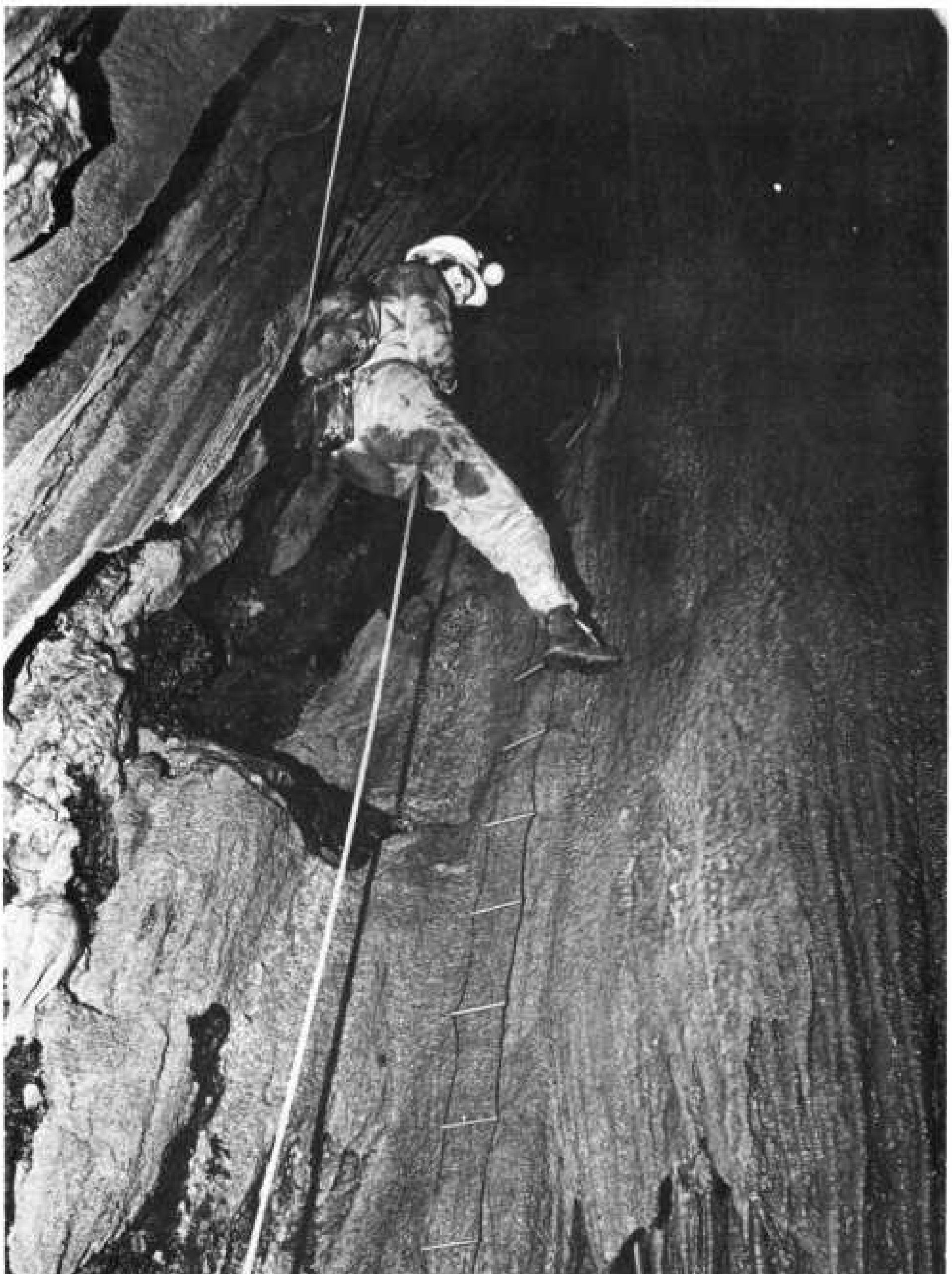
Vol. 14, No. 1 1976

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



Golden Fleece pitch, Odessey Cave, Bungonia, N.S.W. The flowstone is being eroded by Enipeus stream. (photo: A.J.Pavey)

H E L I C T I T E

Journal of Australasian Cave Research

Foundation Editors

E.A. Lane, Aola M. Richards

Editors

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VOLUME 14(1) 1976

CONTENTS

Helictite, Volume 14, 1976, consists of two issues. Price per volume, Aust. $5.00, post paid. Correspondence contributions and subscriptions to "Helictite", Post Office Box 183, Broadway, New South Wales 2007, Australia. "Helictite" is printed and published by The Speleological Research Council Ltd.

NEW PUBLISHER OF HELICTITE

On 28th February, 1976 the Speleological Research Council Ltd., became owner and publisher of Helictite. Since the journal's inception in 1962, Edward A. Lane and Aola M. Richards have strenuously sought to maintain its high standard. They remain associated with Helictite as Foundation Editors, and Consultants in History and Biospeleology.

Under the Council, the scope of Helictite will remain as originally stated in Volume 1, page 2: "...Helictite will be wide ranging 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. It will also include fringe subjects such as rock paintings and excavations of rock shelters, in view of their great interest in relation to similar art and artifacts found in caves in Europe, Africa, etc.

The territory to be covered incorporates all Australasia, New Zealand, the near Pacific Islands, New Guinea and surrounding areas, Indonesia and Borneo.

Helictite is a non-profit publication devoted to providing a reliable news service and collection of speleological papers for those interested in any of its disciplines".

The Speleological Research Council Ltd. is a non-profit limited liability company formed in 1964 to promote cave exploration and mapping, support scientific study of caves, foster speleology as a science and sport, assist speleological societies and to publish information. Membership of the Council is open to people with a serious interest in speleology. The current membership reflects a balance of professional, amateur, scientific, and recreational interests.

REVIEW

CAVES by A.C. Waltham, Macmillan London Ltd., 1974, 240 pp, 19.5 x 24 cm, 170 Black and White and 67 colour photographs, 24 maps and diagrams, $10 + post.

A.C. (Tony) Waltham is a well known and well travelled British caver and geologist. He is also an excellent cave photographer and it shows in Caves. This is primarily a picture book about caves, with about one third of the book devoted to explanatory text of an introductory nature.

The photographs cover most aspects of caves and caving and depict caves from about 30 countries. Naturally enough, English and Welsh caves feature predominantly, with France, U.S.A. and Belgium getting the next best coverage. Australia gets just one photograph (Koonalda Cave, Nullarbor Plain by T. Wigley).

The photographs are magnificent but have, unfortunately, suffered in reproduction, particularly the colour shots, which are somewhat hazy. Some of the best photographs are spoiled by the fact that they run across the join of pages.

The text is in an easy to read style and, like the photographs, takes examples from all over the world. The nine chapters which cover the world of caves, karst, cave exploration, the use of caves, their formation, decorated caves and cave deposits, cave life, man in caves, and caves of the world, constitute an excellent introduction to the subject of caves for anyone new to caving, while the photographs alone make the book a must for all those interested in caves.

Australia is briefly covered in the final chapter wherein Jenolan, the Nullarbor and Mullamullang Cave, the Junee area and Khazad-dum and Mini Martin Caves, and Exit Cave, Ida Bay are mentioned.

Overall, a presentable book at a reasonable price and one which will help you show sceptics who ask, "Why do you go caving?", just some of the marvellous features of natures handiwork that can be seen underground.

Ross Ellis

THE GEOLOGY, GEOMORPHOLOGY, HYDROLOGY AND DEVELOPMENT OF ODYSSEY CAVE, BUNGONIA, NEW SOUTH WALES

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Abstract

Odyssey cave is described in detail and its development is related to the regional geology, geomorphology and hydrology of the Bungonia karst.

INTRODUCTION

Odyssey Cave (B24) is located in the Bungonia Caves Reserve, near Goulburn, N.S.W. The entrance grid coordinates are 30117-70197 on the Lands Department Caoura Sheet (number 8928-III-N). The discoverers of the entrance, and the early excavators of the cave are not known: however, the Sydney Rockclimbing Club is thought to have participated. In 1970, the Baptist Speleological Association (BSA) began digging at a depth of 20 m in the boulder pile of what was then an unnamed and unnumbered cave. A breakthrough occurred in January, 1971, through a series of boulder squeezes and then a bedrock cave passage. A few days later, a combined BSA and Sydney Speleological Society (SSS) party bottomed the cave (Nurse 1971).

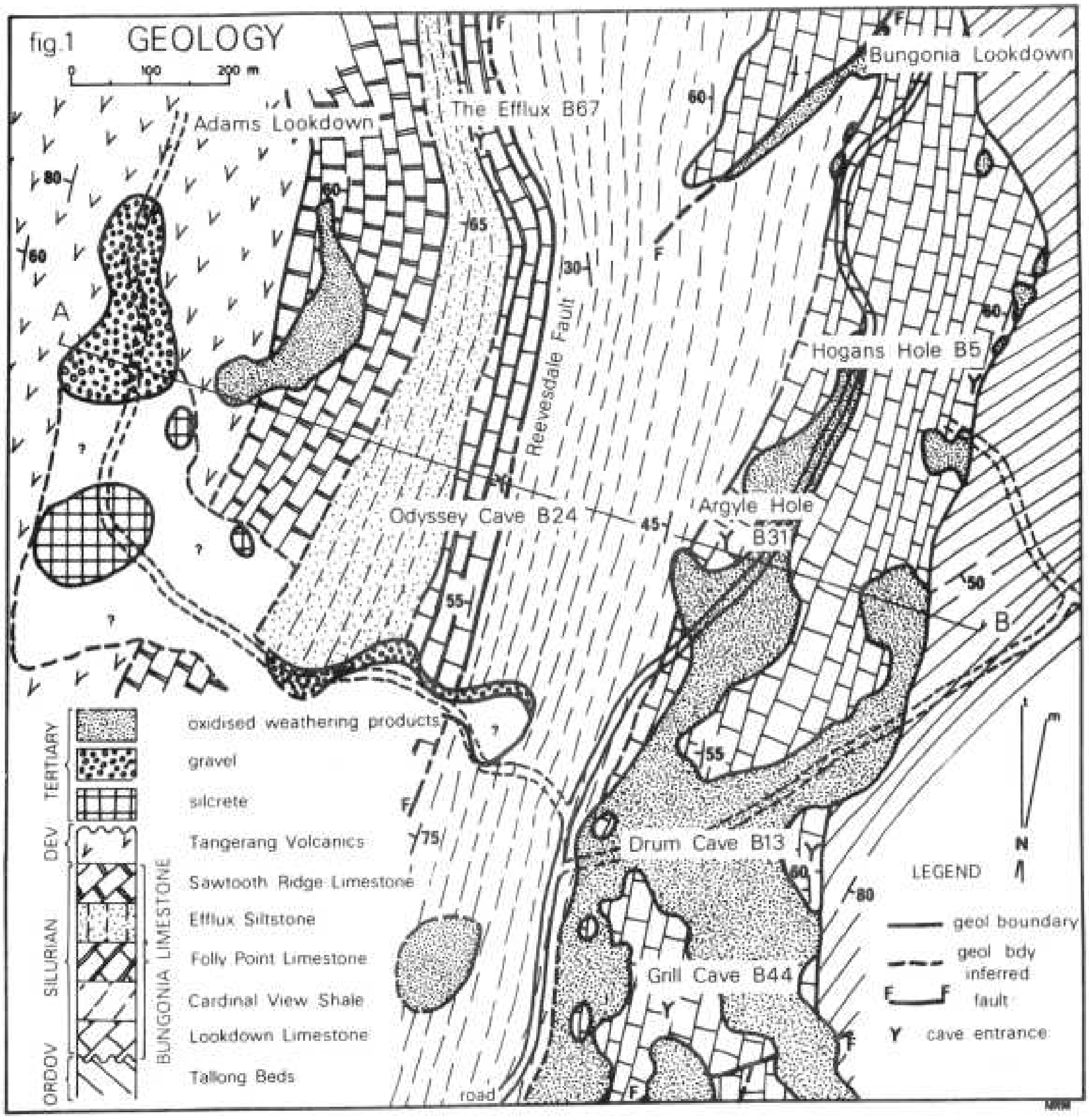
GEOLOGY

Stratigraphy

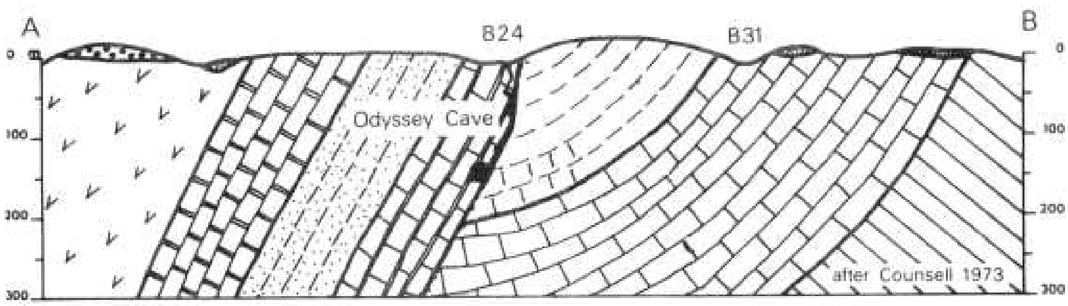
The geology of Bungonia Caves is discussed by Jennings et al (1972) and in an unpublished honours thesis by Counsell (1973). There have been several systems of nomenclature used for the Bungonia limestone and their merits have been presented by Counsell. The system suggested by Counsell is adopted here (Figure 1).

Odyssey Cave is developed in the Folly Point Limestone and in the Cardinal View Shale members of the Bungonia Limestone series (see cross section Figure 1). The Bungonia Limestone is a strike oriented belt of Silurian limestone overlain by the Tangerang Volcanics (Devonian-toscanites, tuffs, sandstone and rhyolite) and underlain by the Tallong Beds (Ordovician-shales, slates, phyllites and quartzite).

The lowest member of the Bungonia Limestone is the Lookdown Limestone, which consists mainly of massive grey recrystallised limestone. It is



CROSS SECTION



300 m thick and contains most of Bungonia's known caves. It is overlain conformably by the Cardinal View Shale, which has a maximum thickness of about 200 m. Counsell described this member as being largely comprised of argillaceous beds, predominantly yellow/orange shales, grey-green calcareous shales, calcareous siltstones and sandstones, and siliceous mudstones and siltstones. However, the section of it visible in Odyssey Cave reveals that the argillaceous beds lense into shaley limestone near the base of the member.

The Cardinal View Shale is overlain by the 100 m thick Folly Point Limestone. In Odyssey Cave this appears as a massive, dark grey recrystallised limestone, typical of most of the unit. Next in the sequence are the two uppermost members of the Bungonia Limestone, the Efflux Siltstone and then the Sawtooth Ridge Limestone.

