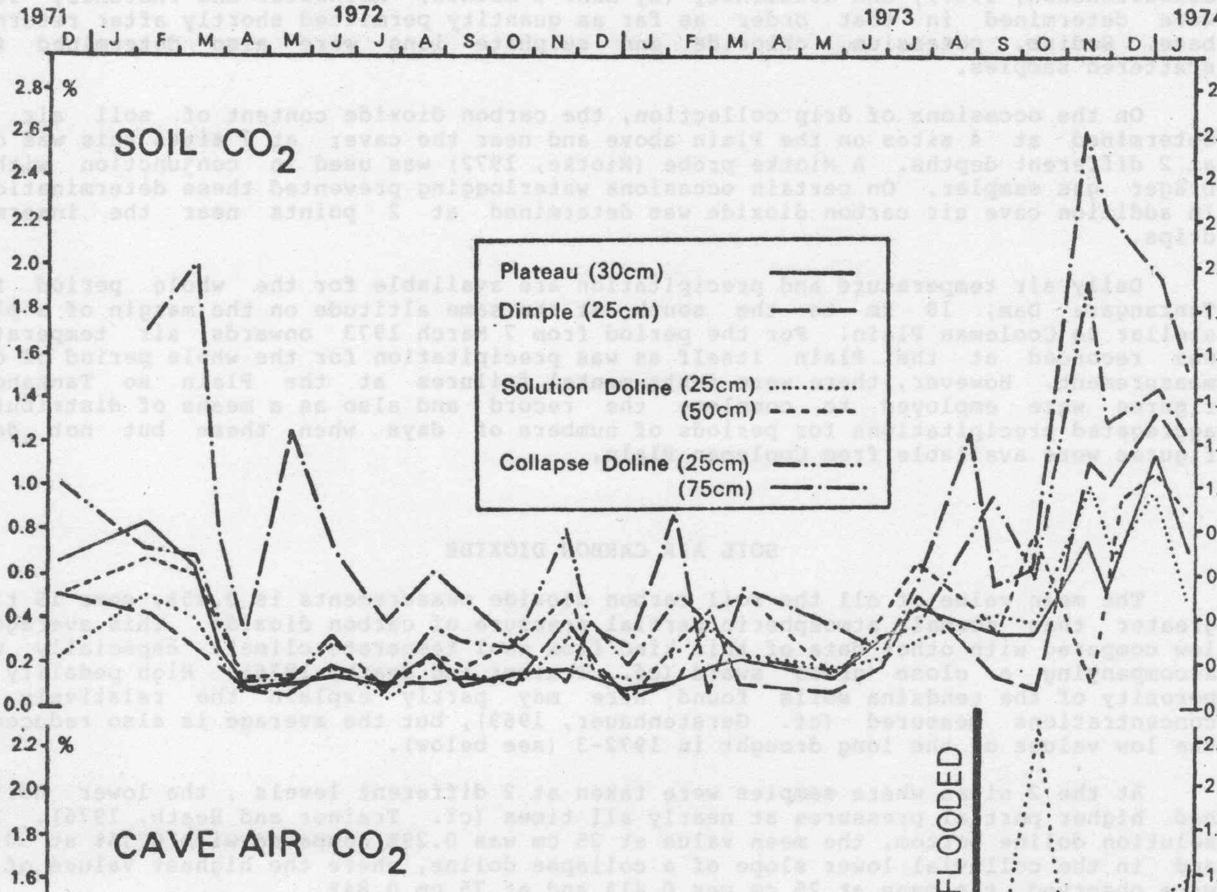

Figure 2 Graphs of soil air and cave air carbon dioxide contents from December 1971 to January 1974.

METHOD

Murray Cave, a horizontal cave normally without a stream, was chosen primarily for its shallowness and ease of access. With 5 to 50 m of limestone above the passage along which drips from stalactites were selected, it resembles Poole's Cavern, Derbyshire, quite well in this respect. The soil above is shallow at both caves, though it carries a short tussock grassland at Cooleman Plain instead of the deciduous tree plantation above the English cave. The disadvantage of Murray Cave was that drips were slow and indeed several chosen drips dried up completely in prolonged dry spells or slowed so much as to be impracticable for collection. It is unlikely, however, that any other shallow cave in the area would have behaved better in this respect.

From December 1971 to January 1974, drips were collected at approximately monthly intervals; more frequent collection was advisable but the travel time to the site prevented this. The method was to set out plastic bottles with funnels beneath the drips on arrival in the morning and return to collect them in the afternoon. Initially 9 drips at irregular intervals from the Entrance Chamber to the First Watertrap Chamber (Figure 1) were sampled but in the dry winter of 1972 a number of these became ineffective. In 1973 micro-titration was adopted which helped by requiring smaller samples but 4 further drips were included to improve the data set. The results from some drips have had to be excluded from some of the calculations because their records were too broken. On one occasion a roaring torrent through the cave, which occasionally acts as a flood overflow from River Cave, prevented drip collection.

Whenever the volume of sample permitted, temperature and pH were determined prior to removal from the cave atmosphere. Total hardness and calcium hardness (by E.D.T.A., Schwarzenbach, 1957), and alkalinity (by Mohr's method; Rainwater and Thatcher, 1960) were determined in that order as far as quantity permitted shortly after return to base. Sodium, potassium, chloride and sulphate ions were also determined from scattered samples.

On the occasions of drip collection, the carbon dioxide content of soil air was determined at 4 sites on the Plain above and near the cave; at 2 sites this was done at 2 different depths. A Miotke probe (Miotke, 1972) was used in conjunction with a Dräger gas sampler. On certain occasions waterlogging prevented these determinations. In addition cave air carbon dioxide was determined at 2 points near the innermost drips.

Daily air temperature and precipitation are available for the whole period from Tantangara Dam, 18 km to the south at the same altitude on the margin of a plain similar to Cooleman Plain. For the period from 7 March 1973 onwards air temperature was recorded at the Plain itself as was precipitation for the whole period of drip measurement. However, there were instrumental failures at the Plain so Tantangara figures were employed to complete the record and also as a means of distributing aggregated precipitations for periods of numbers of days when these but not daily figures were available from Cooleman Plain.

SOIL AIR CARBON DIOXIDE

The mean value of all the soil carbon dioxide measurements is 0.45%, some 15 times greater than normal atmospheric partial pressure of carbon dioxide. This average is low compared with other data of this kind from cool temperate climate, especially when accompanying a close grass sward (cf. Trainer and Heath, 1976). High pedality and porosity of the rendzina soils found here may partly explain the relatively low concentrations measured (cf. Gerstenhauer, 1969), but the average is also reduced by the low values of the long drought in 1972-3 (see below).

