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JOURNAL OF AUSTRALASIAN CAVE RESEARCH

Photo: E. A. LANE.

The Sydney Speleological Society's fifty-foot scaling pole being used to investigate a hole in the roof of the Grand Arch, Jenolan Caves, New South Wales.

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"H E L I C T I T E"

Journal of Australasian Cave Research

Edited by Edward A. Lane and Aola M. Richards

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CONTENTS

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A B S T R A C T S

COMMENTS ON "TRANSITION FROM MOUSTERIAN TO PERIGORDIAN" BY L. PRADEL. By A. Gallus. Current Anthropology, 7, 1966 : 39 - 40.

In his comments on Pradel's paper, Gallus gives the first radiocarbon dates to be obtained from his own excavations in Koonalda Cave, a large limestone cave on the South Australian portion of the Nullarbor Plain. The dates of 13,700 plus or minus 270 BP at a depth of one yard, and 18,200 plus or minus 550 BP at three yards have been determined by Kunihiko Kigoshi at Gakushuin University, Toyko. Gallus considers that as human artefacts are still turning up at depths of seven yards, the time depth of the sequence in the cave might be at least around the 30,000 mark. At a depth of one yard a rich industry has been found containing polyhedric burins; clumsy, backed, curved knives; a few large side-scrapers; points; small "laurel-leaf" bifaces and flake-blades. - A.M.R.

AUSTRALIAN INSTITUTE OF ABORIGINAL STUDIES NEWSLETTER, 2, 1966 : 23 - 24.

Records of dating of samples collected by Dr. A. Gallus from Koonalda Cave, Nullarbor Plain, South Australia, tested by Gakushuin University, Tokyo.

Gak. 510. 13,700 plus or minus 270 (12,750 BC). Wood charcoal scattered on floor b, trench III, assemblage five of implements provisionally called Koonalda B, a distinct industry.

Gak. 511. 18,200 plus or minus 500 (16,250 BC). Spot date of a large piece of charcoal on floor "three yards" deep in layer VI, in cave accumulation stone industry immediately over it marked with large choppers. Below sample extends downwards four yards. The Newsletter states that this is the oldest date recorded from a stratified deposit in Australia.

A W A R D S

Royal Geographical Society Medals and Awards for 1965

Her Majesty Queen Elizabeth approved the awarding of the Gill Memorial Medal to Dr. G.T. Warwick, of the University of Birmingham, for contributions to cave research. (Nature, 206, 4984, 1965 : 559).

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MURRAY CAVE, COOLEMAN PLAIN, NEW SOUTH WALES

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Abstract

Murray Cave is an almost horizontal former outflow cave, which is now on the brink of inactivity. A heavily decorated upper branch functioned during the first outflow phase and the present inactive entrance succeeded it as the outlet point. Both are at the level of a low aggradational terrace of the North Branch of Cave Creek outside the cave; this probably belongs to a Pleistocene cold period. An undecorated lower branch provided the third phase outlet, which still functions occasionally when water rises up a watertrap at the inner end of the main passage and flows along that passage into it. The entrance chamber has angular gravel fill due to frost shattering, which post-dates the development of the lower branch passage and belongs to a late Pleistocene cold period. Evidence of free surface stream action predominates in the cave but shallow phreatic conditions must have contributed to its development.

Introduction

Until the construction of the power line maintenance road from Brindabella to Rules Point and of the road past Tantangara Dam to the siphon at Pocket Saddle, Cooleman Plain* was one of the more inaccessible limestone areas in southern New South Wales. Nevertheless, some of its caves have been known a long time in terms of New South Wales history. Once the difficult terrain surrounding the Cumberland Plain had been penetrated and pressure on pastures had built up within that plain, squatters and their stockmen spread rapidly both westwards and southwards (Perry, 1963). The open grassy plains of even the highest parts of the Southern Tablelands proved no exception, since natural grasslands were most easily brought into use in the pioneering days. Dr. Andrew Gibson of Goulburn ran stock on Cooleman Plain in the late 1830's and Sir Terence Aubrey Murray, who had previously been granted land at Collector, established a station there in 1839 (Mrs. J.Q. Ewens, personal communication). The cave, which bears his name, was well known to him in 1851 (Clarke, 1860) and it is most likely that he discovered it in 1839. The renown which various scions of the Murray family achieved gives a special distinction to this cave name, for Australian cave designations usually lack significant historical association.