Structure

The strike of the Bungonia Limestone generally varies between 0° and 35°, and in the vicinity of B24 it is about 15°. A westerly dip of between 45° and 90° is predominant. The beds are highly jointed in two main directions: one along the strike and the other in the dip direction. Both sets are vertical or near vertical. The Cardinal View Shale has a strong vertical cleavage trending on 0°.

Baker (1972), working to the north of Bungonia Gorge, recognised that the Lookdown Limestone and the Cardinal View Shale are folded in a synclinal structure plunging northward at a low angle. Here all but an eastern synclinal limb is lost by faulting (the Reevesdale Fault). The same situation probably also occurs south of the Gorge. In Odyssey Cave the Reevesdale Fault certainly separates beds of different dip. Dips in the Folly Point Limestone vary between 50° and 60°, while those in the Cardinal View Shale vary between 35° and 50°.

TOPOGRAPHY NEAR B24

The entrance to Odyssey Cave (B24) lies in a shallow earth floored doline in a tributary of Bretons Creek (Figure 2), at an altitude of 530 m (Anderson, 1973). Apart from this doline and those of Spider Cave (B27) and Double N Cave (B28) there are few karst features in the upper Bretons Creek catchment area shown in Figure 2. It is similar to many of the non-limestone valley systems on the Bungonia Plateau, which are characterised by low relief and a dendritic pattern.

The upper part of Bretons Creek is cut into the Folly Point Limestone, partially following the Reevesdale Fault. Here its eastern tributaries run off a strike ridge of the Cardinal View Shale. The western ones drain an area of Tertiary gravels and silcretes capping Adams Lookdown Ridge before flowing across the Lookdown Limestone and Efflux Siltstone. These streams only flow after heavy rain.

Above its junction with the B24 tributary, Bretons Creek has a low uniform gradient and no stream channel; 20 m above the junction it becomes noticeably steeper and a shallow channel has been cut. At the junction a western tributary also joins and there is a small grassy alluvial plain before Bretons Creek passes through a 15 m deep limestone gorge. A distinct stream channel starts here and persists for the remainder of the creek. Below the small gorge the valley sides are gently sloping until the entry of the next eastern tributary. After this junction the valley sides steepen considerably and the stream channel is cut into the Reevesdale Fault plane. Finally the valley joins Bungonia Gorge and its former low gradient increases dramatically. It drops 130 m in 300 m horizontally to join the perennial stream from the Efflux Spring (B67).

This change in gradient along Bretons Creek has been attributed to rapid rejuvenation caused by the 'Kosciusko uplift' (Jennings et al. 1972). While this rejuvenation had only a minor effect on the topography near Odyssey Cave entrance, it did find considerable expression in the Cave itself.

CAVE DESCRIPTION (Figures, 3 and 4)

A view down the 1 x 0.5 m entrance of Odyssey Cave (Plate 1) gives a good indication of the cave's nature directly below: a constricted steeply inclined passage through rockfall. This rockfall, known as The Rocks Wandering (A on cave maps), extends to a depth of 25 m and trends westerly. The boulders are angular and often sharp, but have experienced a little corrosional rounding. They have settled with the passage of time and numerous cavers, although caution is still required. The stream which occasionally sinks at the entrance has marked its route through The Rocks Wandering with scallops one centimetre or less in length, and small deposits of poorly sorted quartzose sediment. The particles are typically well-rounded and less than 5 cm in length. Near the entrance, the spaces between the boulders are earth filled.

The first 20 m of The Rocks Wandering (Plate 2) involve a succession of five short climbs between boulder platforms. Then a constriction opens into a small chamber, the limit of the cave until the BSA dig in 1971 at the present site of Lawlers Gate* (AA).

Below Lawlers Gate the route becomes tight and tortuous for 10 m. Finding the beginning of this tight section on the way out has baffled many; hence its lower end is named Confusion Corner (B).

After passing through several small interconnected chambers below Confusion Corner, in situ bedrock is met for the first time in a descending passage. This passage bears north following the line of an impure lime-

* Key to this gate is available to member societies of the Australian Speleological Federation. The gate was installed to protect the excellent decoration and scientific equipment in the cave.

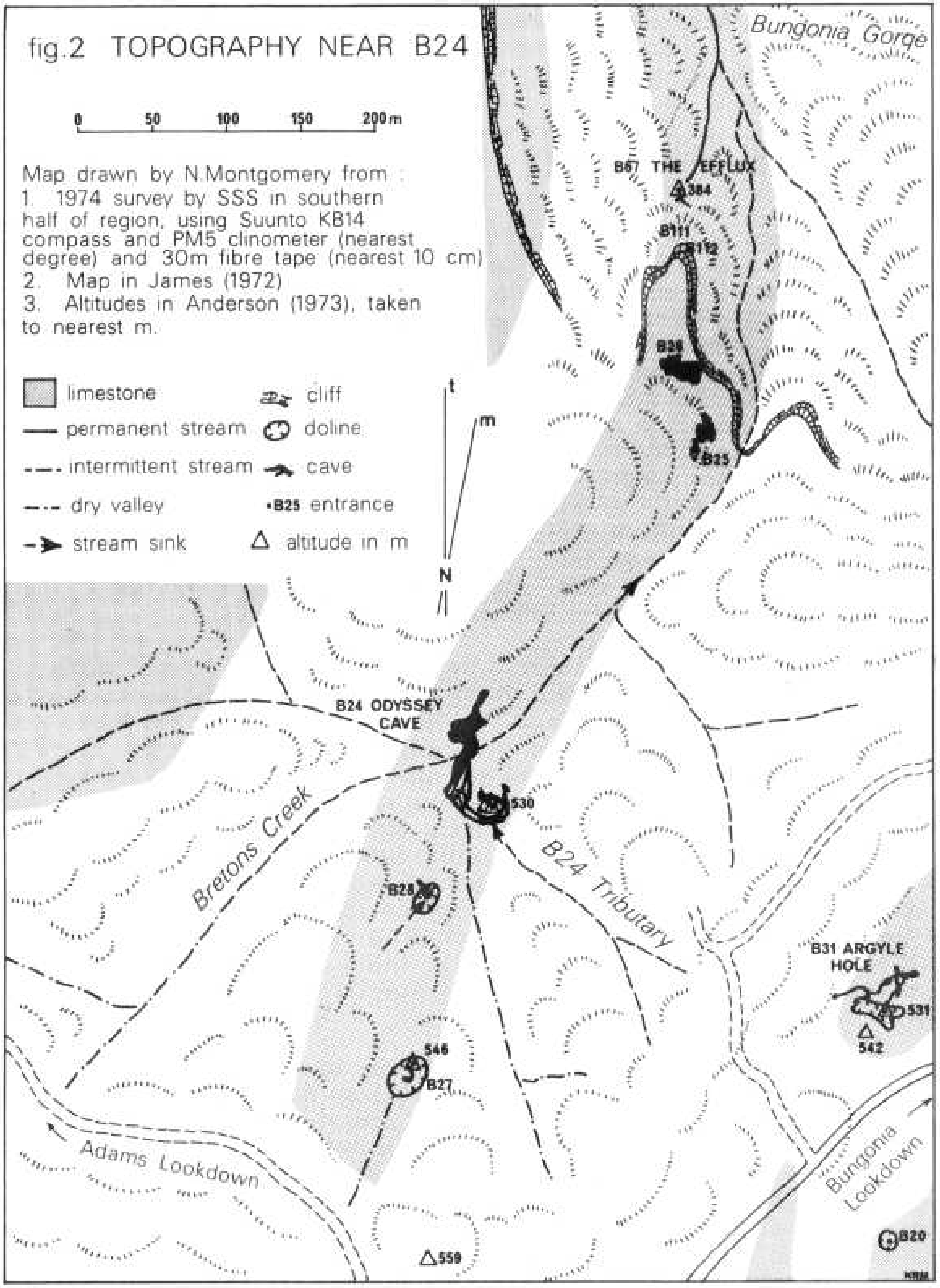


fig.2 TOPOGRAPHY NEAR B24

stone bed for 7 m before broadening into a low boulder floored chamber. The bed has weathered to form a soft, cream calcite and clay mixture. A small continuation of the passage called Argos Kennel (AB) contains some speleothems, notably rock milk. The low chamber slopes down to a drop of 5 m, which is avoided by climbing to the right through Two Stitch Slot (C). This tricky climb has already claimed a casualty, giving its name (James 1974).

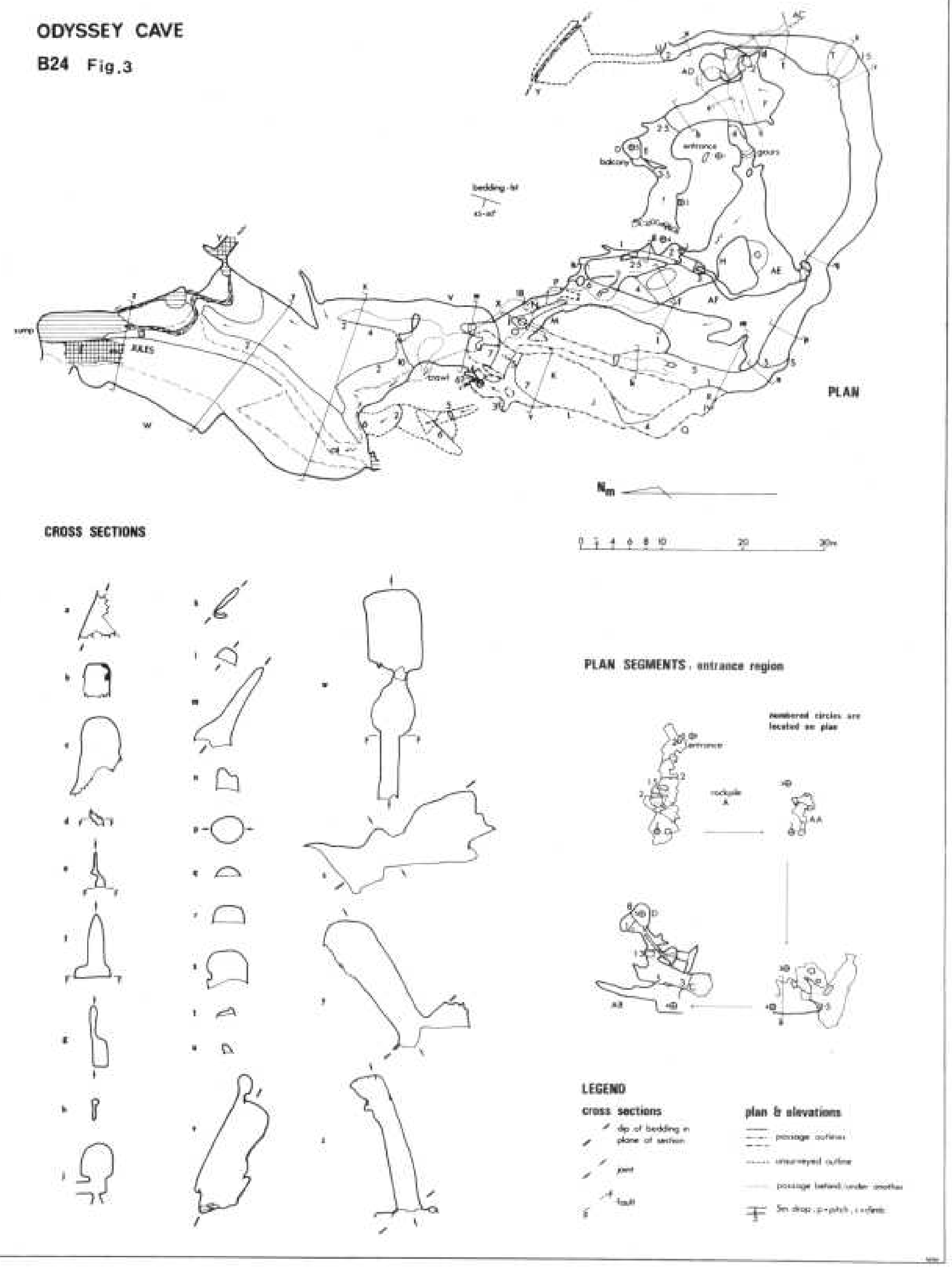
After the Slot there is the cave's first roomy chamber. 2 m wide and 5-7 m high, and like all previous ones floored with collapse blocks. The chamber is paralleled on the east by an upward shaft 1.5 m in diameter and 4 m high ending at the foot of a dip joint chimney laced with fibrous tree roots. A trickle of water seeps in here and has cut a shallow floor canyon at the base of the shaft. At the north end of the chamber a 1.3 m deep hole drops to the floor canyon. There is a crawl along the top of the floor canyon, a slide around a column and the 8 m Acrobatic Pitch (D) is reached. However, for those not yet tired of squeezing, a tiny hole in the base of the floor canyon drops onto a decorated platform below the pitch top. From here a 3.7 m chimney descends to a point near the bottom of the pitch. Acrobatic Pitch itself goes vertically down a broken rock face, undercut in its lower half. It ends in a sloping boulder floored passage 4 m high and 2-3 m wide. Two stubby rounded stalagmites at the bottom of Acrobatic Pitch have been named The Mummies (E).

Upslope from The Mummies, there is a dip in the roof, beyond which the passage ends in a boulder choke. There are some stream sediments similar to those currently being deposited in the upper section of The Rocks Wandering. These probably relate to an abandoned stream course for there is no evidence of recent flow. Downslope, the cave maintains its walk-through character, and there is a 2.5 m climb down wedged boulders before the gradient eases. The short gently sloping passage which follows has sediment deposits trapped on ledges and under false floor remnants, 2-3 m above its floor. Sphinx Chamber (F) terminates the passage. It is elliptical in plan with a domed roof 7 m high and collapse blocks and clay deposits rim its western side. The bedrock exposed in this region is a limestone breccia, featuring large limestone blocks and angular rubble held in clay. It is mechanically weak and accounts for the large quantities of breakdown and the passage size.

From the southeast corner of Sphinx Chamber there is a 2 m climb then a further 2 m boulder climb to the top of Golden Fleece Pitch (AD), named after the fine coating of golden flowstone covering the black walls. It is here that the Cardinal View Shale is first encountered in the cave. It is cream to yellow in a fresh sample but often has a black manganese dioxide coating. One sample of the Cardinal View Shale was thin sectioned and shown to be a siltstone (Ohler, <u>pers. comm.</u>). Other samples of this siltstone have been shown to have a high carbonate content (Jennings <u>et al.</u> 1972). Just below the pitch top the semi-permanent Enipeus Stream (AC) enters from a passage in the southern wall of the shaft. It is possible

ODYSSEY CAVE

B24 Fig.3



to pendalum into the stream passage and crawl up it for 10 m until it branches, both branches being too small to negotiate. This passage is developed along the Reevesdale Fault, and its roof has collapsed at one point to allow a sight connection with the rockslope above the pitch.