At the 2 sites where samples were taken at 2 different levels , the lower horizon had higher partial pressures at nearly all times (cf. Trainer and Heath, 1976). In a solution doline bottom, the mean value at 25 cm was 0.29% compared with 0.36% at 50 cm and in the colluvial lower slope of a collapse doline, where the highest values of all were observed, the mean at 25 cm was 0.41% and at 75 cm 0.84%.

The mean for all October-March determinations was 0.59% and for all April-September ones 0.27%, the difference being significant at the 0.1% confidence level by Student's t-test. This agrees with what has generally been found in mid- to high-latitudes (cf. Trainer and Heath, 1976).

Though they vary in detail (Figure 2), the six records of soil carbon dioxide exhibit a more complex general tendency than this summer-winter contrast suggests. Thus, although carbon dioxide content was relatively high in the summer of 1971-2 and even higher in the spring and summer of 1973-4, values were low through the intervening period of two winters and the summer of 1972-3, though there were small peaks which did not always coincide at the different sites. The low 1972-3 summer values may be attributed to reduced plant growth in drought (cf. Gerstenhauer, 1972).

Thus, although the lagged correlation of the mean CO_2 values from all sites with antecedent mean air temperatures of 3 weekly periods over 6 months gave a significant direct correlation with the 1st to 3rd weeks before and a significant inverse correlation with the 22nd to 24th weeks before, the amount of variance explained was small (21% and 25% respectively). Indeed, a stronger correlation, explaining 49% of the variance, was found between the mean CO_2 and the precipitation of the 10th to 12th week antecedent.

CAVE AIR CARBON DIOXIDE

These determinations were made at 1 m above the floor of the First Watertrap Chamber and at 10-20 cm above the ground in the nearby Webbs Fissure (Figure 1). The means, respectively 0.029% and 0.059%, were significantly different at 0.05P. The higher values in the confined space of and nearer the ground in the fissure agree in principle, if not in absolute values, with the very high levels measured in a fissure in Trou Jouay at Comblain-au-Point in Belgium (Ek, Delecour and Weissen, 1968) and in fissures in Polish caves (Ek, Gilewska, Kaszowski, Kobylecki, Oleksynowa and Oleksynowna, 1969).

The cave air roughly paralleled the soil air in variation in carbon dioxide content through time (Figure 2). In the long period of low soil air values through the middle of the observation period, many of the Watertrap Chamber figures and a few of the fissure ones were below normal atmospheric content. This cannot be explained by altitude above sea level and it may be due to instrumental error. Ek et al. (1969) noted similarly low values in Polish caves but they were associated with low temperatures.

Following the flooding of the cave, there were violent fluctuations in the CO_2 content of the cave air, with some high values. Beyond the First Watertrap there are several bodies of air normally locked between waterfilled sections and during the flood, turbulent flow may have entrained abnormally large quantities of air from these entrapped bodies into the forward part of the cave. Such air bodies may possess high CO_2 partial pressures through decay of organic matter.

DRIP TEMPERATURES

There are small differences between the mean temperatures of individual drips, mainly not statistically significant. However, there is a small and irregular gradient of increasing warmth from the forward to the inner part of the cave (mean of 6 forward sites = 10.3^{0}C; mean of 6 inner sites = 10.8^{0}C).

More difference occurs in the variation over time, which is greater near the entrance. Drip 12 just inside the entrance had a range of 9.1^0 in the observation period whereas the inner ones had ranges of 3-4^0. Standard deviations were generally greater in the forward part of the cave than in the inner. Drip 12 reached its maximum in February and its minimum in July, in each case one month before the inner drips reached their turning points.

All temperatures recorded in the November-April period gave a mean of 11.2^0 whereas the mean for the winter period, May-October, was 9.4^0 (significantly different at 0.001 P). The annual mean of all drips is 10.5^{0}C.

DRIP pH

The mean pH of all drips was 7.9 and individual drip means ranged from 7.6 to 8.2. November-April measurements gave a mean of 7.8 and the May-October mean was 8.0 (significantly different at 0.001P). Four of the 12 drips had a significant inverse rank correlation with temperature, explaining between 95 and 18% of the variance. This greater summer acidity matches the findings of Moore (1962) who ascribes it to greater microbial activity in the warmer months producing more carbon dioxide which renders the soil water more acid.

Correlation of the 12 drip pH records with the 5 soil carbon dioxide sites yielded significant figures in only 5 out of the 60 combinations; of these 2 were direct and 3 inverse relationships. Thus there can be said to be no relationship between drip pH and contemporary soil CO_2.

SULPHATE, CHLORIDE, SODIUM AND POTASSIUM

All these ions are present in the drips in small quantities only. 22 samples yielded a sulphate mean of 3.8 $mg.l^{-1}$. Despite the sporadic occurrence of pyrites in the Cooleman Limestone, sulphate content of the drips is thus insufficient for there to have been much contribution to calcite solution by this mineral. Summer values are significantly higher than winter ones.

The mean value of chloride from 22 samples was 0.72 $mg.l^{-1}$ compared with a mean of 6.2 $mg.l^{-1}$ from the Blue Waterholes (Jennings, 1972). This supports the earlier conclusion that the igneous rocks supply most of the chloride rather than the rainfall.

Sodium (mean of 0.4 $mg.l^{-1}$ from 44 samples) and potassium (mean of 0.26 $mg.l^{-1}$ from 45 samples) are also low compared with the levels in the groundwater output at the Blue Waterholes. The mean (Ca+Mg)/(Na+K) of the drips, 95, is nearly six times as great as that for the springs, 16.75. The higher ratio for seepage in the superficial zone of the limestone suggests that weathering of the igneous rocks surrounding the limestone plain contribute through peripheral sinks a larger share of the Na and K to the groundwater than was contemplated previously (Jennings, 1972).

Mg/Ca RATIO

This ratio differs from drip to drip and from time to time. Analysis of the mean values for the different drips based on common occasions shows that those from drips 4 and 11 are significantly higher. There are dolomitised veins running through the bedrock and it may be that these drips tap water making contact with such veins.

The mean value from all samples of 0.074 is much lower than those of 0.81 for the Devil Hole and of 0.35 for Six by the Fence, both peripheral streams from the igneous surround, which sink into the limestone. This is a typical difference between carbonate and igneous rock catchments. The ratios of 0.11 for the Cliff Foot Rising, the largest single spring of the Blue Waterholes, and of 0.14 for the occasional surface stream flow down Cave Creek into the Blue Waterholes show the dominant imprint of the limestone on the hydrochemistry of the output of Cooleman Plain.