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* The original spelling was Coolalamine, but the official spelling for the plain is now Cooleman and for the homestead on it is Coolamine.

Unfortunately, Murray Cave's greatest claim to fame, or rather to notoriety, is that it is one of the earliest of Australian caves to have been despoiled of natural decorations. Stalactites and stalagmites were brought down by drayload from Cooleman Plain to ornament the gardens of Queanbeyan. Murray Cave yielded most of these trophies; stubs of stalactites and stalagmites in their hundreds along the main passage of this cave tell the tale. The "brilliant stalactites" described by Clarke (1860) have disappeared and only some of the bluntest of stalagmites too bulky to be removed indicate the quality of what has gone. Leigh and Etheridge's description in 1893 bears witness that the destruction had been accomplished before then. Despite this damage, there is sufficient of interest in the cave's geomorphology to warrant visits by speleologists and an account of it here.

Cooleman Plain (Figure 1)

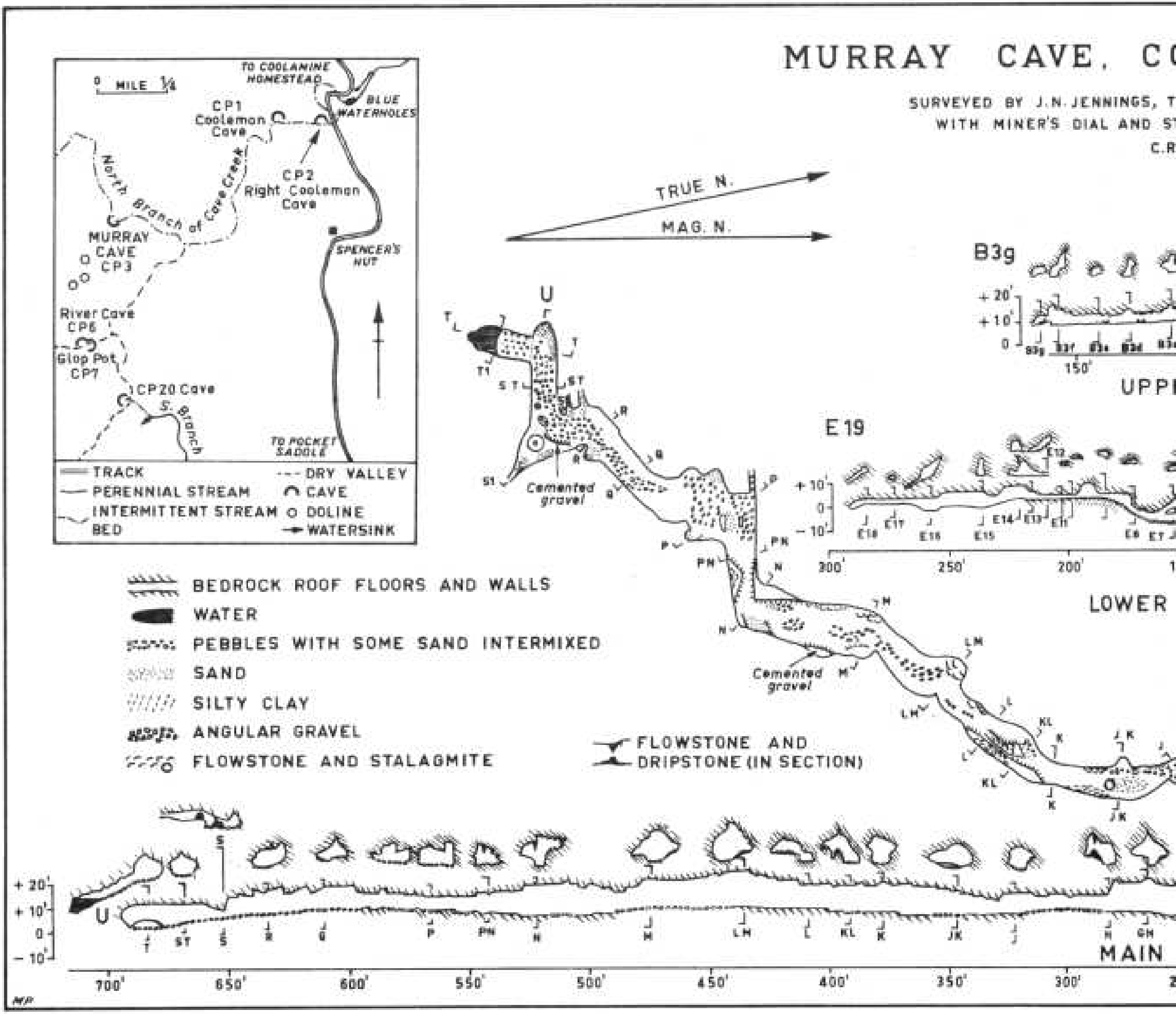
Surrounded by igneous rock ranges rising to over 5,000 ft, Cooleman Plain lies at 4,100-4,200 ft and is mainly underlain by Cooleman Limestone of Silurian age. From the big springs of the Blue Waterholes on the eastern margin of the Plain, Cave Creek runs perennially through Clarke and Wilkinson Gorges to join the Goodradigbee River some 400 ft lower down. The North Branch of Cave Creek occasionally flows all the way down to the Blue Waterholes, but normally its bed is dry over at least two miles above the springs. The South Branch usually sinks at grid reference 693979 (Army 1/50,000 Sheet 8626-IV Currango) about three-quarters of a mile above the junction of its valley with that of the North Branch and the stream rarely, if ever, flows over most of this lower part of its valley, though in infrequent flood it runs a further two hundred yards into a small cave (CP20) at 692980. Murray Cave (CP3) opens at an elevation of about 4,000 ft in the southern wall of the North Branch gorge at 691992 about one-quarter of a mile above the junction of the North and South Branch valleys.