Golden Fleece Pitch is in a shaft 2-3 m in diameter, on a vertical section of the Reevesdale Fault. The remainder of the fault plane exposed in the cave dips at 50° or less to the west. A large ledge interrupts the shaft 7 m down, and here a bulky stalagmite makes a suitable anchor for the second half of the pitch. Below the ledge the flowstone reaches its full glory, coating almost the entire shaft. At present it is discolving and some sections show that it was formerly very thick and at one point nearly blocked the shaft. The shaft enlarges a little in its last 6 m and contains many shawls.

A shallow plunge pool containing some breakdown floors the shaft. 1.2 m above this a ring of calcite cemmented sediment indicates a former pool floor level. This pool was dammed behind a gour, subsequently cut through by stream action. Enipeus Stream leaves the shaft in a 4 m high canyon passage which is 1 m wide at stream level, narrowing to 10 cm or less in its upper half. It is dip joint controlled. The canyon is floored with stream sediments and after 3 m bedrock shale is exposed at the top of a 4 m waterfall. A flowstone traverse on the left bypasses the drop and one hops down over a series of stranded gours to the floor. The roof is decorated with fine helictites. Beyond the gours is the top of the Shale Band Pitch (H), a sloping 30 m descent. Here the passage turns to the northwest off the dip joint to descend the fault plane at an angle of up to 50°. However, the influence offthe dip joint is continued in the beautifully decorated Olympus Chamber (AE), entered by leaving the Shale Band Pitch 4 m below its start. Its most impressive decorations are tall draperies festooned with helictites. Apollos Walk (AF), a tight passage, begins at the western end of the chamber (described later). There is also a steep spiral passage here and a slippery 10 m climb to its top is rewarded by the best display of helictites known at Bungonia.

The Shale Band Pitch begins in a steep passage elongated in the Reevesdale fault plane (Plate 3) and takes Enipeus Stream. The fault line is a sharp boundary with little shattering just above the shale floor. As on the surface the shale has a strong northsouth cleavage which provides many flaky foot and handholds. The limestone roof and walls are uneven and show no flow markings. Golden flowstone is common and like that on Golden Fleece Pitch, it is dissolving. Half way down the pitch the gradient lessens and there is a small alcove on the right (Ogygia Z) with more speleothems, kept sparkling by sheet flow from above. Ogygia gives access to the end of Apollos Walk and the beginning of the Way to Ithaca (described later). The Shale Band Pitch ends with a 4 m vertical drop into a small chamber. Above this drop there is an 8 m high elliptical blind shaft in the passage roof, elongated along a joint in the limestone, striking on 340°. This and other close, parallel joints have exerted a strong control on orientations of passages in this vicinity.

ODYSSEY CAVE

B24 Fig.4

ELEVATIONS

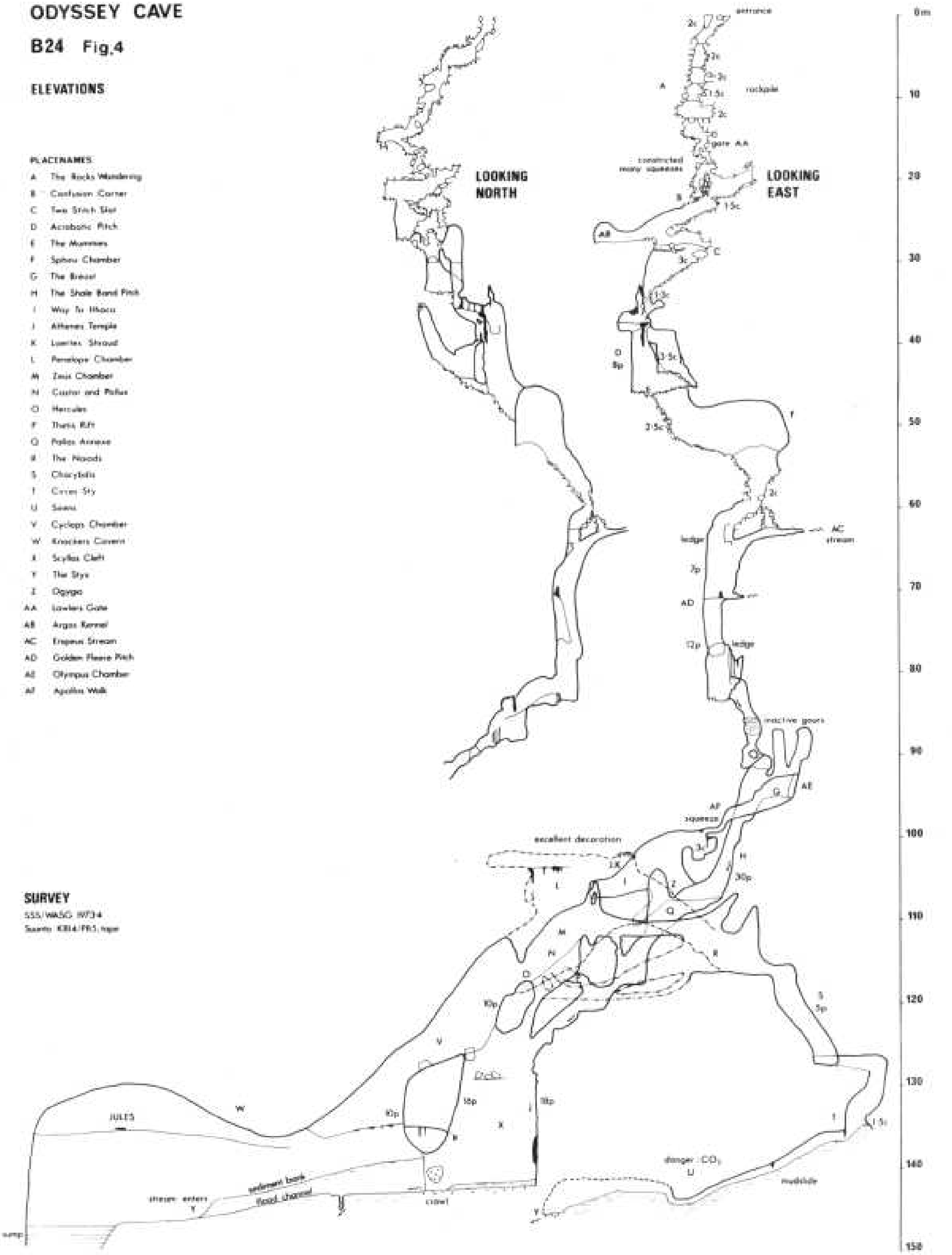
PLACENAMES

- A The Rocks Wandering
- B Confusion Corner
- C Two Stitch Slot
- D Acrobatic Pitch
- E The Mummies
- F Sphinx Chamber
- G The Breast
- H The Shale Band Pitch
- I Way To Ithaca
- J Athenes Temple
- K Laertes Shroud
- L Penelope Chamber
- M Zeus Chamber
- N Castor and Pollux
- O Hercules
- P Thetis Rift
- Q Pallas Annexe
- R The Naiads
- S Charybdis
- T Circes Sty
- U Sirens
- V Cyclops Chamber
- W Knockers Cavern
- X Scyllas Cleft
- Y The Styx
- Z Ogygia
- AA Lawlers Gate
- AB Argos Kennel
- AC Erapeus Stream
- AD Golden Fleece Pitch
- AE Olympus Chamber
- AF Apollos Walk

SURVEY

SSS/WASG 1973-4

Suunto KB14/PM5, tape



Below the small chamber the fault passage (dotted on plan) resumes with a 3 m chute; then a roof canyon starts, developed on the 340° joint. Thetis Rift (P) starts in the roof canyon; it is a short horizontal passage encrusted with cave coral which leads to Zeus Chamber (M). The Enipeus continues down the fault passage over a few small drops to the 18 m pitch into Scyllas Cleft (X).

Zeus Chamber can also be reached from Olympus Chamber by taking Apollos Walk. This passage begins with a very tight squeeze in a smooth canyon. It then opens into the roof of a small pretty chamber with a 3 m climb to its floor. After this chamber the floor drops away into Ogygia (10 m below) and a descending traverse close to the roof connects into the Way to Ithaca (I), 3 m from Ogygia. The Way to Ithaca was first entered early in 1973, resulting in the discovery of the complex of passages to the south, as well as the tube leading down to the Sirens (James and Montgomery 1973). Apollos Walk was explored over a year later.

The Way to Ithaca is a 9 m long horizontal passage with a keyhole cross-section, featuring a smoothed upper tube 80 cm in diameter and a lower meandering canyon up to 30 cm wide and 1.4 m deep. There are no flow markings. The passage walls are coated with a soft weathering crust and sometimes a thin deposit of crumbly dead flowstone, which contrasts sharply with the superb flowstone in Ogygia.

The Way to Ithaca ends at the head of a 6 m pitch into Zeus Chamber. This chamber is developed along a 340° joint. It slopes northwards. A shallow canyon in the solutional roof and a deeper floor canyon delineate the joint position. Seepage from the roof joint has formed Castor and Pollux (N), twin stalagmites and stalactites, the most heavenly of the speleothems in Zeus Chamber. The floor canyon is 2 m or more deep and runs the length of the chamber, finishing at its lower end in a hole overlooking Scyllas Cleft. 2 m above this is the smooth archway where Hercules (O) resides. This hefty little stalagmite can be used to anchor a handline for the sloping 5 m descent to the left into Penelope Chamber (L, dash-dotted on maps), or for the 10 m pitch to the floor of Cyclops Chamber (V) below.

Penelope Chamber is a 15 m high chamber solutional in origin with some wall collapse. It is elongated along the strike of the limestone. Its roof is nearly flat and its eastern and western walls are formed down the dip at about 50°. The overhanging western wall is devoid of speleothems but the eastern wall is almost totally covered with flowstone, most of it pure white. This is named Laertes Shroud (K). Althenes Temple (J), a double dome, occupies the extreme southern part of the roof. It contains a classical display of helictites, straws and stalactites. The western wall has a few poor scallops 10 cm long which suggest a former northward flowing current. A bank of unconsolidated, poorly sorted mud and sand borders this wall, with well rounded pebbles up to 4 cm long and angular pieces of limestone up to 10 cm long. An inclined flake juts from the wall north of

Plate 1 The entrance to Odyssey Cave (photo A.J.Pavey)

Plate 2 The Rocks Wandering (photo: J.M.James)

Plate 3 The top of the Shale Band Pitch. The passage is developed on the Reevesdale Fault, its floor is of shale and its roof limestone. (photo: P.Caffyn)

Plate 4 The phreatic tube between the Naiads and Zeus Chamber the highest point of the phreatic loop. (photo: A.J.Pavey)

this bank. This can be climbed 4 m to a ledge with a 3 m deep pit and a recess 6 m long. The recess has a connection with the roof of Cyclops Chamber. It also contains well rounded sediments, their antiquity guaranteed by a flowstone cover. The particles grade upwards from pebbles and cobbles to gravel. Pieces of charcoal lie on top of the sediment and on the walls, indicating the level reached by a recent monumental flood.

The ledge at the mouth of the recess was used to gain entry to a tantalising hole at the roof level (Montgomery 1974). 6 m of scaling pole was used in the attempt, which ended disappointingly when only a small chamber was found. The promising trickle of water it issues proved to be fed by sheet flow across flowstone girdling the northern end of the chamber.

Paralleling Penelope Chamber on the east are two strike passages both entered from Zeus Chamber and left at the Naiads (R), some 15 m to the south. They are formed at different levels on the same bedding plane and in cross section are generally elongated in that plane.

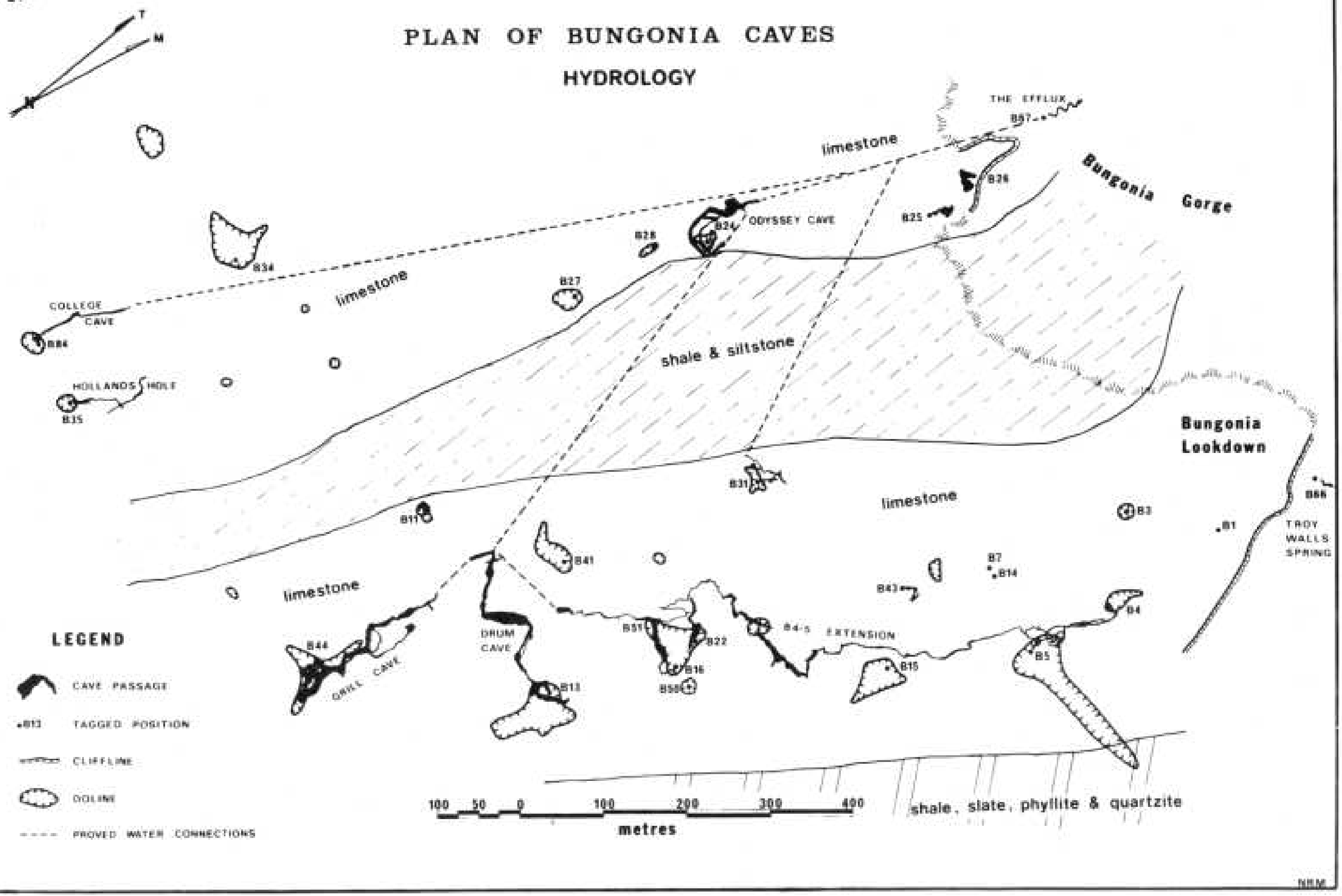
The lower passage (dash-double dotted on map) begins as an elliptical tube sloping gently away from Zeus Chamber. At a trough it divides into two upward sloping branches separated by a false floor. The top branch is a bedding plane squeeze 10-20 cm across, the bottom is an equally unpleasant muddy flattener. Scallops up to 10 cm long are developed in the bottom branch and the current responsible for them clearly flowed north. Near Zeus Chamber, the upper strike passage contains a large pendant and nearby a few scallops give evidence of a northward current. Its floor is thickly coated with dried laminated brown clay. A narrow shaft connects this passage to the chamber at the base of the Shale Band Pitch a few metres below. Close to the Naiads a recess reaches up dip to intersect the Reevesdale Fault and some shale detritus has rolled from this into the passage.