DRIP HARDNESS

Calcium and total hardness are extremely closely correlated as the Mg/Ca ratio would indicate. The mean total carbonate hardness of the individual drips varied between 91.1 $mg.l^{-1}$ and 161.0 $mg.l^{-1}$. Drip 11, with the lowest figures, was significantly different from all others and the next lowest value from drip 12 was significantly different from the rest except drip 10. These 3 drips are the most forward in the cave and drip 12 has only 5 m of rock above it. Nevertheless correlation of hardness against rock depth did not give a significant result. There is more variation in hardness from drip to drip and they have higher coefficients of variation than Pitty found with Poole's Cavern drips.

The mean total hardness of all drip measurements is 141.4 $mg.l^{-1}$ (n=228,S.D.=30.0). This value lies close to the mean of 152 $mg.l^{-1}$ (n=35,S.D.21.0) from 5 collections in 1962-1963 on 3 winter and 2 summer occasions, only some of the drips being the same ones. Thus the previous use made of the second mean to allocate limestone solution within the Cooleman Plain karst system is sustained in principle. The high proportion of the limestone solution taking place in the superficial zone is reduced from 73% to 68%.

The mean value for all measured drips on each occasion varied between 78.0 $mg.l^{-1}$ and 153.7 $mg.l^{-1}$ but the lowest value was much below the rest and followed the occasion of the flooding of the cave so that there was an extreme amount of water about at this time (Figure 3).

There is a difference between winter and summer mean values (lagged behind the sun one month) which is significant at 0.001 P; November to April is 149.1 $mg.l^{-1}$, May to October 131.5 $mg.l^{-1}$. This suggests that there can only be a small lag in hardness behind the thermal regime and associated phenological events.

Correlation of mean total hardness of each drip with the mean CO_2 of each soil measuring point showed significant relationships in only 5 cases out of 72 (12 drips x 6 measures of CO_2); 2 of these were direct and 3 were inverse. Calcium hardness and alkalinity gave consistently direct correlations but even fewer of them. There is thus negligible correlation between the chemical characteristics and the soil CO_2 at the same time. This is the expectable result since the seepage water must take some time to pass from soil to cave.

Because of the irregular intervals between the dates to which these measures apply, it is not possible to lag correlations between them. If resort is made to shifting a CO_2 graph for means of all determinations on each occasion backwards in time relative to a similar graph of means of total hardnesses on each occasion, the best fit appeared subjectively to be with 2 months lag. There persists with this selection marked departure of the two curves in the dry 1972-3 summer when soil CO_2 was low but hardnesses remained high. To explain this there is the possibility that solutes were evaporatively concentrated whilst passing through the soil but this is in conflict with low soil throughflow concentrations actually measured in a small catchment in 1975-6, a dry summer also (Jennings, 1978).

Pitty (1966) showed that neighbouring drips might have different lags for their strongest correlations with surface conditions, implying routes of varying difficulty for percolation water through the rock. Therefore the Murray Cave individual drips records were lagged on a weekly basis over 13 weeks as Pitty did. Few significant correlations resulted. Thus with HCO_3 only 4 significant results were obtained out of 312 (12 drips x 2 atmospheric variables x 13 weeks). Calcium hardness gave more, 29

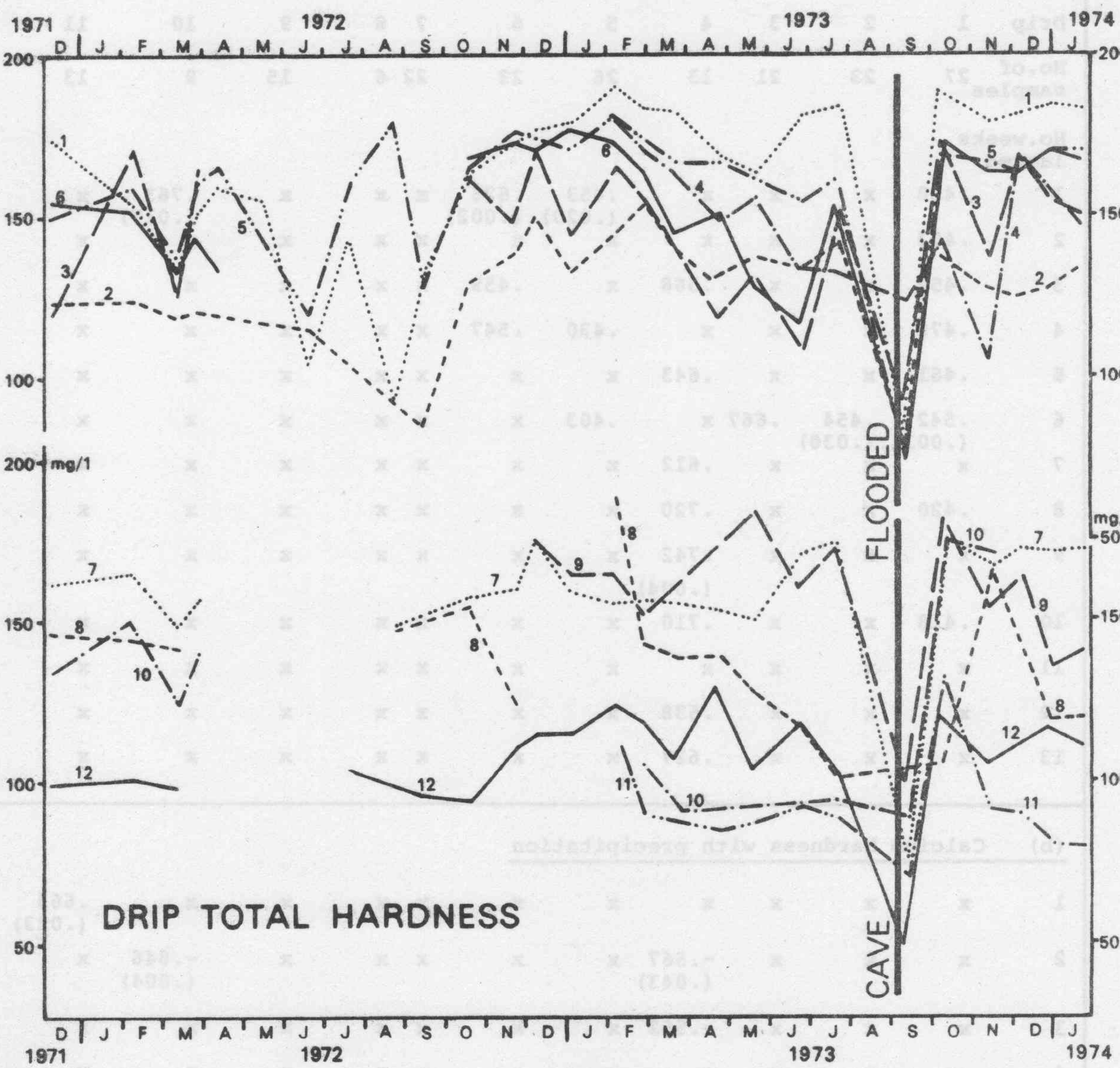

Figure 3 Graphs of total carbonate hardness of Murray Cave drips from December 1971 to January 1974.

air temperature correlations out of 156, 9 precipitation correlations out of 156 (Table I). These are meagre numbers in comparison with Pitty's equivalent analyses. Moreover, the significant precipitation correlations all came from drips with small numbers of samples giving less confidence that they have causal meaning. Even with the more numerous significant air temperature correlations, when 7 out of 12 drips had at least one such, the pattern over time is somewhat incongruous, with drip 12, which has only 5 m of rock above, giving the longest lag of all.