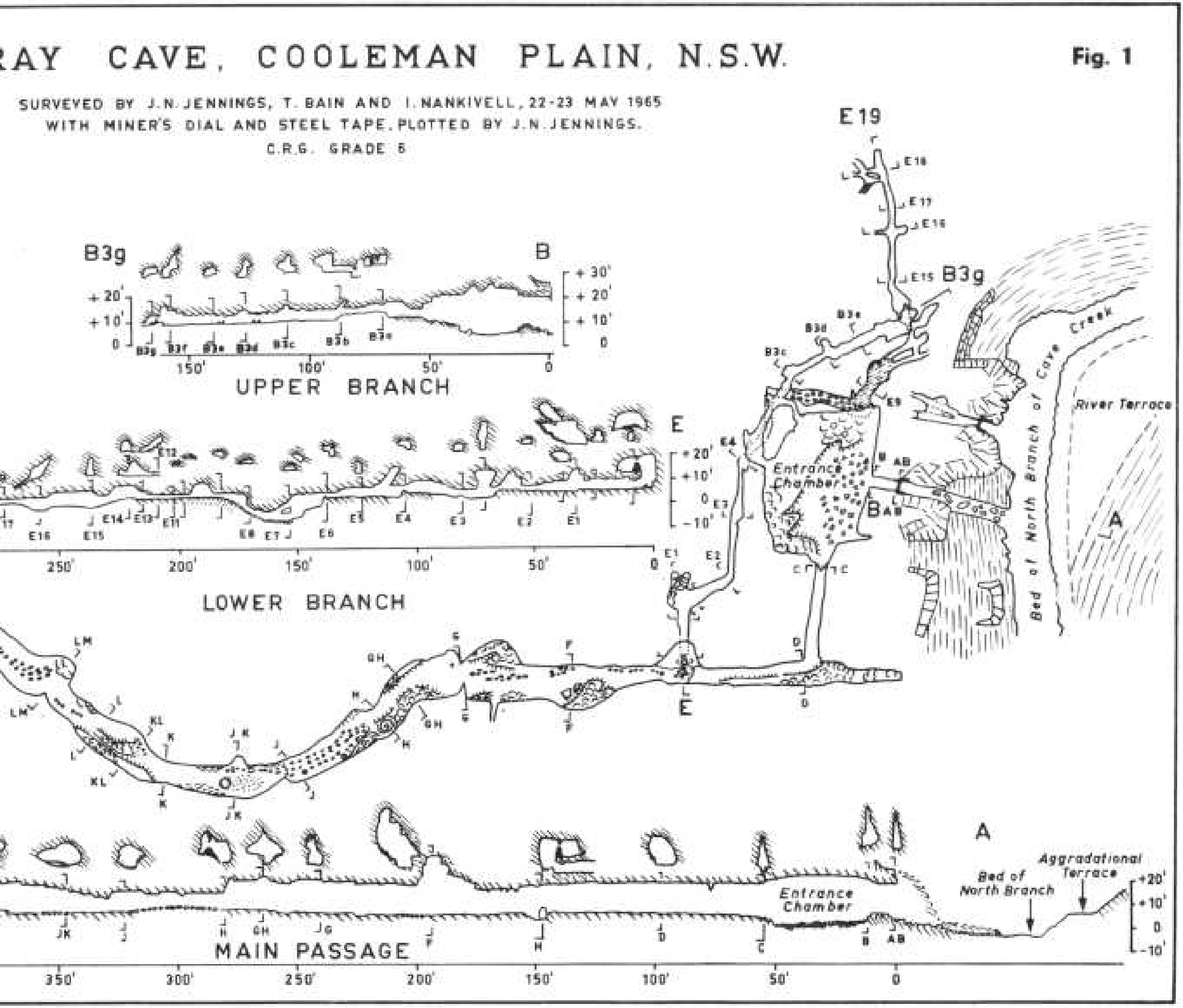
The Cave (Figure 1)