The Naiads themselves are two small smooth stalagmites of constant thickness. They lie at the intersection of the two strike passages and a sloping tube passage some 3 m in diameter, which can be followed upwards or downwards from the intersection. Pallas Annexe (Q), the upward tube portion, has a dirty flowstone floor and connects to the southern end of Penelope Chamber. The roof displays some large scale phreatic spongework. Solution pockets are common here and in the downward tube portion and are generally formed on joints. Trains of asymmetric pockets are frequently aligned on a single joint. The first 60 m of the downward tube portion is an impressive elliptical passage averaging 3-4 m wide and 2-3 m high. The complete tube is only exposed at Charybdis (S), a steep part near the Naiads; the rest of it is partially sediment filled. Just above Charybdis the Reevesdale Fault crosses the tube and there is a change in the dip of the bedding from 50° in the Folly Point Limestone to 35° in the Cardinal View Shale. The rest of the tube including Charybdis is formed

Fig. 5

PLAN OF BUNGONIA CAVES

HYDROLOGY



in the Cardinal View Shale.

Charybdis is developed on an easterly dipping strike joint and is steep enough to require a handline (13 m). At its base a deep mud and silt floor is met and the joint plane disappears beneath it. The tube maintains a moderate slope until its end and in places is over half filled with sediment. Scallops up to 5 cm long appear on one small part of the southern wall and indicate a westward (upward) current flow. The limestone (part of the Lookdown Limestone) is shaley - with shale laminae imparting a fine ribbed texture on the walls and roof. The tube ends in Circes Sty (T) - a circular bowl 4 m in diameter and 1-2 m deep with a heaped mud floor, mantled in part by guano. Decaying stalactites with red iron oxide streaks line the walls. From Circes Sty a mud floored passage goes north following the strike and is much diminished in size from the tube, averaging 1-2 m in width and 1 m in height. The walls and roof are thickly coated with mud so that minor solutional sculpture is hard to discern. Stalactites are common, some having their tips buried beneath the mud.

The floor levels after 22 m into the Sirens (U), a dismal area only 30 cm high. The region beyond defied exploration for over a year because of CO_2 levels of over 6.5% (Hickson 1975). Finally during June 1974 prolonged rain lowered the CO_2 sufficiently for a party to proceed beyond the Sirens. There is a 2 m climb up a sediment bank, then a 8 m crawl ending in a small chamber, its mud and silt floor sloping down to a stream, which is transformed into a lake during floods. The stream emerges from a low passage and flows northwest across a bed of well rounded pebbles and small cobbles to disappear at the chamber wall. The Sirens contains some unusual decorations; thin flexible spears of calcite and organic matter up to 20 cm long which hang like stalactites.

At 146 m depth, the Sirens is only slightly higher than the other deep point in the cave, Knockers Cavern (W). To reach the cavern it is necessary to continue on downwards from the Shale Band Pitch or climb into Thetis Rifs and descend through Cyclops Chamber.

Cyclops Chamber is a lower continuation of Zeus Chamber separated from it by a smooth archway and a 10 m pitch. Guided along the same 340° joint, it too has a solutional roof with a shallow roof canyon. Unlike Zeus Chamber, there are small pendants and parts of the roof and walls follow bedding planes. From the base of the 10 m pitch the floor slopes northwards, interrupted one the right by a rift-like hole into Scyllas Cleft, 16 m deep. On the left a recess in the wall contains a 4 m shaft and an impenetrable hole at the base of this opens onto a further shaft of about 6 m (not shown on elevation). Towards its northern end the chamber becomes progressively steeper and muddier before dividing and entering the roof of Knockers Cavern. There is a 10 m drop to the cavern floor in the larger western branch and the eastern branch drops onto an orange flowstone slope, which descends very steeply to a final 4 m drop rimmed with stalactites.

The preferred route into Knockers Cavern follows Enipeus stream from the Shale Band Pitch to the pleasant 18 m pitch in Scyllas Cleft. The stream flows down this pitch and after heavy rain a complete soaking is unavoidable. At the pitch top the Cardinal View Shale changes lithology. The shale is last seen at the pitch top; the walls below it are of shaley Limestone. Slabs of it often break off during a descent.

Scyllas Cleft meanders slightly along its 12 m length. At its northern end a constricted canyon passage continues with the Enipeus winding on a bed of deep mud. Poorly consolidated sands and pebbles are stranded 2 m up in the roof. The canyon enters Knockers Cavern after 4 m and Enipeus follows the left hand wall, flowing in the 4 m deep trench it has cut in the cavern's sediment floor.

Knockers Cavern is 46 m long and up to 22 m wide and 17 m high. In form, it is divided longitudinally into two distinct parts. The eastern part is between 3 and 7 m in height with no dominant structural control, though minor roof and wall segments follow the bedding. Most exposed sediment in the cavern lies on this side forming on its western edge a 3 m high bank into the flood course of Enipeus stream. The stream usually sinks before this in a 1 m deep bedrock walled pit in the southwestern corner of the cavern. Above the bank the roof rises into the cavern's western part. This part is controlled by a plane (a joint or fault) which strikes parallel to the bedding and dips to the east at 60-70°. This easterly dip is unusual in beds whose strike joints have been recorded as vertical or westerly dipping (Jennings et al. 1972). It is possibly the same plane as that encountered in Charybdis. Along the plane the cavern roof rises from 7 m in the south to 17 m in the north. The north end is formed solely along the plane. Its overhanging eastern wall features many small bedding plane projections, not developed on the smooth mud covered western wall. At the south end a passage at roof level continues in the plane, entered by a muddy climb. It is well decorated but ends after about 10 m. A further climb up its eastern wall gives access to a 5 m long upward sloping tube which ends in flowstone. It may connect with the 3 m deep pit near the recess in Penelope Chamber.

A sump pool 10 m long occupies the far northern end of Knockers Cavern and is fed by The Styx (Y), a permanent stream of usually about 0.5 litre/sec flow. The Styx enters Knockers Cavern in a pool in the NE Corner and flows along the undercut northern wall.

During a syphoning of The Efflux (B67, the rising of The Styx) this pool disappeared and 4 m of low gradually descending passage was visible but not entered (Montgomery 1972). Late in 1974 the sump was dived to yield an estimated 20 m of westerly passage that dropped about 6 m. The passage had widened into a large underwater chamber at the furthest point reached. Diving this pool remains as one of the most promising leads at Bungonia.

HYDROLOGY

Intermittant Streams

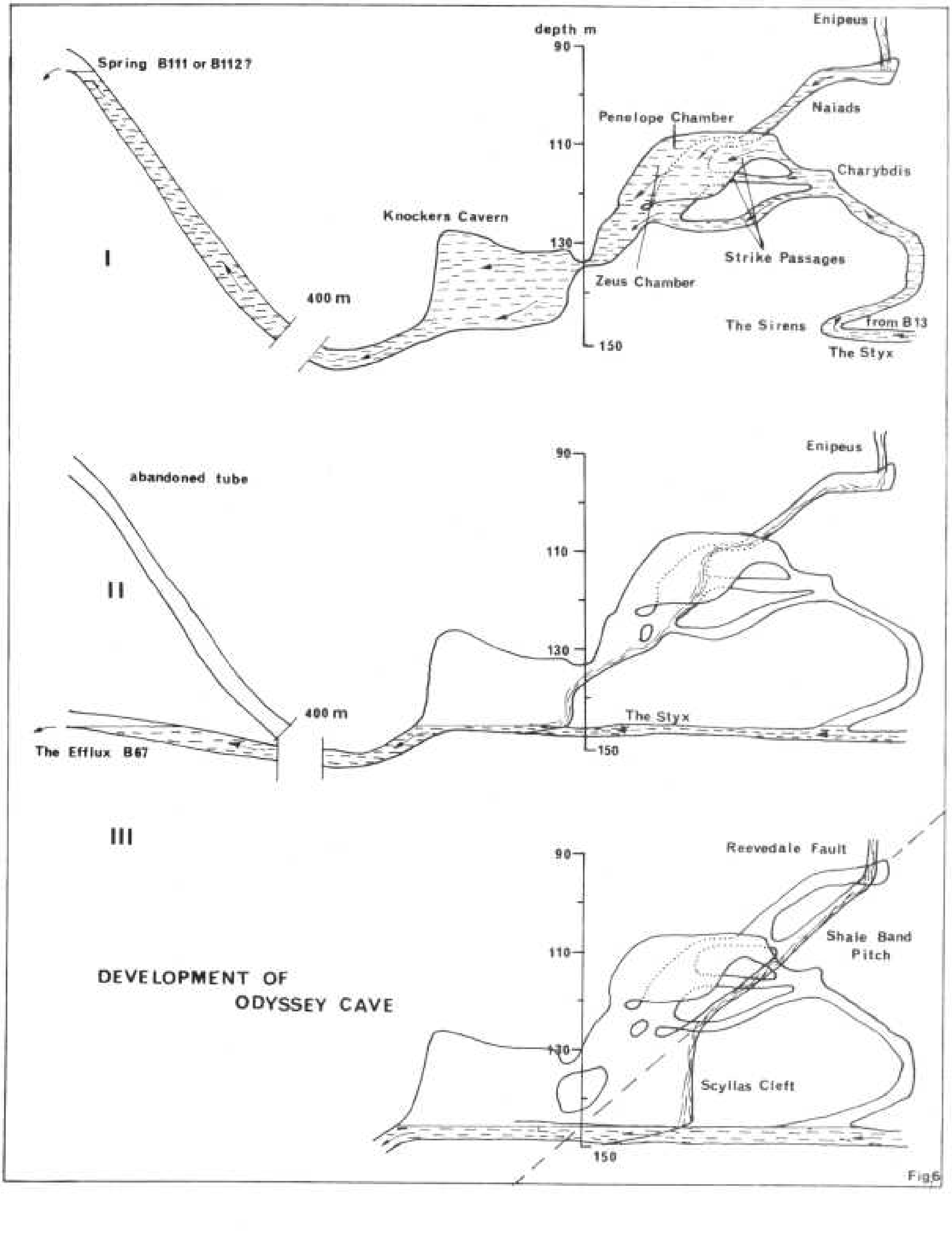
The eastern tributaries of Bretons Creek (Figure 2) flow strongly after heavy rain and sink on meeting the limestone. The stream in the B24 tributary (Figure 2) sinks on the Reevesdale Fault at the doline rim. This is an ill defined sink into gravel, with a limited intake, for in heavy flood water overflows the sink to run across the doline floor into Odyssey Cave entrance. The path of this flood overflow stream in the cave is much the same as that taken by cavers until the 45 Minute Squeeze, after which it disappears through boulders. A second stream, which is known to start flowing approximately twelve hours after heavy rainfall, enters from the dip joint chimney near Two Stitch Slot. The time delay suggests that it is derived from seepage water, probably in the local catchment area of the B24 doline. When the rain ceases, these two streams dry up within several days. By contrast Enipeus stream is much more persistent, ceasing flow only in drought. It enters the cave near the top of Golden Fleece Pitch and shows a sharp increase in flow rate an hour or so after heavy rain, when it is thought to be fed by the B24 tributary sinking at the doline rim. A fourth stream of undetermined origin flows from the passage at roof level in Penelope Chamber. These intermittent streams vary widely in flow rate but seldom exceed 0.5 litre/sec. They all join the Enipeus, which itself enters The Styx below water level in the terminal pool in Knockers Cavern.

Permanent Streams

The Styx is the only permanent stream in the cave. It is first seen at the Sirens and then disappears briefly before flowing through Knockers Cavern. The connection between the Sirens and Knockers Cavern was proven using optical brighteners (Hickson 1975).

The Styx gathers water from nearly all the caves in the Lookdown Limestone (Figure 5). The water in these streams is derived from seepage except after heavy rain, when streams sink in many places on the Bungonia plaateau. This water's apparent underground breaching of the non-karst rocks of the Cardinal View Shales has been considered by Jennings and James (1973). They raised the possibility that the shales might thin out with depth and this has now been supported by geological work in Odyssey Cave.

After passing through Knockers Cavern, The Styx flows to The Efflux (B67), 350 m away. Highgrade levelling by Anderson (1971) coupled with cave surveying, show that The Styx only drops about 2 m in this distance. The connection was proved in May 1972 (James 1973) confirming an earlier postulate based on water chemistry (Lockwood and James 1971). The closeness in level has had some interesting effects. In 1972 syphoning of the Efflux caused the level of the sump in Knockers Cavern to fall 2 m. More-



depth m
90
110
130
150
Spring B111 or B112?
Enipeus
Naiads
Penelope Chamber
Charybdis
Knockers Cavern
I
400 m
Zeus Chamber
Strike Passages
The Sirens
from B13
The Styx
II
abandoned tube
Enipeus
400 m
The Styx
The Efflux B67
III
Reevedale Fault
Shale Band Pitch
DEVELOPMENT OF ODYSSEY CAVE
Scyllas Cleft
Fig6

over it seems certain that the initial opening of The Efflux, which lowered the altitude of the spring by some 10 m, had the effect of draining Knockers Cavern, which must have been half water filled beforehand.

The Styx only supplies about 20% of the water issuing from The Efflux; the waters of some other caves drain to it without first passing through Odyssey Cave. This has been shown by dye tracing for Argyle Hole (B31) and College Cave (B84). While Argyle Hole has only a small catchment area, College Cave entrance lies in an uvula on the Folly Point Limestone with considerable catchment, all of which probably drains to The Efflux. It is possible that this water joins The Styx in the water filled chamber reached by diving 20 m from Odyssey Cave sump.