In his later paper, Pitty (1968) settled on a 3-weekly basis for his lagged correlations and Table II sets out the results of applying this interval to the Murray Cave figures over a 6 month period. The proportions of significant correlations remain much the same and their sense also. However, over this longer time period, the temperature results appear a little more consistent; 3 drips gave their strongest and most significant correlations of hardness with temperature of the 4-6 week period before, 1 with the 7-9 week period and 2 with the 10-12 week period. This gives some support to the concept of rhizosphere carbon dioxide influence on drip hardnesses.

TABLE I CORRELATION OF DRIPS WİTH AIR TEMPERATURE AND PRECIPITATION LAGGED WEEKLY

Product moment correlation coefficients P=.05 or better

(a) Calcium hardness with air temperature

Drip	1	2	3	4	5	6	7	8	9	10	11	12
No.of samples	27	23	21	13	26	23	22	6	15	9	13	22
No.weeks lagged												
1	.488	x	x	x	.453 (.020)	.626 (.002)	x	x	x	.763 (.017)	x	x
2	.403	x	x	x	x	x	x	x	x	x	x	x
3	.455	x	x	.568	x	.459	x	x	x	x	x	x
4	.476	x	x	x	.430	.547	x	x	x	x	x	x
5	.461	x	x	.643	x	x	x	x	x	x	x	x
6	.542 (.003)	.454 (.030)	.667	x	.403	x	x	x	x	x	x	.481
7	x	x	x	.612	x	x	x	x	x	x	x	x
8	.420	x	x	.720	x	x	x	x	x	x	x	x
9	x	x	x	.742 (.004)	x	x	x	x	x	x	x	x
10	.418	x	x	.710	x	x	x	x	x	x	x	.459
11	x	x	x	x	x	x	x	x	x	x	x	.452
12	x	x	x	.638	x	x	x	x	x	x	x	x
13	x	x	x	.627	x	x	x	x	x	x	x	.509 (.016)

(b) Calcium hardness with precipitation

Drip	1	2	3	4	5	6	7	8	9	10	11	12
1	x	x	x	x	x	x	x	x	x	x	.663 (.023)	x
2	x	x	x	-.567 (.043)	x	x	x	x	x	-.846 (.004)	x	x
3	x	x	x	-.552	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x	-.834	x	x	x	x
6	x	x	x	x	x	x	x	x	x	x	x	x
7	x	x	x	x	x	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x	x	x	-.764	x	x
9	x	x	x	x	x	x	x	-.863 (.027)	x	x	x	x
10	x	x	x	x	x	x	x	x	x	x	x	x
11	x	x	x	x	x	x	x	x	x	x	x	x
12	x	x	x	x	x	x	x	x	-.554 (.032)	x	x	x
13	x	x	x	x	x	x	x	x	x	x	x	x

Figures in brackets are probabilities of the strongest correlation coefficient of each drip.

TABLE II CORRELATION OF DRIPS WITH AIR TEMPERATURE AND PRECIPITATION LAGGED THREE-WEEKLY

Product moment correlation coefficients P=.05 or better

(a) Calcium hardness with air temperature

Drip	1	2	3	4	5	6	7	8	9	10	11	12	Mean
No.of samples	27	23	21	13	26	23	22	6	15	9	13	22	12
No.weeks lagged													
1 - 3	.467	x	x	x	.372	.626	x	x	x	x	x	x	.468
4 - 6	.517 (.006)	.420 (.046)	x	.637	.423 (.031)	x	x	x	x	x	x	.438	.514 (.006)
7 - 9	.427	x	x	.710 (.007)		.459	x	x	x	x	x	x	.489
10-12	x	x	x	.646	x	.547 (.008)	x	x	x	x	x	.461 (.031)	x
13-15	x	x	x	x	x	x	x	x	x	x	x	.456	x
16-18	x	x		x		x	x	x	x	x	x	x	x
19-21	x	x	x	x	x	x	x	x	x	x	x	x	x
22-24	x	x	x	x	x	x	x	x	x	-.749 (.020)	x		

(b) Calcium hardness with precipitation

Drip	1	2	3	4	5	6	7	8	9	10	11	12	Mean
1 - 3	x	x	x	-.625 (.023)	x	x	x	x	x	x	.623 (.023)	x	x
4 - 6	x	x	x	x	x	x	x	x	x	x	x	x	x
7 - 9	x	x		x	x	x	x	.905 (.013)	x	x	x	x	x
10-12	x	x	x	x	x	x	x	x	x	x	x	x	x
13-15	x	x	x	x	x	x	x	x	x	x	x	x	x
16-18	x	x	x	x	x	x	x	x	x	x	x	x	x
19-21	x	x	x	x	x	x	x	x	x	x	x	x	x
22-24	x	x	x	x	x	x	x	x	x	x	x	x	x

Figures in brackets are probabilities of the strongest correlation coefficient of each drip.

Overall the results about drip hardness controls are far from clearcut. There is a weak case for the higher hardnesses to relate to early spring and summer growth with lags varying from 1 to 3 months. There is little support for the opposing hypothesis that antecedent precipitation is the prime control. At Cooleman Plain the factors governing drip hardnesses seem to operate in too complex a fashion for the experimental method adopted here to disentangle them. In his Table I, Pitty (1966) lists 6 mechanisms whereby temperature influences carbonate hardness, of which 4 operate positively and 2 negatively, and lags can vary from one mechanism to another. An additional mechanism has been proffered here, namely evaporative concentration of soil water solutions. As regards precipitation, Pitty cites 3 possible causes of direct correlation and 2 of inverse. In these circumstances, a more detailed approach is necessary. Drip samples should be collected at least daily, though it would be better to monitor conductivity continuously as a measure of carbonate hardness. Drip rates are also needed; indeed Pitty measured discharge of percolation water in this way. At Murray Cave, drip slowness prevented this, given the operational method adopted. Additionally, these more detailed methods must be applied over quite long periods in different seasons for an adequate unravelling of the factors controlling drip hardness.