Murray Cave is a horizontally developed system, with a roomy main passage about 700 ft long and with two more confined branches which together add a further 400 ft to the length.

A shallow, unused channel in the bedrock rises a few feet from the North Branch river bed to the cave's fissure entrance, which leads almost immediately into a square-cut chamber. In the upper part of this channel there are cylindrical holes, up to 1 ft diameter and 1.5 ft deep, which are regarded as rock mills (i.e. fluvial "potholes", but see glossary in Cullingford, 1953) partly modified by standing water after the channel ceased to be used by the outflow stream from the cave.

The front part of the entrance chamber lies below the threshold of the entrance fissure and is floored with angular gravel, chiefly of pebble size (the "road metal chips" of Leigh and Etheridge (1893), who did not discuss


MURRAY CAVE, CO
SURVEYED BY J.N. JENNINGS, T
WITH MINER'S DIAL AND ST
C.R
TO COOLAMINE HOMESTEAD
0 MILE 1/4
CP1 Coolemon Cave
BLUE WATERHOLES
CP2 Right Coolemon Cave
North Branch of Cave Creek
MURRAY CAVE CP3
SPENCER'S HUT
River Cave CP6
Glop Pot CP7
CP20 Cave
S. Branch
TO POCKET SADDLE
TRACK
PERENNIAL STREAM
INTERMITTENT STREAM BED
DRY VALLEY
CAVE
DOLINE
WATERSINK
TRUE N.
MAG. N.
B3g
UPP
E19
LOWER
BEDROCK ROOF FLOORS AND WALLS
WATER
PEBBLES WITH SOME SAND INTERMIXED
SAND
SILTY CLAY
ANGULAR GRAVEL
FLOWSTONE AND STALAGMITE
FLOWSTONE AND DRIPSTONE (IN SECTION)
Cemented gravel
Cemented gravel
MAIN
700' 650' 600' 550' 500' 450' 400' 350' 300'
300' 250' 200'
150'


RAY CAVE, COOLEMAN PLAIN, N.S.W.
Fig. 1
SURVEYED BY J.N. JENNINGS, T. BAIN AND I. NANKIVELL, 22-23 MAY 1965
WITH MINER'S DIAL AND STEEL TAPE. PLOTTED BY J.N. JENNINGS.
C.R.G. GRADE 6
UPPER BRANCH
LOWER BRANCH
MAIN PASSAGE
Entrance Chamber
River Terrace
Bed of North Branch of Cave Creek
Bed of North Branch
Aggradational Terrace

their origin, however). It is the only part of the cave so floored. The roof above has an angular, fractured form. Together, these facts are interpreted as the effects of frost shattering on the chamber. Although the writer has recorded air temperatures as low as 8°F as night minima at the Blue Waterholes and frost liability lasts through much of the year, it is thought that these frost shattering effects do not relate to present conditions but are relict.