1974 was a year of exceptional rainfall and Odyssey Cave experienced a number of floods. Prior to October 1974, flood pulses seemed to pass rapidly through the cave. Even though the level rose 10 m during the August flood, it had recovered its normal level after a week later. However, in October 1974 the water level rose after heavy rain, and continued to rise slowly until it reached a seemingly stable level 6 m above the former normal level. This new level dropped very slowly over two months and in January 1975 was 1 m above the former normal level. It is suggested that some blockage has occurred between B24 and B67, thus hindering the passage of flood waters.

Development of the Cave

Though Odyssey Cave has many special features, in broad aspect its evolution is similar to the other deep caves at Bungonia. Jennings et al (1972) have attributed their verticality and depth to an early period of rejuvenation in the Bungonia landscape. This period was responsible for the steep part of Bretons Creek above The Efflux (B67) (Figure 2). The Efflux at an altitude of 384 m, lies a short distance below the nickpoint relating to features of the early rejuvenation and near the top of the features of a later sharper rejuvenation, the most striking of which is the 270 m deep Bungonia Canyon. The later rejuvenation apparently proceeded too rapidly for cave development to keep pace. Jennings and James (1973) review recent ideas on regional geomorphic history, which provide evidence that the later rejuvenation took place in the Lower Miocene. However, this implies an age for the caves which seems too great to match their form and sediments. Radiometric dating is being carried out to provide further data.

In detail, the formation of Odyssey Cave can be ascribed to the actions of two cave streams. These are the B24 Tributary (Figure 2) which on sinking and collecting seepage from the entrance catchment area becomes the Enipeus, and the permanent cave stream from the Lookdown Limestone, The Styx. The upper 90 m of the cave has been formed solely by Enipeus while the lower 55 m is due to the action of both.

The cave shows none of the near surface horizontal development present in many other Bungonia Caves, notably Argyle Hole (B31) and Fossil-Hogans System (B4-5)

Plate 5 The phreatic tube between Charybdis and The Sirens. The elliptical tube follows a steeply dipping joint. (photo: J.M.James)

Plate 7 Gravel and sand sediments in Knockers Cavern. (photo: J.M.James)

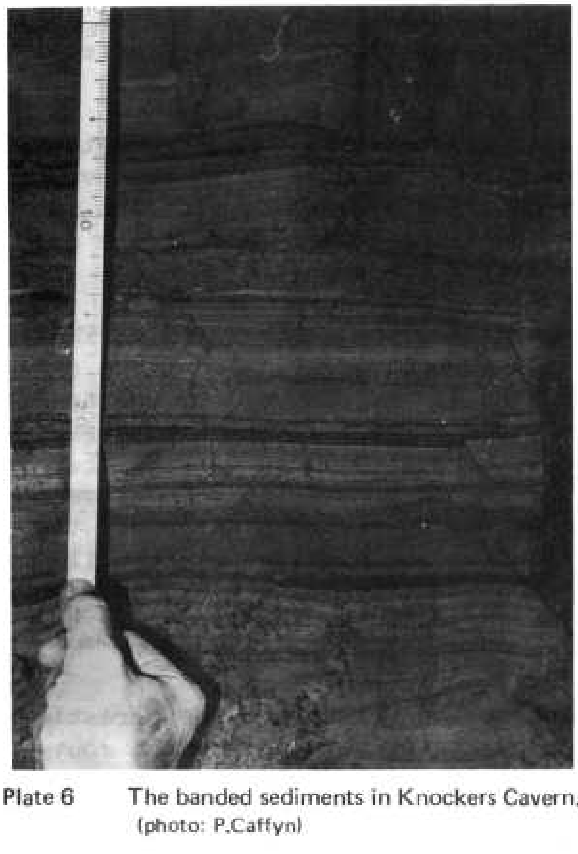


Plate 6 The banded sediments in Knockers Cavern. (photo: P.Caffyn)

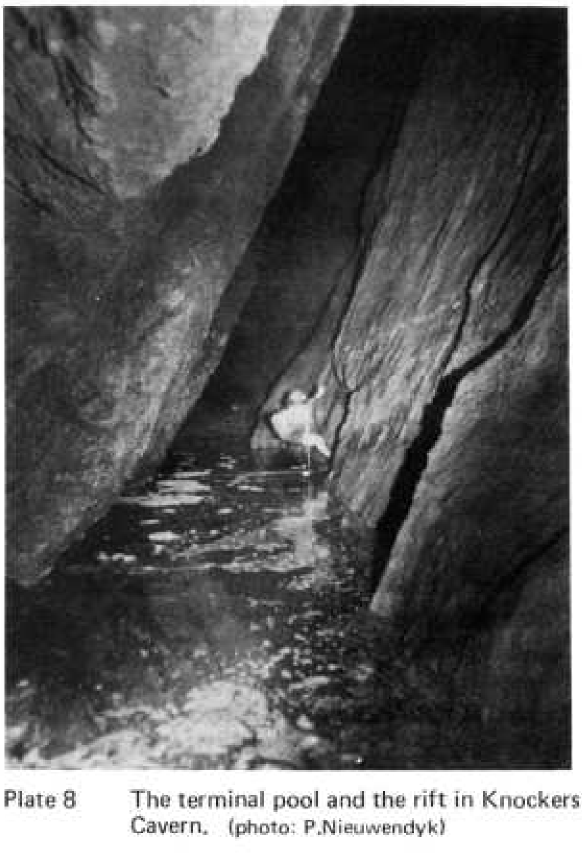


Plate 8 The terminal pool and the rift in Knockers Cavern. (photo: P.Nieuwendyk)

attributed by Jennings et al (1972) to phreatic development beneath a peneplain surface before the early rejuvenation. The upper 90 m is chiefly vadose formed from sinking of the B24 Tributary at the Reevesdale Fault, which itself exerts major control on the passage orientation.

The entrance collapse doline and The Rocks Wandering have formed through collapse of a large passage or chamber with subsequent vadose modification. The passage between the Rocks Wandering and Golden Fleece Pitch is mainly roomy dry passage, much of which has developed in a limestone breccia. Collapse has again been so extensive that only the results of recent vadose activity can be seen in the form of small bedrock shafts, chimneys and floor canyons.

At a depth of 65 m the Enipeus emerges from a very small yet active and hence young passage on the Reevesdale Fault. When flowing, the B24 tributary sinks at the surface on the fault plane and quite possibly its young route follows the near vertical fault plane between these points. After the Enipeus enters the cave it continues to follow the steep fault plane in a vadose passage until at Olympus Chamber, at a depth of 95 m, the first major branching occurs. From here a fossil flow route of the Enipeus may be followed through Cyclops Chamber, Apollos Walk, The Way to Ithaca and then into the roof of Zeus Chamber. The present flow route goes directly down the Reevesdale Fault in the Shale Band Pitch.

At a depth of 110 m Penelope Chamber is met and this chamber together with the cave below it, was formed primarily by The Styx as it took various routes through the limestone. The Enipeus still exerted significant influence in certain sections. Figure 6 traces the development of the complex lower section of the cave in three stages.

Stage I. The Styx formed a complex phreatic loop, commencing at The Sirens, going up the tube to Charybdis and then through one of three or possibly four different routes, which united in various ways to descend to a common point in Knockers Cavern. The three certain routes are those through Penelope Chamber and the two strike passages joining Zeus Chamber to The Naiads. The fourth possibility could be the postulated join between the high recess in Penelope Chamber and the muddy rising passage off the southern end of Knockers Cavern (see cave plan). This possibility will not be discussed further. The existence of the phreatic loop, which is a novel occurrence for this part of Australia, is suggested by scalloping in Penelope Chamber.

Stage II. The Styx commenced draining to The Efflux and the phreatic loop was drained as The Styx came to occupy its present horizontal route between The Sirens and Knockers Cavern. It is unlikely that spring positions intermediate between the B111-112 area and The Efflux existed, for there are no markings in the cave suggesting a long standing pond level at intermediate elevations.

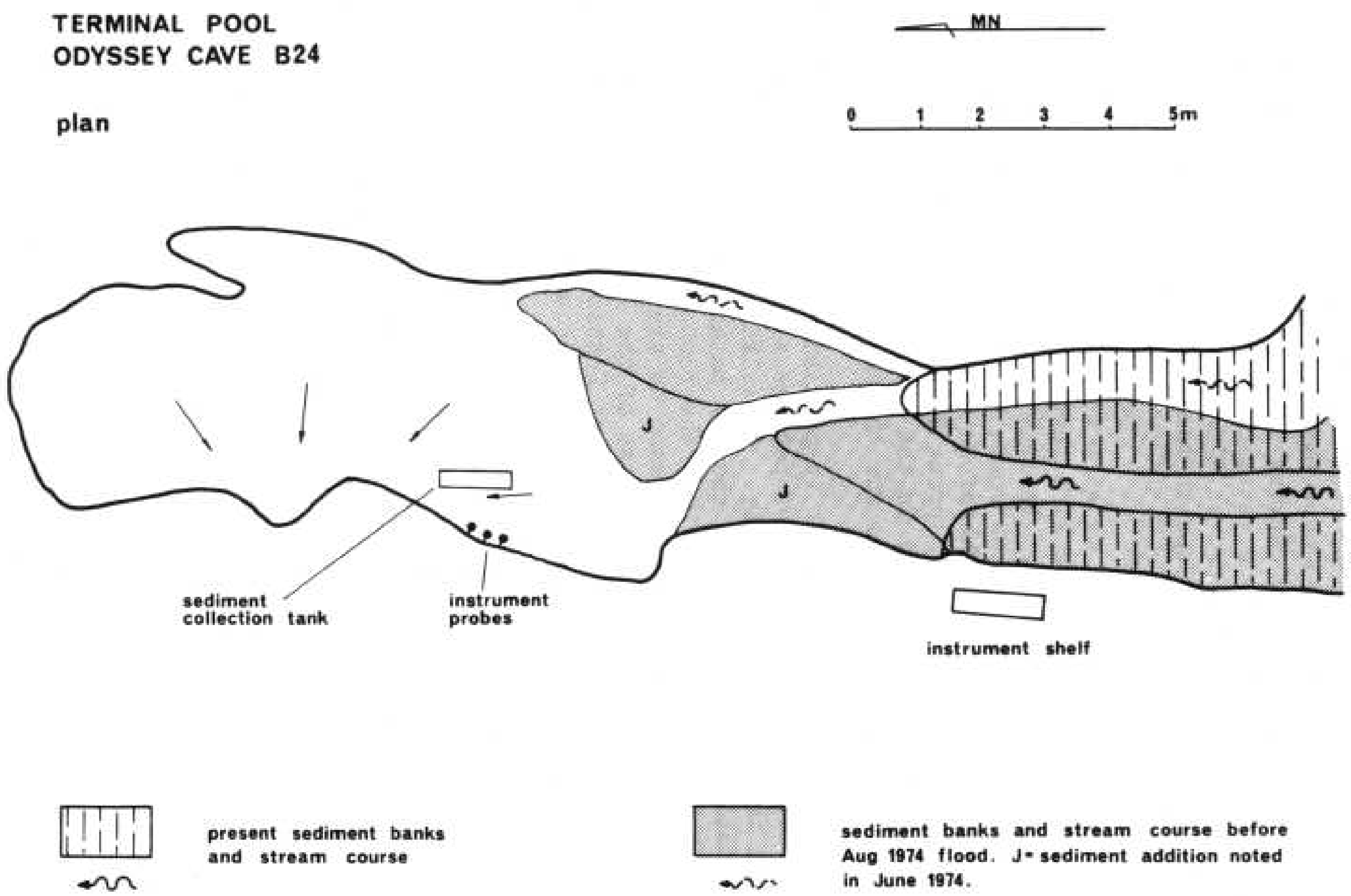

TERMINAL POOL
ODYSSEY CAVE B24
plan
MN
0 1 2 3 4 5m
J
J
sediment collection tank
instrument probes
instrument shelf
present sediment banks and stream course
sediment banks and stream course before Aug 1974 flood. J = sediment addition noted in June 1974.

Fig. 7

The Efflux may have been formed at the time of the loop's draining or it may have existed previously as a spring to the waters from the region of College Cave (B84). In the former case the phreatic loops would have probably drained slowly, which would have caused vadose canyons to form at the loop tops. The absence of such canyons suggests that the latter case is more likely - that the B84 region water completely captured The Styx and the two strike passages, which proves a northward flow direction. There are a few poor upward flow scallops in the tube passage above The Sirens which lend support.

The loop had a maximum height of 45 m to the solutional roof of Penelope Chamber. This is a phreatic lift through the lower third of the karstified limestone at Bungonia. It is scarcely credible that a loop of this magnitude and the present flow route to The Efflux Cave (only 350 m distant) existed concurrently. Therefore while the loop was operative its water must have drained through a spring 50 m or more higher than The Efflux. B111 or B112, short caves in the cliffs above The Efflux (Pavey et al 1972) could be possible sites for this spring.

Given that the spring existed, it is possible that the four flow routes operated at once, but a comparison of passage sizes makes it improbable that they were initiated concurrently. Thrailkill (1968) has shown that in such a situation routes offering shorter paths have higher discharge than those offering longer routes. Had the routes been formed together, it could be expected that they would decrease in size moving vertically. The reverse is the case, though the true size of the lowest route is concealed by sediment fill. It is thus probable that Penelope Chamber was formed well before the two strike passages below it in quite a short period.

The Enipeus must have then flowed through Zeus and Cyclops Chambers for some time, since the Zeus Chamber contains a vadose floor canyon commencing below the entry point of The Way to Ithaca. This canyon could not have been formed while the phreatic loop was operative.

Stage III. The Enipeus developed its current flow route down The Reevesdale Fault and into Scyllas Cleft.

The Origin of the Phreatic Loop and the effect of the loop on other Bungonia Caves

The known water connection down dip between Drum Cave (B13) and Odyssey Cave requires that the cave waters have to pass under the impervious Cardinal View Shale. In the early development of Bungonia Caves water passing under the shale would have been under considerable hydrostatic pressure and would have had sufficient energy to work up joints and bedding planes to initiate the loop we see in Odyssey Cave.

Judging by the tube size in the loop, the phreas did not for a long while drop below the loop top. Thus at about this altitude (430 m) there was a rest level which probably accounts for the size of the Railway Tunnel and its level roof in the Drum Cave and for a similar level in the Grill Cave (B44).

Since the draining of the loop the sumps in the other deep caves have fallen to a fairly common level at 403 m altitude, 19 m above the water level in The Sirens. The distance between Drum Cave sump and The Sirens is only 550 m suggesting that the flow route is constricted (possibly due to sediment blockage) and this is further confirmed by the inability of the caves in the Lookdown Limestone to cope with flood waters.