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AN UNUSUAL SANDSTONE CAVE FROM NORTHERN AUSTRALIA

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Abstract

The finding in recent years of much longer and more elaborate caves in quartz sandstone in South America than were known previously prompted a search for caves other than weathering caves in Arnhem Land in 1978. Though in the main unavailing for social reasons, it did lead to recognition that Yulirienji Cave, St Vidgeon Station, Northern Territory, well known for its Aboriginal rock art, is an abandoned, short river cave in quartz sandstone modified by weathering.

INTRODUCTION

Australian Speleological Federation data (P. Matthews, pers. comm.) which were supplied for the construction of a map of Australian caves to be published in the Australian Speleological Federation National Heritage Study, included the numbers of caves for each State and the Northern Territory in four categories - carbonate karst, primary volcanic, littoral and 'other'. A most revealing aspect about this information was the haphazardness of the number of littoral and 'other' caves, which bore no relation to the size and the geology of each state. Lack of limestone near to Melbourne and to Brisbane obviously leads cavers there to search out their quarry in other rocks, whilst Sydneysiders, though not bothering about 'other' caves because of more numerous nearby limestone caves, are nevertheless unable to resist exploring the sandstone sea cliffs of their suburbs. Any map of caves is bound to reflect variation in intensity of search for caves to some degree but these distortions of the true distribution are clearly too great for littoral and 'other' caves to be included in the map.

Of the 'other' caves in Australia, the guess may be hazarded that in the long run sandstone caves will prove to be the most numerous. For the most part these will be small weathering caves, indeed mainly rock shelters, rather than true caves. However, there are extensive areas of quartz sandstone and quartzite in tropical Australia and the history of speleology in the tropics suggests that our North should be able to provide more than weathering caves. Even as far back as 1920, substantial quartz sandstone caves were described from French West Africa, now Mali. Subsequently the same story has emerged from other parts of tropical Africa (Mainguet, 1972). More startling findings have been coming in recent years from the southeastern part of Venezuela, which was once part of Gondwanaland (as was most of Africa and Australia). Complementary discoveries are now being made in the neighbouring part of Guyana and also from Brazil, most of which also belonged to the ancient super-continent of Gondwanaland.

To review systematically the literature growing on this subject would be inappropriate as prelude to the description of the small Australian cave which follows. Suffice it to say that the discoveries in Venezuela range from abandoned labyrinths, several hundreds of metres long and with circular passages up to 20 m high, to active river caves of greater length still. Surface features include dry collapse dolines as much as 400 m deep and large cenotes, which make the limestone cenotes of the Southeast of South Australia look small. Figure 1 gives an idea of what has been found in quartz sandstone with siliceous cement. On the sandstone plateau of Guaiquinima in southeastern Venezuela, a big river and its tributary disappear underground in the dry season to reappear in big springs nearly 2000 m away in a straight line. The plateau is so inaccessible that so far it has only been visited by helicopter.

Arnhem Land is the part of Australia where I have considered basically similar phenomena might occur from my own experience but that this may not be the only area can be seen in Sir George Grey's account of his travels in North Kimberley (1841). On p.97 he writes of 'the gurgling of water, which I heard beneath me...I ascertained that streams were running in the earth beneath my feet...on descending and creeping into a fissure in the rocks, I found beneath the surface a cavern...through it ran a small stream, which in the rainy season must become a perfect torrent.' He goes on later (p.98), 'I subsequently, during the season of heavy rains, remarked the usual character of the mountain streams to be, that they rose at the foot of some elevation, which

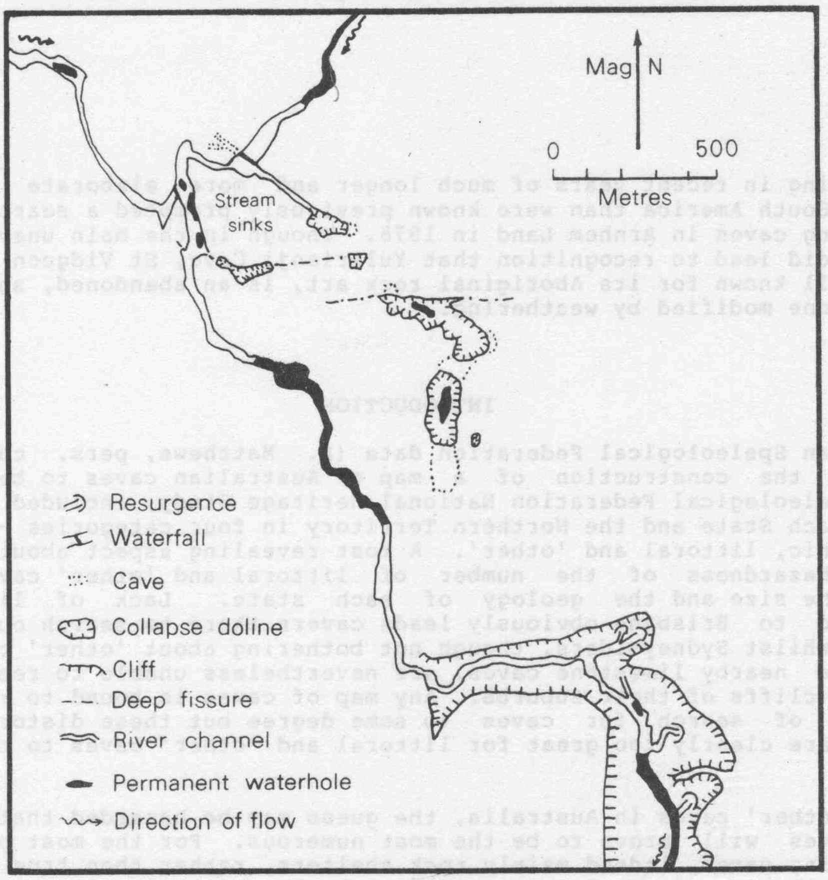

Figure 1 **Karst features in the sandstone plateau of Guaiquinima, southeastern Venezuela (after Szczerban, Urbani and Colvée, 1977).**

stood upon a lofty table land composed of sandstone, then flowed in a sandy bed for a short distance, and afterwards mysteriously sank in the cracks and crevices made in the rocks from atmospheric influences, and did not reappear until they had reached the foot of the precipice, which terminated the table land, whence they sprang; here they came forth foaming out in a rapid stream, which had undoubtedly worked strange havoc in the porous sandstone rocks among which it held its subterraneous course'. This kind of thing is happening in many places, he states.