The inner part of this chamber consists of a bedrock bench, inclined northwards down dip and partly covered by flowstone and stalagmites. Two passages - the main passage and the upper branch - join the chamber at the level of this bench.

Leading eastwards from the chamber, the main passage is straight, tall (12-14 ft) for its width (4-6 ft), with a very level bedrock floor, which is due to former stream action but shows some effects of corrosion by standing water supplied by roof drips. Where it descends to the chamber floor, however, there are some cylindrical pits like those in the entrance fissure. On the walls there are good current markings ("scallops"), which indicate former flow towards the entrance. Beyond a T-junction, the main passage maintains much the same character to begin with, but the dead end running northwards is choked with flowstone and dripstone.

The main passage changes character inward of its junction with the lower branch, where there is a small step down in the floor. It becomes both wider on the average and more variable in width, between 10 and 25 ft. The variability in width is partly due to former stream meandering, but width is also affected by vertical resistant veins and recessive joints. It is also more variable in height; maximum height in cross-section is usually between 10 and 15 ft, but ranges between 5 and 25 ft. Bedrock benches occur at a number of points along the sides of the main passage but not in the final 200 ft. Much of the former rich calcite ornamentation of the cave was located on these benches. There are active drips now and fresh deposition is taking place on the fractured stubs.

The floor rises gently with irregularities to a point about 100 ft short of the inner end of the main passage. Bedrock is exposed over much of the floor but there is an increasing proportion of the floor covered by loose sediments inwards from the lower branch junction. The floor bedrock is irregular in detail, mainly due to corrosion by drips as well as by stream flow, but also due to corrasion by pebbles. Short gullies a foot or two wide and deep run inwards from small steps in the floor and are due to headward erosion. Well rounded* gravel appears beyond the junction, at first as scattered pebbles and meagre trails, farther in as more general and thicker spreads. There is also a progressive increase in finer fractions inwards. The gravel includes an increasing proportion of sand, then patches of coarse sand

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* See Appendix.

on its own appear. Finally, near the inner end, where the floor begins to descend, patches and coatings of silty clay are found. There are also patches of well cemented gravel left as terrace remnants up to 1.5 ft thick. Some stalagmites and flowstone have accumulated on both sands and gravels.

At the far end of the main passage, a low passage descends steeply into standing water. It is partly gravel filled, but the roof and sidewalls suggest that it has an elliptical form. A small porthole at the back is partly exposed at times of low water, but beyond this are water-filled fissures not penetrated in recent years. There is an oral tradition, however, that in the great drought at the turn of the century members of the Southwell family, who at that time lived at Coolamine Homestead, found this watertrap dry and were able to follow the cave farther back.

The lower branch leading west from the main passage is much smaller than it, being mainly 2-4 ft wide and 2-5 ft high, though there are irregular enlargements. It descends overall from the junction and the lowest points are at the far end where standing water is found in steeply descending, tight tubes. There is also an almost equally low U-loop about halfway along this lower branch, in which water stands on occasions as well. Gravel and sand are found as far as this U-loop, but beyond silty clay floors occur. Clay coatings of roof and walls are found along most of the passage, but secondary calcite deposition is slight. The U-loop lies very close to a short, rising cave passage running into the cliff from the river bed outside but lying above the branch passage.

The upper branch passage leads from the entrance chamber and it also descends gently overall inwards, though it lies above the other branch. The passage, for the most part 2-4 ft wide and high, is largely floored and walled by dripstone and flowstone, which are mainly dry. This branch terminates close to a recess in the valley wall outside and at a level above that of the river. There may have been formerly an opening to the surface here, now concealed beneath rockfall and soil.

Joints influence the plan of the cave quite markedly. Straight W-E sections occur at the beginning and at the inner end of the main passage, and along the lower branch passage. Joints of this trend also influence the form of the entrance chamber. A long section of the main passage follows a N-S joint, but SSW-NNE lineaments are more frequent.