The Blockage of The Efflux

In recent geological time there was a cliff collapse at The Efflux which was consolidated by massive amounts of tufa. As the tufa pile grew higher, the depth of water in the lower reaches of Odyssey Cave increased, appearing to reach a steady level at Circes Sty and in Knockers Cavern at about 10 m above the present sump level. The extensive banded sediment beds in The Sirens and Knockers Cavern could have only formed underwater in such a lake, rather than being deposited by transient floods. This blockage probably caused a sediment build-up in the water-filled passages connecting the deep caves of the Lookdown Limestone and The Styx. In Odyssey Cave the presence of these sediment beds must conceal the true shape and size of the bottom part of the cave. Knockers Cavern would have been considerably larger. The passage between The Sirens and the Cavern could have been a relatively free route. The same applies to the connection between Knockers Cavern and The Efflux. As a result of the sedimentation floods could now raise the water level in Knockers Cavern dramatically. The charcoal in the high recess of Penelope Chamber may record a flood level reached during this period and these floods would account for the copious coating of mud on all surfaces in the lower part of Odyssey Cave.

Samples of charcoal collected from the base of the exposed sediment in Knockers Cavern were dated at 600 + or - 50 years (James 1973). Older sediments must lie buried beneath so the age of the rockfall causing the Efflux blockage may be little greater than 1000 years. Aside from the sedimentation, several important changes were wrought. The blockage must have caused organic material carried in by floods to be trapped in the caves, which on decaying charged the cave atmospheres with high concentrations of CO_2. The CO_2 has partially dissolved the large and beautiful arrays of speleothems that must be older than the blockage. In the lower reaches of the caves, these speleothems must have been deposited after the draining of the phreatic loop in Odyssey Cave; dating them will give a minimum age for this event. The CO_2 also corroded exposed limestone, leaving a weathering crust 2 cm or more thick and destroying most small scale solutional features.

The Clearing of The Efflux

This period of transformation has been somewhat reversed since 1923 (Nurse 1972) when excavation of The Efflux started in the hope of draining the caves of 'foul air'. By 1967, when excavation ceased, the level of rising had been lowered 10 m.

The lake in Knockers Cavern had then been reduced to a pool at the northern end. As The Efflux was lowered the sediment banks became exposed and were immediately vulnerable to erosion by the Enipeus and The Styx, especially in periods of high rainfall. When Knockers Cavern was first entered in 1971 the top of the sediment bank was 5 m above water level and the Enipeus and The Styx had cut deep trenches in it. Undercutting of the sediment banks by Enipeus followed by collapse had created a clean vertical section, which displayed the excellent banding in the sediment.

From 1971 to 1974 there were no floods and the sediment banks were not disturbed; then in August 1974 a record rainfall of 500 mm in two days was recorded near Bungonia Caves. B24 was not entered during this time; however, one week later the gate was found to be blocked by gravel and a boulder fall, and there was considerable flow in all the cave streams. In the entrance boulder pile there was organic debris as well as fresh sediments. Moreover, further down the cave in Sphinx Chamber, movement of clays and sands had exposed clean limestone boulders. On both the Golden Fleece and the Shale Band Pitches, the manganese deposit covering the Cardinal View Shale had been mechanically eroded and the flowstone deposits reduced in size.

However, the most dramatic changes occurred in Knockers Cavern. The earth pillars at the floor of the 18 m pitch had disappeared. The sediment banks had crumbled, and a stream from Penelope Chamber was flowing down the centre of the sectioned face. Much of the sediment had been washed away. The Styx had changed its course and in the region of the terminal pool a fresh sediment bank had been deposited (Figure 7). The pool had deepened by 1.5 m.

Such storms are rare at Bungonia; however, a further minor flood in October 1974 caused considerable movement and further collapse of the sediments in Knockers Cavern. This catastrophic destruction of the sediments by even minor floods indicate that it can only be a matter of decades before the sediment accumulation is largely removed, allowing a freer passage of water through the system.

CONCLUSION

Odyssey Cave is not simply the deepest cave at Bungonia; it is the centrepiece of the hydrological system south of Bungonia Gorge. Here the drainage of most of the caves of the Lookdown Limestone, the biggest limestone outcrop, unite with descending waters from the Bretons Creek catchment. There is also the possibility of a junction with water from the uvula containing B84 (College Cave) and Hollands Hole (B35) on the Folly Point Limestone.

Geological study of the cave has cleared the mystery of the breaking of the Cardinal View Shale by the water from the Lookdown Limestone. Morphological study has explained certain features of other major caves as well as producing an example of phreatic lift unequalled in south eastern Australia, where phreatic development is usually only expressed in more or less horizontal epiphreatic conduits.

The development of this large phreatic loop may have arisen because of the extremely rapid incision of Bungonia Creek, to which the marked vertical character of caves here has previously been related.

Apart from these considerations, Odyssey Cave has interest because of the complex recent history of its final chambers. Rockfall from the cliff above The Efflux became cemented by tufa and caused extensive sedimentation in Knockers Cavern and The Sirens area in Odyssey Cave and probably also in the other major caves. This blockage caused atmospheric changes in the caves. Artificial lowering of the outflow has led to the removal of much sediment and consequent improvement in atmospheric conditions so that underground scientific work is possible most of the time today.

Odyssey Cave has lost the premier position it held so shortly as the deepest cave on the mainland of Australia but it retains an outstanding place among Australian caves because of its scientific interest.

ACKNOWLEDGMENTS

The authors would like to thank J.N. Jennings, D.C. Ford and P. Smart for critically reading this script, the many cavers who assisted with surveying, exploration and hydrological work. This work was supported in part by the Australian Research Committee and a University of Sydney Research Grant.

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A GEOMORPHOLOGICAL ASSESSMENT OF THE CHILLAGOE KARST BELT, QUEENSLAND

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Abstract

The geomorphological characteristics of the Chillagoe karst belt are analysed in terms of an evolution controlled by seasonally arid climatic conditions and lithological variation in the metamorphosed host rock.

INTRODUCTION

The landforms of Chillagoe National Park in northern Queensland contrast with those of most other Australian karst localities. Serrated towers, riddled by extensive, well-decorated cave systems, rise abruptly from soil-covered pediments. The limestone, a member of the Palaeozoic Chillagoe Formation, outcrops as a 10 km wide belt from Almaden (17°20'S, 45°40'E) northwest to the Walsh River. The karst belt lies in hill country west of the Great Divide, 200 km from Cairns. Chillagoe, a former mining centre, is situated centrally on the northern margin of the outcrop. The region was relatively accessible during the heyday of mining in the late nineteenth and early twentieth centuries and many of the caves were then show caves (S.S.S. 1969), but latterly the area has been neglected. Geomorphological investigation has been limited and scientific publications few. This paper discusses the characteristics of this Queensland seasonally arid karst region in terms of environmental controls.

PREVIOUS LITERATURE

As early as 1910 Danes provided the first geomorphological description, noting the association of old caves with towers, or bluffs+, rising 30 m to 50 m above the plains and the contrast between jagged and rounded outcrops. The rounding and pot-holing of Lion's Head, (The Dome

* The research embodied in this paper was carried out during the tenure of a C.S.I.R. post-doctoral bursary. The author would like to thank Frank Kinnear and Paul Wilson of Chillagoe without whose help this paper would not have been possible.

+ The limestone risiduals are locally termed 'bluffs'.

(Wilson, 1975)) was, however, attributed to fluvial action (Danes, 1911). More recently Hamilton-Smith (1966) commented on the strong joint control exhibited by all major caves and the effect of that joint control on the formation of karst corridors within individual bluffs. He also considered the size of individual towers and contrasted large residuals, up to 900 m in length rising 20 m to 60 m above plain level, with small outcrops only 15 m in length and 3 m to 5 m in height.

Attention has been drawn to the aligned nature of this tower karst belt resultant on the pattern of limestone lens outcrops and to its advanced stage of development as deduced from the residual nature of the towers on pediment foot slopes and the number of collapse dolines within the residual masses (Jennings, 1966). Jennings (1966) also comments on Danes (1911) reference to fluvial pot-holes and suggests that they may be solution pits that trap surface gravels. Investigation by Wilson (1975) has shown that most are solution slots which may be associated with restricted cave development. The large phreatic caves of the bluffs are attributed to impounded flood waters. More recently Wilson (1974) reporting the effects of exceptional rainfall, substantiates Jennings' (1966) hypothesis that cave development is controlled by impounded flood waters. The rate of cave drainage is closely associated with the efficiency of the surface stream network. Where streams are incised below cave level adjacent to the towers, through-flow from the caves takes place within the pediment (Wilson, 1975). Other relevant publications include geological reports (Keyser and Wolff, 1964), cave survey information (Matthews, 1968; S.S.S. 1969) and summaries of available information (S.S.S. 1969). That the Chillagoe karst region is a tower karst with exceptional caving potential is now well known, but geomorphological aspects have not received equal attention as most visitors have been tourists or cavers.

MORPHOLOGICAL CHARACTERISTICS

Terrain analysis: general

The Chillagoe karst belt lies astride an imperceptible watershed between north-flowing drainage, including the Chillagoe Creek, tributary to the Walsh River, and west-flowing catchments draining into the Muldiva Creek and Wandoo River. Many of these headwater creeks are spring-fed although few are perennial. There is a tendency for limestone residuals to form positive relief whereas interbedded chert, greywacke, siltstone and shale have favoured pediment development. Some honeycombed chert residuals are however known (Jennings, 1976 pers. comm.).

North of the Silurian limestone outcrop, granite uplands such as Mt Redcap (500 m), Mt Coonbeta (400 m) and Mt Bocoonbeta (500 m) dominate the landscape, reaching greater altitudes than the limestone bluffs. Westwards the land drops abruptly to the Muldiva Creek pediment. Above this break of slope a greywacke-siltstone belt also creates positive relief which, like that to the north and east, reaches greater altitudes than the limestone residuals (Figure 1). Despite their lower mean summit altitude, however, the limestone residuals produce the most striking relief, since they rise abruptly from pediments and are serrated by surface weathering (Figure 2). Nevertheless, throughout this region, residuals rising above pediments are the characteristic landform irrespective of parent rock. The limestone bluffs are a particular case.

Morphometric analysis

Detailed analysis of an 800 km^2 portion of the limestone belt and adjacent areas was made in an attempt to elucidate the major morphological features. A summit altitude analysis based on 1:100 000 topographic map sheets (Series R631, 7763 and 7863) demonstrated marked bevels in the landscape. In each 100 km^2 sector the most prominent bevel represents the local pediment level (Figure 3). Summit accordance is minimal for this landscape is in an advanced stage of dissection, the height of individual residuals being largely a function of their basal area. The main pediment level lies at 360 m west of Chillagoe but rises east and southwards to altitudes of 400 m to 420 m immediately south of Chillagoe. A lower pediment level at 300 m is associated with the Muldiva Creek and higher bevels have been preserved south of Chillagoe in the headwater catchments of the Chillagoe and Quaker Creeks (Figure 3).

The actual distribution of karst towers, over an area extending 15 km either side of Chillagoe, was mapped on a scale of 1:100 000 from air photographs and extended from a base map compiled by Sydney Speleological Society (Figure 1) (S.S.S. 1969). Large residuals occur in two main localities, south of Chillagoe including Donna and Royal Arch Bluffs, and in the vicinity of Mungana. In both these areas the Chillagoe Formation outcrop is wider and the degree of headwater dissection is less than in the central portion. The paucity of tower karst in the central area near Zillmanton could, however, be due to lithological variation. The stereoscopic air photograph cover was also used to establish the heights of individual towers above adjacent karst pediments. A survey of 89 towers in the immediate vicinity of Chillagoe, was made. Considerable variation in height occurs since height is to some extent a function of the size of the residual; smaller, lower residuals dominate the karst plain in the immediate vicinity of Chillagoe whereas further south, where pediment development has been less pronounced, the towers are higher (Table 1).

Table 1: KARST TOWER HEIGHT (m)

AREA	NO. OF TOWERS	RANGE OF HEIGHT Max.	Min.	MEAN HEIGHT
Chillagoe	27	66.9	15.0	35.3
S.E. of Zillmanton	28	35.0	2.5	19.6
Donna Bluff	10	56.0	10.6	27.9
Royal Arch Bluff	10	43.2	21.9	34.1
Queenslander Bluff	4	87.0	65.6	75.6

Surface karst characteristics

The Chillagoe karst assemblage consists, in the main, of towers and pediments. The lower portions of the pediments are concealed beneath red clay terra rossa soils although limestone usually crops out on the foot slopes nearer to the towers. On some pediments chert rubble conceals the underlying rock and on others the pediment is cut across clastic, non-calcareous rocks. The clay soils reduce infiltration on the pediments where surface drainage towards the seasonal drainage lines, themselves superimposed on thick transported residuum, is in any case slow. Although it is difficult to envisage a true piezometric surface within the context of the complex geology, there is some evidence that wet seasons cause a rise in the saturation level and under exceptional conditions, such as obtained in 1973-4, both pediments and cave systems within the residual towers become flooded. Rate of drainage after the rains have ceased, is closely controlled by the position of the external surface drainage system. Water from the flooded caves feeds through the pediment into the streams as springs (Wilson 1975). The cave systems thus lie within a pharaphreatic zone operating on a cyclic rather than a seasonal basis. An active phreatic zone with waterfilled caves at 10 to 120 m depth is also postulated on geological grounds (Keyser & Wolff 1964, Wilson 1975).

Surface karst forms are most impressive and best developed on larger residuals where a greater area and depth of limestone is available. Structural control affects the distribution of karst corridors, enclosed hollows and large-scale pinnacle karren (the serrations of the tower summits). The karst corridors are aligned along master joints and major dolines are located at the intersections of major lines of weakness, providing low points within the karst corridors. Surface runoff, maximised by high intensity precipitation and bare rock surfaces, is concentrated into these low points and thence into the underlying cave systems. Royal Arch Cave leaks like a sieve! (Wilson 1974). Cliff foot dolines also occur, trapping runoff from the bare rock residuals. Breakdown in the highly fractured limestones is important, corridors and dolines being frequently choked by debris mantled in vegetation.