In my first visit to Arnhem Land in 1965, I examined only rock shelters and weathering caves of archaeological significance but from Carmel White, the prehistorian whom I was advising, I learned of caves inside the Arnhem Land Aboriginal Reserve which fell into a different category. One of her excavations there, Tyimede II, was in the front part of a cave, which her survey shows to run in 35 m beyond which it continues an unknown distance (White, 1967). It is 7 m wide at the entrance and still 5 m wide where the plan ends; its height varies between 0.5 and 3 metres and the long profile does not show it to be closing down. In its sandy floor there is the channel of a wet season watercourse. Close by there is a cave she did not enter with an imposing entrance, 5 m wide and at least 8 m high, from which a small stream flows even in the dry season (White, 1967; Plate VI-1). These caves are clearly not solely a product of atmospheric weathering of the sandstone. In 1978 I was unable to obtain permission to visit these caves; they are near Nabarlek, one of the contentious uranium sites. Also cursory examination of the Ruined City southeastern Arnhem Land, an area of intricately dissected sandstone in which there was reason to expect similar caves, was unsuccessful in this respect, though it is full of weathering caves and natural arches (Jennings, 1979). However, a more thorough search, when this is permitted, may well be rewarded with stream caves.

YULIRIENJI CAVE, ST VIDGEON STATION

Fortunately it was possible to visit a cave of greater interest southeast of Roper Bar just outside Arnhem Land but within Northern Territory. Near the former homestead site of St Vidgeon Station, Yulirienji Cave is well known to local white Australians as well as to the Aborigines to whom it belongs spiritually if not legally. It is also known to archaeologists becase it is rich in paintings, grindstone hollows and human bones, evidence of past Aboriginal occupation (Mountford and Brandl, 1967). It is likely that it is the cave mentioned by Tindale (1925-6, p.61 and Figure 23) as located at a camping site called Wagundu of the Mara tribe. It lies close to a gap in a range consisting chiefly of sandstone where Mountain Creek cuts through along a faultline (Figure 2). A tributary of the Roper River, the creek flows northwards towards this gap along the foot of a west-facing scarp of Hodgson Sandstone. This is a member of the Roper Group of Upper Proterozoic rocks and is described as a medium coarse, friable quartz sandstone (Dunn, 1963). Here this sandstone forms a structural platform carrying small, meridional ridges parallel to the creek and the faultline. Yulirienji Cave runs through the length of one of these ridges forming a top part of the scarp overlooking the creek (Plate I). Its floor is about 8 m above the creek bed and at the level of the platform supporting the ridge, of which it occupies a large proportion.

The cave is essentially an open-ended horizontal passage of roughly semi-circular cross-section with a level floor of sand (Figure 3). It is 50 m long, about 8-10 m wide and between 1.5 and 4 m high (Plate II). However, in addition to the entrances at each end, there is a large lateral entrance on the eastern side near the northern end (cross-section E-E). Also it is nearly cut in two along a cross-joint about halfway along (D-D), with another fissure entrance on one side along a parallel joint (C-C), and there is also a daylight hole about one metre in diameter (B-B).

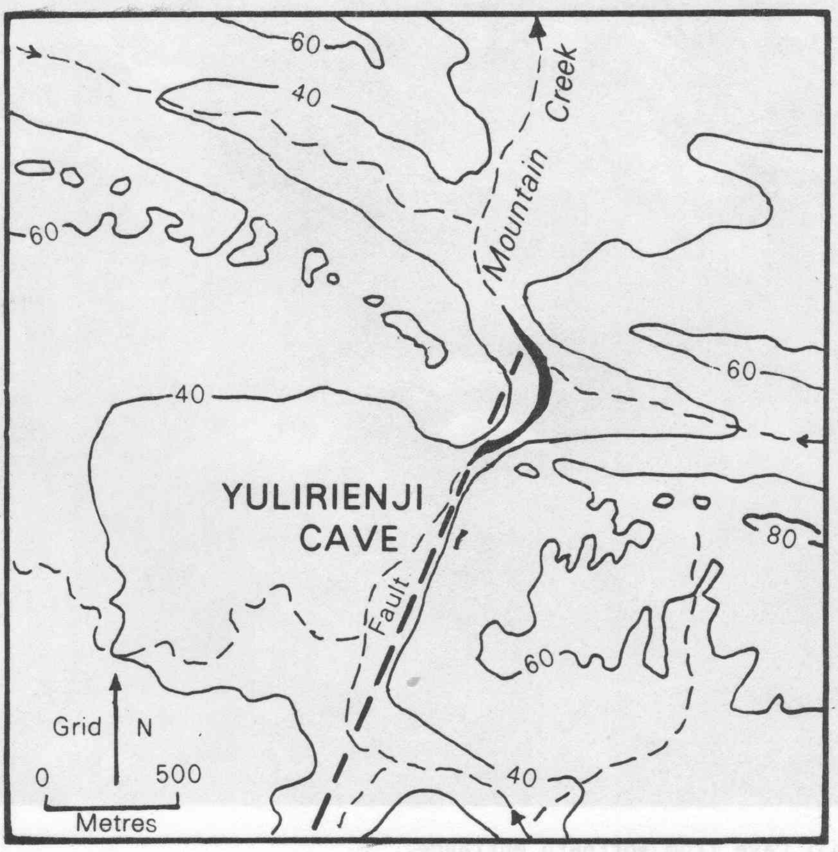

Figure 2 Topography around Yulirienji Cave, St Vidgeon Station, N.T.

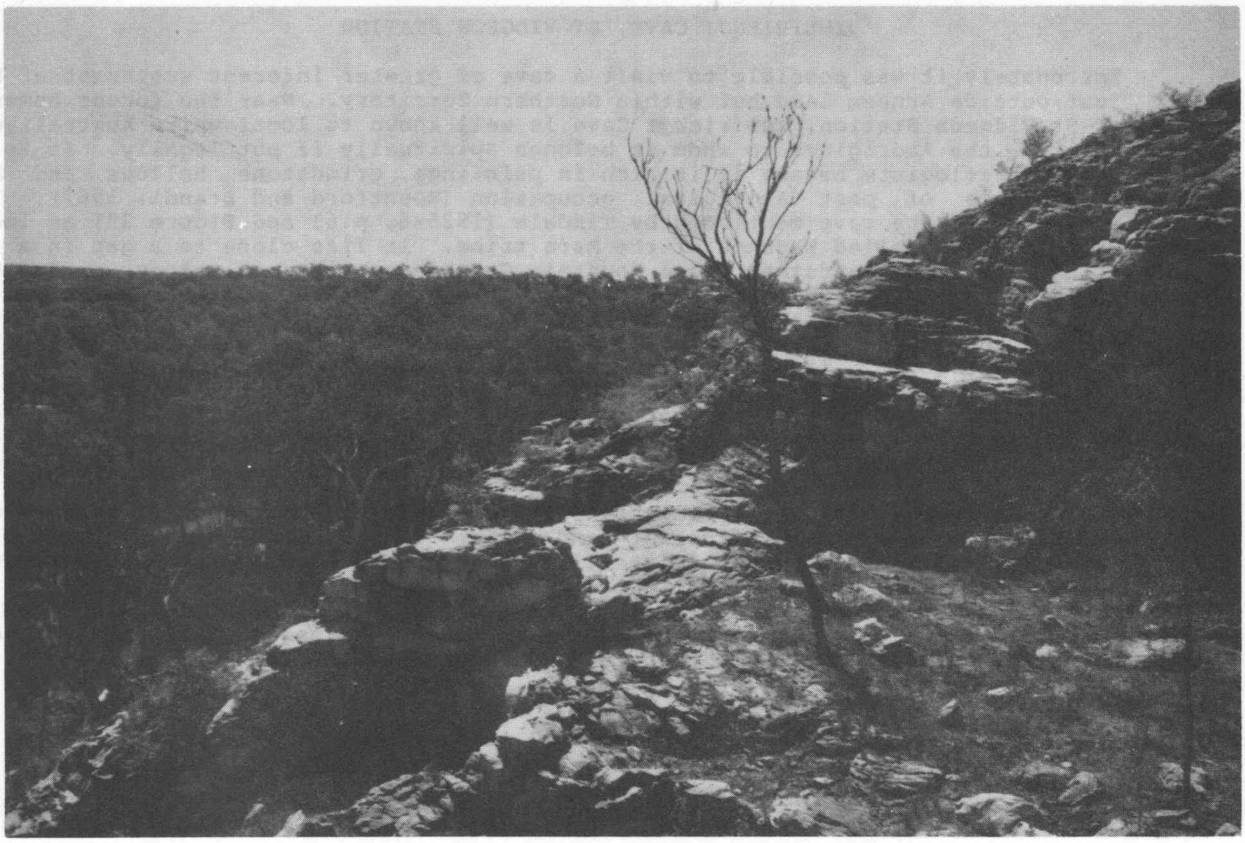

Plate 1. View northward along scarp above Mountain Creek (in nearest trees below). Southern entrance to Yulirienji Cave right centre.

Plate 2. Yulirienji Cave from northern entrance.

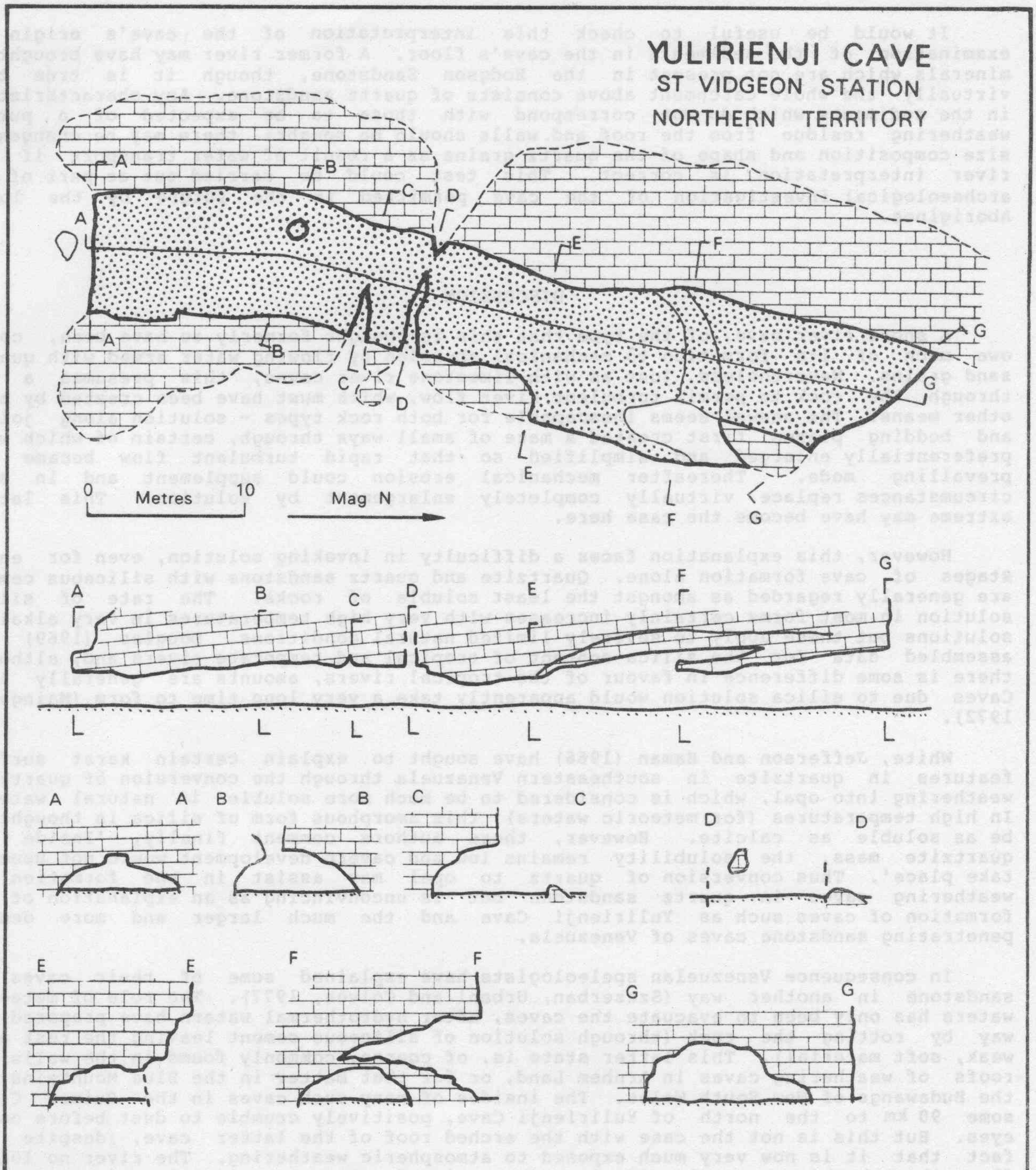

Figure 3 Plan, long- and cross-sections of Yulirienji Cave, St Vidgeon Station, N.T.

The alignment of the cave is in agreement with the main joint direction (187° magnetic), which governs the trend of the ridges and corridors on the structural platform. The dip of 12° south of the rocks is reflected in part of the roof of the cave (F-F and long section A-C); however as a whole the cave cuts horizontally through the rocks.