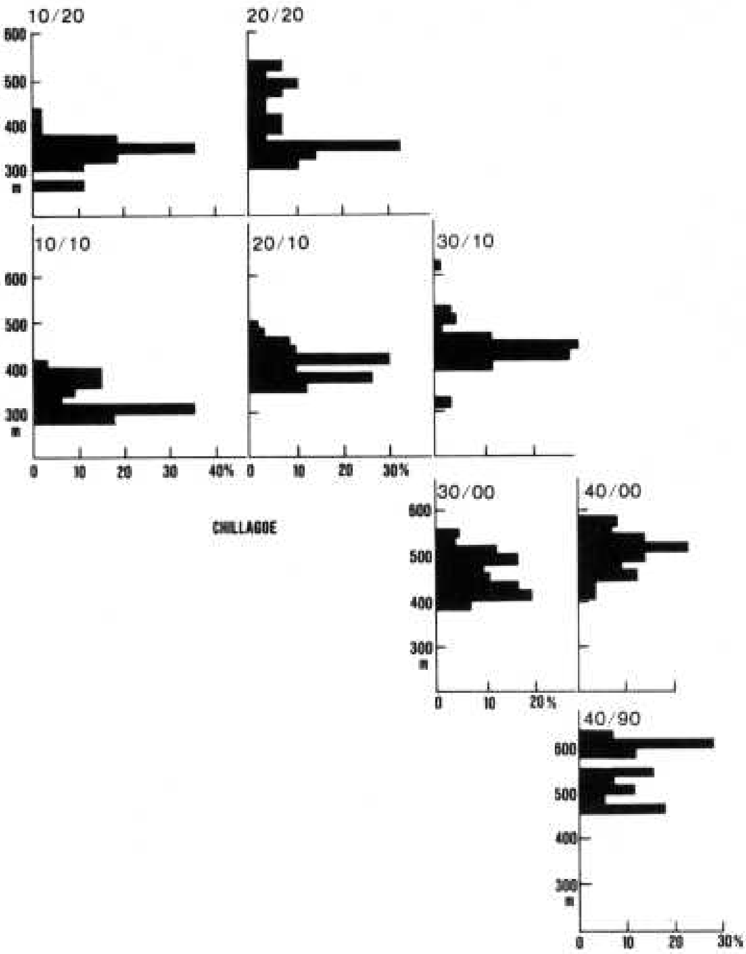


Figure 3   Morphometric altitude analysis by 100 km^2 segments.

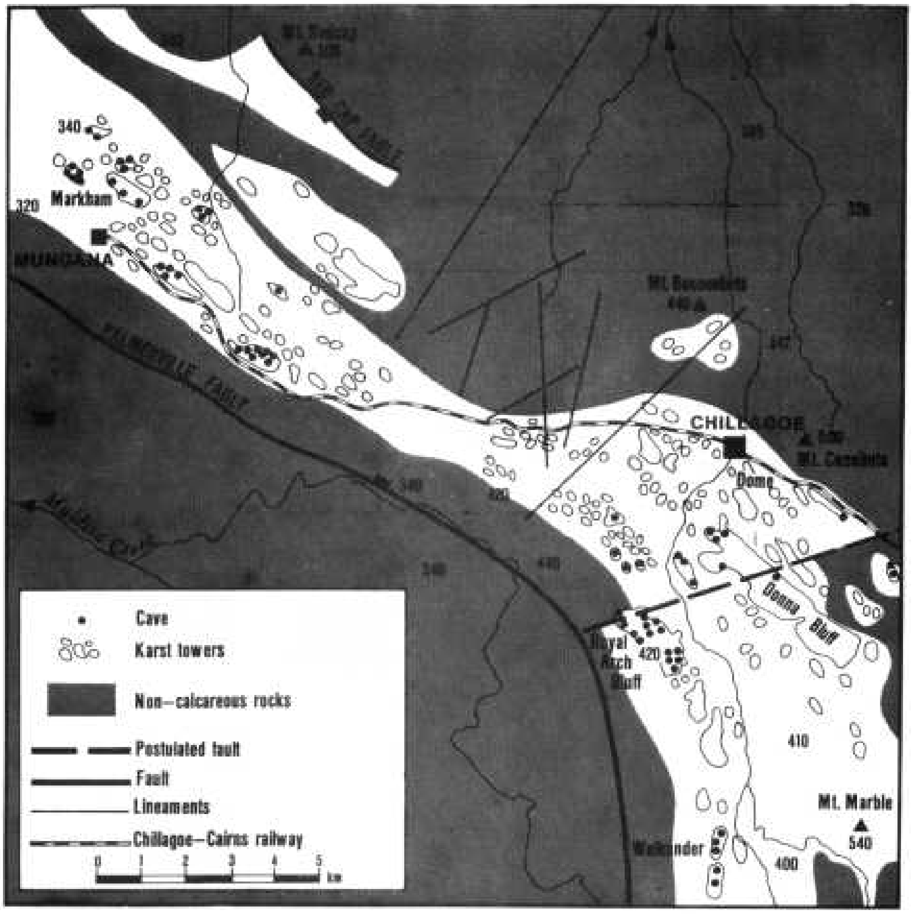


Figure 1 The Chillagoe karst belt showing the distribution of towers and known caves in relation to major structural features (mapped from air photographs and data from Sydney Speleological Society: limestone belt unshaded).

Figure 2 Cathedral Bluff: a typical pinnacled tower showing giant karren with fluting, developed on recrystallised blue limesto...

A characteristic of many, although not all, the larger residuals is their serrated and jagged skyline (Figure 2). Weathering reduces the rock to a series of sharp pinnacles up to 10 m in length. Large rillenkarren, caused by rapid runoff, scar the sides of the pinnacles to form a distinctive 'giant karren' landscape such as has been reported from Brazil (Tricart & Da Silva, 1960) and from the Fitzroy Ranges of Western Australia (Jennings & Sweeting, 1963). Differences in lithology control the distribution of giant karren for more rounded residuals develop on less pure or less fractured parent material.

Superficial karren are also commonplace. Subsoil rounded karren are exposed only where soil has been stripped from the pediments but rillenkarren and kamenitza are also found wherever relatively level limestone is exposed, as in the vicinity of Markham Cave. Such solutional forms are, however, dwarfed by other karst forms.

Underground karst characteristics

Cave systems riddle the towers, larger systems tending to be associated with larger residuals (Table 2). However, the distribution of known caves at first glance suggests that development has occurred in two distinct regions coincident with the distribution of larger residuals (Figure 1). But since most of the known caves are recent re-discoveries, the pattern most probably indicates a control exerted by former mini mining activity, accessibility and the incidence of active exploration. Recent exploration has demonstrated the likelihood of separate cave systems within one residual being in reality part of a single very extensive system (S.S.S. 1969). Such large cave systems all exhibit strong jointing control (Figure 4) and are phreatic in origin as shown by their maze character and the detailed wall solutional forms. Subsequent vadose action appears to be very restricted (Wilson, 1975). The degree of cave breakdown and the size of speleothems, themselves recording evidence of re-solution and renewed deposition, indicate the great age of much of this karst assemblage. Although the relatively level cave floors have been presumed to be accordant with the pediment level (Danes, 1911; Hamilton-Smith, 1966), detailed surveying has shown, in two cases at least, that cave floors may lie up to 20 m below pediment level and extend beneath the pediment beyond the limit of the residual in which they are located (Matthews, 1968).

Older caves can in any case be expected to have silted up to accord with normal saturation levels. The development of cave systems is accentuated by phreatic and paraphreatic solution caused by impounded waters (Wilson, 1974; 1975).

Table 2: MAJOR CAVE SYSTEMS

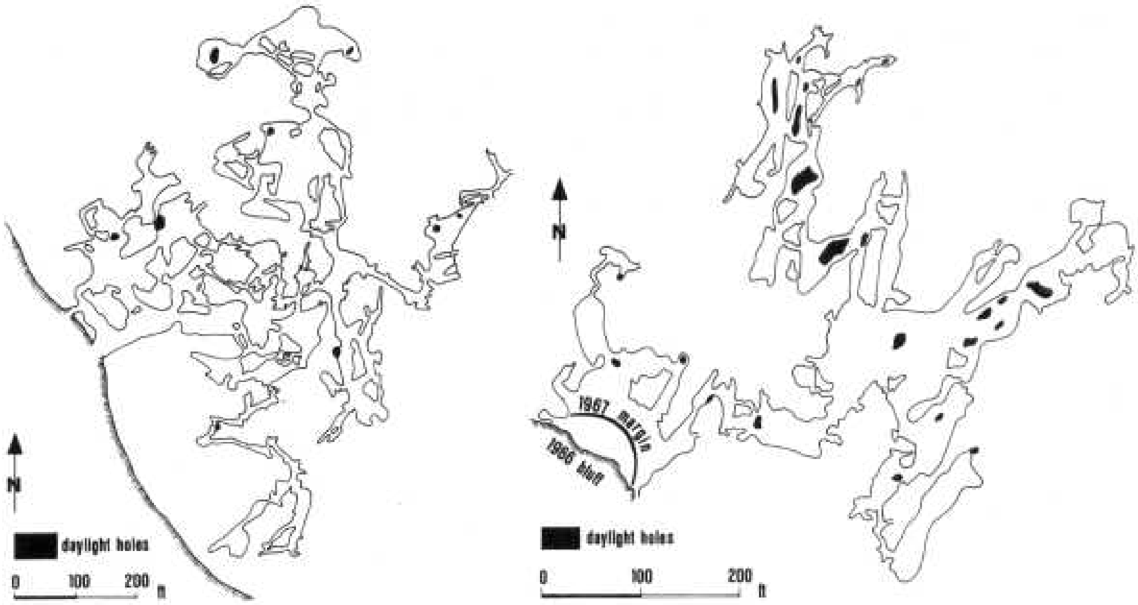
No.	NAME	TOTAL PASSAGE LENGTH (m)	DAYLIGHT HOLES	BLUFF
CH 1	Haunted 1	1500	+	
2	Donna (tourist)	800	+	Donna
3	Royal Archway (tourist)	600	+	Royal Archway
4	Ryan Imperial	400		Walkunder
24	Keefes	1000 +		Walkunder
9	Royal Arch (tourist)	3500 +	+	Royal Arch
10	Markham	3500		Markham
15	Cathedral	180		Cathedral/
25	Carpentaria	3500	6	" Queensland
30	Stop Press	800	+	
51	Queenslander (3 entrances; side passages unexplored)	800		

Compiled after Matthews 1968; S.S.S. 1969.

In general the larger cave systems comprise phreatic passages linking larger collapse 'daylight holes', themselves collapse and solution dolines (Figure 4). Individual caverns have enlarged by upward stoping along lines of weakness into the floor of overlying dolines. Nevertheless, the linking passages are themselves of large dimensions and many upper walls are of solutional and not of collapse origin. This must imply phreatic solution initiated prior to the lowering of pediments to their present levels. Cave formation can be envisaged as having been initiated simultaneously with the isolation of residuals by incision and slope retreat and having kept pace as surrounding pediments were lowered. Simultaneously with vertical development, slope recession by solutional undercutting and collapse reduces the size of both the residual and of its interior cave system. In late 1966 lightning struck the bluff above the entrance to Markham Cave. Extensive collapse occurred and the cliff retreated a distance of approximately 100 m along a 100 m front. Sudden slope recession is a geomorphological factor of importance.

ENVIRONMENTAL CONTROLS

The geology and lithology of the Chillagoe Formation limestones exert a strong control on the characteristics of the karst landform assemblage. The limestone of the mid-Palaeozoic Chillagoe Formation is of reef origin.



a) Royal Arch.

b) Markham

Figure 4 Typical cave systems: a)Royal Arch, b)Markham (after S.S.S. 1969).

The present outcrop has been downthrown along the Palmerville Fault to the west and south and the limestone outcrop is separated from the actual fault line by a belt of clastic rocks. These are interpreted as providing evidence of movement and erosion along the Palmerville Fault during sedimentation (Keyser & Wolff, 1964).

To the north and east, the outcrop has been intruded by Permian granites, but the Red Cap and other faults may represent the other margin of a graben in which the Chillagoe Formation has been preserved (Figure 5). Prior to down-faulting, however, the Chillagoe Formation was severely folded. Metamorphism is widespread but complete alteration of the limestone is not ubiquitous since areas of fossiliferous limestone are located along the Red Cap road, in Royal Arch Bluff and near Spring Cave along the railway. In Donna Bluff, as elsewhere, the original alternation of narrow chert bands and limestone is clear and the vertical disposition of the limestone outcrops is apparent (Figure 6a). The fissures that isolate the giant karren pinnacles of so many residuals are attributed to solution along secondary fractures attendant on severe folding and stress.

The alignment of the Chillagoe towers has been considered to be a function of the disposition of the limestone lenses en echelon (Jennings, 1966). This arrangement is itself a further effect of severe folding. However, the alignment of the karst towers, although holding true over limited areas, in general is, in detail, less marked. Since pediment waste mantles conceal geological boundaries, the lens pattern may be partly a product of geological mapping.

The Chillagoe limestones exhibit considerable variation. Four main lithological varieties can be distinguished. These are:

1. Limited areas of a highly fossiliferous blue limestone. Since solution affects the rock irrespective of fossil content and etching in relief is rare, some alteration can be presumed.

2. A recrystallised highly fractured blue limestone. All original structure has been destroyed and the calcite has been redistributed in such a way that it appears fused or re-solidified.

3. A calcareous breccia consisting of sub-rounded and angular blue-grey limestone, bothrecrystallised and fossiliferous, cemented by blue limestone with small amounts of calcite veining. In some cases chert rubble may be incorporated. In at least one instance (Pink's Cave) the breccia is related to faulting. In other cases intraformational brecciation may have occurred but as the blocks are themselves as recrystallised as the matrix, it is probable that the material is a fault breccia.