Because of its shape, position and cross-cutting of the bedding, this cave is thought to be in the main an abandoned river cave, occupied by Mountain Creek at an earlier period when its valley floor was about 8 m higher than it is today. The lateral entrances, even the large one, and the daylight hole may be entirely due to weathering processes at a later stage breaking into the main passage. However, the rock surface over most of that passage shows no sign of typical weathering characteristics such as overlapping scales of surface crust with incoherent leached rock beneath which crumbles in the hand. It is significant that Mountford and Brandl (1967), anthropologists chiefly familiar with weathering caves, distinguish between the 'tunnel', i.e. the long passage, and the 'cave', the wide, high lateral entrance area (E-E).

It would be useful to check this interpretation of the cave's origin by examination of the sediments in the cave's floor. A former river may have brought in minerals which are not present in the Hodgson Sandstone, though it is true that virtually the whole catchment above consists of quartz sandstone. Any characteristics in the sediments which do not correspond with those to be expected of a purely weathering residue from the roof and walls should be sought; there may be changes in size composition and shape of the quartz grains as a result of water transport if the river interpretation is correct. This test could be carried out as part of any archaeological investigation of the cave permitted in the future by the local Aborigines.

DISCUSSION

A short river cave, of the type that this is thought formerly to have been, could owe much of its formation to mechanical abrasion by flowing water armed with quartz sand grains. Nevertheless, just as with limestone river caves, this presumes a way through the rock to permit turbulent river flow, which must have been created by some other means. The answer seems inescapable for both rock types - solution along joints and bedding planes first created a maze of small ways through, certain of which were preferentially enlarged and simplified so that rapid turbulent flow became the prevailing mode. Thereafter mechanical erosion could supplement and in some circumstances replace virtually completely enlargement by solution. This latter extreme may have become the case here.

However, this explanation faces a difficulty in invoking solution, even for early stages of cave formation alone. Quartzite and quartz sandstone with siliceous cement are generally regarded as amongst the least soluble of rocks. The rate of silica solution in most forms certainly increases with very high temperatures in very alkaline solutions but these apply to severely limited natural conditions. Douglas (1969) has assembled data for the silica content of tropical and temperate rivers and, although there is some difference in favour of the tropical rivers, amounts are generally low. Caves due to silica solution would apparently take a very long time to form (Mainguet, 1972).

White, Jefferson and Haman (1966) have sought to explain certain karst surface features in quartzite in southeastern Venezuela through the conversion of quartz by weathering into opal, which is considered to be much more soluble in natural waters. In high temperatures (for meteoric waters), this amorphous form of silica is thought to be as soluble as calcite. However, these authors comment finally, 'Inside the quartzite mass, the solubility remains low and cavern development would not usually take place'. Thus conversion of quartz to opal may assist in the formation of weathering caves in quartz sandstone but is unconvincing as an explanation of the formation of caves such as Yulirienji Cave and the much larger and more deeply penetrating sandstone caves of Venezuela.

In consequence Venezuelan speleologists have explained some of their caves in sandstone in another way (Szczerban, Urbani and Colvée, 1977). The role of meteoric waters has only been to evacuate the caves, after hydrothermal waters have prepared the way by rotting the rock (through solution of siliceous cement leaving the rest as a weak, soft material). This latter state is, of course, commonly found in the walls and roofs of weathering caves in Arnhem Land, or for that matter in the Blue Mountains and the Budawangs of New South Wales. The insides of many such caves in the Ruined City, some 90 km to the north of Yulirienji Cave, positively crumble to dust before one's eyes. But this is not the case with the arched roof of the latter cave, despite the fact that it is now very much exposed to atmospheric weathering. The river no longer flows through this cave enlarging it and exposing fresh rock. Also there is a strong likelihood that former cave passage has been lost from both ends. Nor do the geological accounts of its neighbourhood nor of the huge sandstone plateaus of Arnhem Land immediately to the north include any reference to hydrothermal alteration.

Is it then a question of there having been inordinately long periods of time available for very slow silica solution to have taken place? The relief in which Yulirienji Cave is found, at about 40 m above sea level, lies at the margin of the coastal plain, in a zone of dissection and destruction of an erosion surface higher and older than the coastal plain. In the chronology of Hays (1967), which however lacks absolutely dated controls, this would place the formation of this cave in the Late Tertiary. Thus no more time seems to have been available than has been the case for the caves in the Limestone Ranges of West Kimberley, which have likewise developed in the course of destruction of an erosion surface 30-100 m above the coastal plain there. There are, of course, many more and much larger caves in this limestone than in the sandstones of the Northern Territory.

Thus many questions remain open with regard to speleogenetic mechanisms and their rates of action in producing caves in quartz sandstone other than weathering caves and these add their interest to the intrinsic novelty of these kinds of cave in the present state of Australian speleological exploration.

ACKNOWLEDGEMENTS

I thank my companions in Arnhem Land in 1978, Sergeant Peter Watton and Constable Barry Frew of the Northern Territory Police and Mr Wayne Mollah of the ANU's North Australia Research Unit, who organised the logistics. Peter's good standing with the local Aborigines was crucial and he enlisted the help of Roy, police tracker from the Roper Bar police station. Roy led us to the cave and I am grateful to him also. Last it is a pleasure to express my gratitude to my old friend, Dr 'Slim' Bauer, Director of NARU, for all his help with the trip.

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ANNOUNCEMENT

COLLECTION OF CAVE SNAILS

Subterranean snails are known from many parts of the world including New Zealand, Japan, Europe and North America. At the present time none are known from Australia but they almost certainly do occur here and are just awaiting discovery. Most cave dwelling snails are very small, white and live in seepages and streams in the caves. They are important in helping to understand the past distribution of animals because many appear to be the relics of once widely-distributed groups which have disappeared from the surface but have survived in caves. For example one genus of small snails lives in Europe, Japan and New Zealand but is only known from caves.

These little snails can be collected by using a fine mesh net (maximum mesh size about that of a tea strainer - an ordinary kitchen sieve is too coarse). Many subterranean snails are only 1 to 2 mm in size although slightly larger ones of 2 to 3 mm in length are also known. It is probably for this reason that they have been overlooked in Australian caves.

The net should be scooped across the surface of mud or sand, or debris, stones or rocks picked up and washed over it. Another method is to stir up the debris in the stream or pool, to lift the snails from the bottom, and then scoop with the net. Any debris collected in the net should be shaken into a container and preserved in 5% neutral formalin (most easily made by adding sodium bicarbonate to concentrated formalin to excess) or, if formalin is not available, in 70% ethyl alcohol. It is important to preserve the samples because the "soft parts" are essential to work out the taxonomic relationships of the snails.

The writer is very interested in receiving samples that may contain snails for a research project in which he is currently engaged. Any postage or freight costs will be reimbursed if necessary and full acknowledgement will be given in any publication in which the material is included.

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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.

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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, Ltd., Sydney.

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