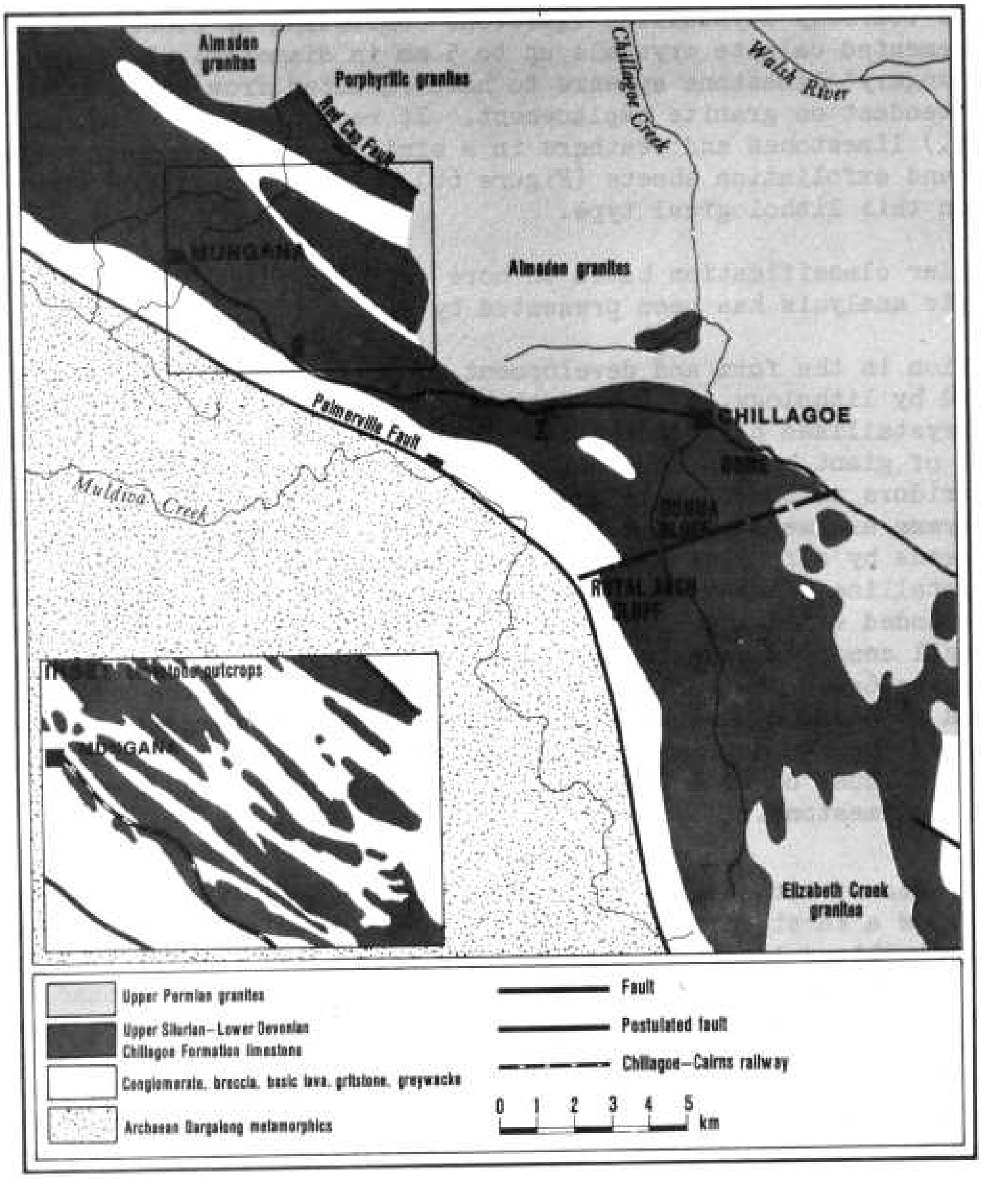


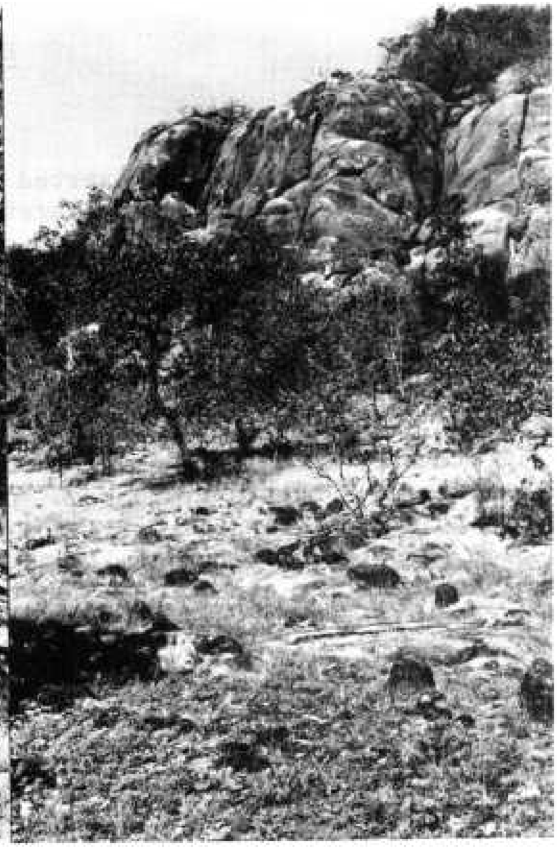
Figure 5 The geology of the Chillagoe region with inset to show limestone lenses (shaded) [after Keyser & Wolff, 1964].

4. A white coarsely crystalline limestone consisting of close-packed and well-cemented calcite crystals up to 5 mm in diameter. This crystalline 'sugary' limestone appears to have resulted from heat metamorphism attendant on granite emplacement. It resembles some Wombeyan (N.S.W.) limestones and weathers in a similar way to rounded surfaces, slots and exfoliation sheets (Figure 6b). Giant karren are never present on this lithological type.

A similar classification based on more detailed field sampling but less microscopic analysis has been presented by Wilson (1975).

Variation in the form and development of the tower residuals is closely controlled by lithology. The characteristic pinnacled residuals are formed on recrystallised blue limestone. Easy entry of water facilitates the formation of giant karren, dolines and the development of joint-controlled karst corridors on the surface and phreatic caves underground. At the other extreme are well-rounded residuals such as The Dome where development proceeds by a form of exfoliation resembling granite weathering. These crystalline white limestones favour pedimentation and the development of rounded wells and elongated slots (Figure 6b). Where the limestone is very well cemented sheeting occurs and incipient A-tent structures develop (Figure 6c). The contrasts between the effects of the same solution process on the blue limestone and on the white limestone could not be more pronounced. The two extremes are well exhibited in Royal Arch Bluff, a pinnacled residual on blue recrystallised limestone and The Dome on white crystalline limestone.

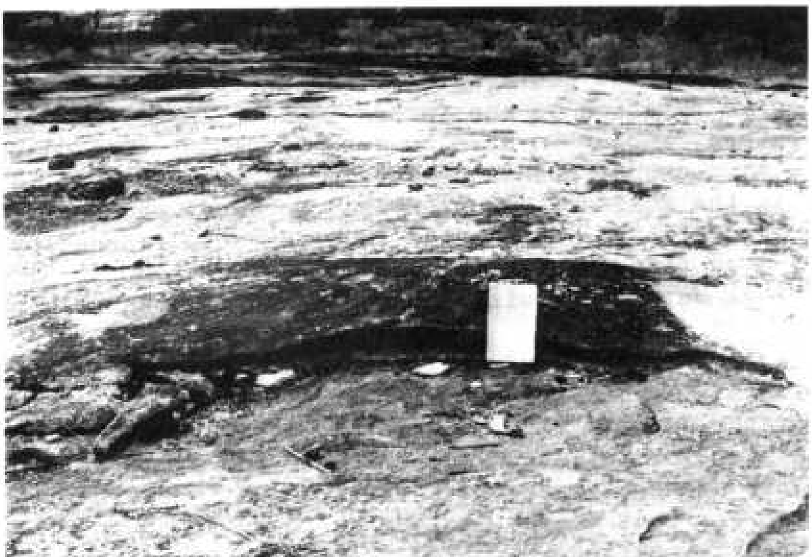
The effects of lithological transition are demonstrated on Donna Bluff, viewed across a karst corridor and enclosed hollow. At the extreme east, blue recrystallised limestone predominates associated with giant karren. Westward as the limestone becomes more broken so the karren pinnacles are less pronounced and where brecciated limestone replaces the blue limestone, the distinctive karren form is lost and the residuals are irregularly rounded (Figure 7). In areas where chert is closely bedded with limestone, solution frets the rocks irregularly and the tower residuals have little morphological distinction (Figure 8). Fossiliferous limestones, recrystalised blue limestones and limestone breccias all give rise to karst forms. However, the most spectacular karst is associated with the vertically fractured recrystallised blue limestone with which all pinnacled residuals and larger cave systems are associated. Caves can occur, in all the limestones but they are less frequent in crystalline and cherty limestones than in the fossiliferous and brecciated limestones. The presence of lines of weakness, whether vertical fractures or major joints, promotes the entry of water and enhances the development of karst forms.



a) Chert interbedded with limestone, Donna Bluff, indicating the vertical disposition of the Chillagoe Formation.

b) The Dome: Pediment and rounded residual developed on white crystalline limestone.

Figure 6



c) A-tent structure in exfoliating white limestone. limestone.

Climatic considerations

Despite the strong control exerted by lithological variation, the Chillagoe karst is everywhere a tower karst. All types of limestone give rise to abrupt residuals rising from rock-cut pediments. In detailed morphology the towers vary according to the solubility and jointing of the host rock but the essential characteristic remains the residual nature of the limestone hills. It has been suggested that seasonally arid conditions, such as obtain in this area of Queensland, favour the process of pedimentation (Jennings & Sweeting, 1963). Furthermore, the intercalated arrangement of clastic and calcareous rocks would have promoted the initial separation of the limestone by incision concentrated on clastic rocks (Jennings, 1966). That the residual bluffs are not co-extensive with individual limestone outcrops is apparent in the field and from photographic and map evidence. Recession has occurred. The collapse at Markham Cave indicates that solutional undercutting and surface fretting renders the residuals liable to sudden slope retreat.

The pedimentation process is pre-eminent at the present time. However, cave evidence indicates subsurface development concomitant with pediment lowering. At Donna Bluff remnants of a former higher pediment level with which the present caves are associated, can be seen, whereas at Royal Arch the present pediment, subject to inundation, abuts against the bluff. Royal Arch Cave, with more extensive breakdown, is at a more advanced stage of development than Donna Cave and drains more freely than the Donna system feeding phreatically through the bluff to the Chillagoe Creek (Wilson, 1974).

The Donna Cave system drains slowly since water is impounded behind a rock barrier, indicating that the hydrological system is not yet in phase with the new lower pediment level (Figure 9). The presence of cliff foot dolines, some now acting as cave entrances, on the higher remnant level and their absence on the present pediment also indicates that the hydrological network developed in relation to the former level. The pedimentation process would, therefore, appear to have been the dominant control over a long period of time. At present, mean annual rainfall in Chillagoe is 770 mm of which 86% falls in the monsoon season between December and March inclusive. Effective water availability is, however, considerably reduced by high evaporation rates, mean temperatures ranging from about 18°C to 31°C with considerable diurnal variation owing to the inland rain-shallow position.

Tower karst has been considered characteristic of tropical humid environments (Sunartadirdja & Lehmann, 1960; Gesternhauer, 1960). Comparison of climatic hythergraphs for two typical tower karst areas in Celebes and coastal Mexico with that for Chillagoe demonstrates the latter's greater aridity and concomitant higher temperatures (Figure 10). Nevertheless, no unequivocal evidence for past wetter periods has been found and in any case tower karst has previously been reported from other seasonally arid areas

Figure 7 Lithological transition on Donna Bluff, view across an enclosed hollow within a karst corridor-intersection. Extreme right (east) pinnacle karren developed on recrystallised limestone; centre more broken recrystallised limestone and left (west) limestone breccia giving rise to irregular residuals.

Figure 8 Serrated skyline developed by differential solution in interbedded chert and limestone.

of Australia (Jennings & Sweeting, 1963). The frequent association of tower karst with the humid tropics may itself be fortuitous and the characteristic alluviated plains may merely conceal former pediments. In the Chillagoe area of northern Queensland, the karst towers are residuals resulting from pediment extension. Their giant karren silhouettes are a function of lithology and are by no means ubiquitous.

CONCLUSIONS

The Chillagoe tower karst belt is developed on mid-Palaeozoic limestones that have been subjected to considerable alteration. The dominant characteristic of the striking landform assemblage is limestone residuals rising abruptly from pedimented plains. The residuals are the loci for karst development, karst corridors, dolines and giant karren on the surface and extensive, shallow phreatic caves underground. The overall landform assemblage appears to be a function of climatic controls, of an evolution under seasonally arid conditions subject to periodic flooding. In detail variation is closely controlled by lithological differences.

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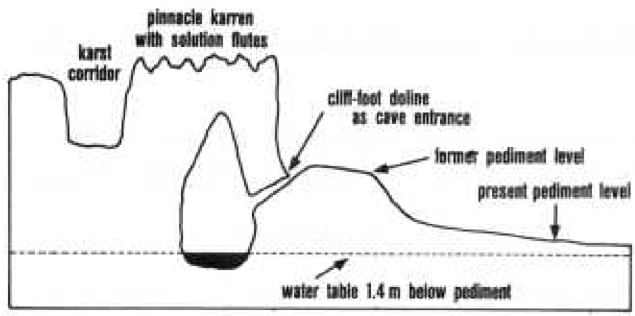

Figure 9 Cross section of Donna Bluff showing upper pediment level.

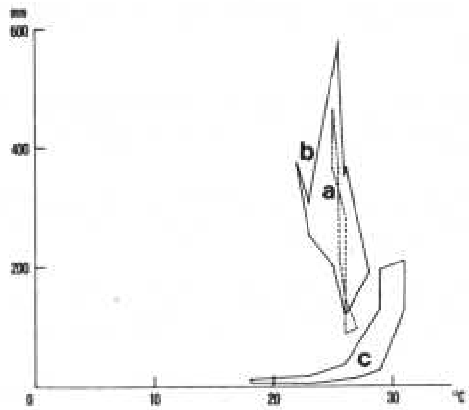

Figure 10 Climatic hythergraphs: Celebes (a) and Mexico (b) humid tropical tower karst regions contrasted with Queensland (c) [Chillagoe precipitation figures used in conjunction with Cloncurry temperature figures].

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LIST OF FIGURES

LIST OF TABLES

ABSTRACTS

HUMAN OCCUPATION OF DEVIL'S LAIR, WESTERN AUSTRALIA DURING THE PLEISTOCENE. By C.E. Dortch and D. Merrilees. Arch. & Phys. Anth. Oceania, 8, 1973:89-115.

Further excavations in Devil's Lair in 1972 were in materials similar to those reported before but with less rubble. Some 3 m were dated between 12,000 and 25,000 B.P., with more sediment below unexcavated. A hearth and two pits of unknown purpose demonstrated actual human occupation of the cave. More stone and bone implements were recovered. It is suggested that an older entrance became blocked in late Pleistocene or early Recent time which put a stop to human occupation. The present entrance is new and Aboriginal occupation was not renewed through it. An average rate of sediment accumulation of much less than 1 mm a year is thought to conceal short bursts of sedimentation, perhaps during heavy rainfalls, separated by long periods without accumulation. However the dates obtained do not give proof of this. - J. N. Jennings

A SALVAGE EXCAVATION IN DEVIL'S LAIR, WESTERN AUSTRALIA. By C.E. Dortch and D. Merrilees. J. Roy. Soc. W.Aust., 54, 1971:103-13

Devil's Lair opens from the same doline as Nannup Cave in the aeolian calcarenite of the southwest of Western Australia. In 1970 limited excavation yielded a column of 3.4 m of earth rubble and flowstone layers which accumulated in the early Recent and Late Pleistocene according to earlier dates of Lundelius. Each flowstone layer probably accumulated at a time when the rate of supply of other materials slowed down. In the upper 1.4 m, stone and bone tools, bones and teeth with apparently artificial incisions were found. There was also bone of a rich fauna, especially of small mammals, most frequent in the rubbly layers. No definite climatic implications can be drawn. In the top part, the bones probably represent remains of human food, though human occupation of the cave is not certain; in the lower part the bones are probably the remains of food of animals such as the Tasmanian devil, native cats or owls. - J. N. Jennings