In the front part of the cave, the beds dip at 15-25° in a northerly direction, whereas to the rear the direction of dip has swung round to the north-east and the dip is 20-30°. The overall direction of the main passage changes in broad sympathy with this change in direction of dip but it is by no means sure that there is any causal connection between the two.

The entrance fissure, the upper parts of the entrance chamber, the upper branch passage, and the beginning of the main passage are developed in massive, pure grey limestone. The remainder of the cave is excavated in underlying limestones which are much thinner-bedded and include darker laminae of lesser purity. These laminae project to form irregular ribs on walls and ceilings. These are simply effects of differential solution of structural origin and must not be confused with spongework due to deep phreatic solution. The absence of current markings along most of the main passage is probably due to the nature of the rocks.

Hardness determinations of water in the watertrap have been made on six occasions, well distributed seasonally between 1957 and 1963. The temperature varied between 10 and 11.3°C and the pH between 7.3 and 8.2. Calcium carbonate content varied between 75 and 146 mg/l, magnesium content between 6 and 13 mg/l. On the basis of Trombe's graphs, the water was aggressive on all occasions except one. On the latter occasion, which followed a long, dry spell, it reached saturation equilibrium.

On one occasion only, in midsummer, air temperature by the watertrap was recorded; it was at 11°C with a relative humidity of 100 percent.

Discussion

The most interesting aspect of Murray Cave is that it is a former outflow cave approaching the point of complete inactivity. The upper branch passage, the entrance chamber and the main passage forward of the junction with the lower branch passage are now inactive in respect of stream flow. On the other hand, water occasionally rises up the watertrap and flows down the main passage and then along the lower branch passage (cf. Leigh and Etheridge, 1893). The cave functions so infrequently in this way that not many speleologists have had the opportunity of seeing it in operation. On the other hand, evidence that it has been in action is available in the smooth surfaces of the sand patches, which are reworked in these active spasms and receive the trampling of feet in the intervening, much longer periods of inactivity. Occasional flushing through the watertrap is also witnessed by the general state of aggressivity of its water. If it were not renewed periodically, it would be saturated or supersaturated all the time.

There is evidence in the shape of the mud coatings of walls and low roofs that the inward part of the lower branch fills up more or less completely with water on these occasions of overflow from the watertrap along the main passage. The higher parts along here are just above the level of the river bed outside and water most probably escapes to it through small openings not penetrable by cavers. When the level in the lower branch falls below river bed level, there is slow escape to an unknown underground system, probably crudely paralleling the surface valley and heading for the Blue Waterholes.

The source of the Murray Cave water is also a matter of inference only as yet. Indeed the possibility of being able to time a water-tracing test to coincide with a spasm of overflow into Murray Cave is not great. Actual exploration or geophysical testing is the more likely approach for resolution of this question. Murray Cave projects south beneath the broad flat interfluve between the North Branch gorge and the next valley southwards, a dry valley tributary to the South Branch valley. Three dolines, unusually large for Cooleman Plain and distinctively placed in the middle of this interfluve, appear to continue the line of Murray Cave further south to within 200-300 yards of the bottom end of River Cave (CP6), which is entered from the dry valley referred to. The origin of the big river in River Cave is also not known certainly but on the grounds of its comparable size to the South Branch and of proximity to its watersink, it is generally thought to be the continuation underground of the South Branch. It is probable then that Murray Cave represents a former outflow for South Branch water into the North Branch valley.

The history of Murray Cave may now be reconstructed. The upper branch passage belongs to the earliest phase of the development of the cave, though excavation remains necessary to determine whether it ever had a penetrable opening out to the valley side. The rock benches along the main passage are probably remnant from the cave floor of this first stage and the longitudinal profile at this time must have had a gentle downward gradient outwards, except for a gently rising portion from the top of the watertrap tube. This gentle rise reached about 100 ft further along the cave than at present. Even along the downward profile, the cave may have been filled with water, at least intermittently, so that shallow phreatic (or epiphreatic) solution may have been in action in this section as well. There is little direct evidence in surviving cave forms to support this contention, however.

A second phase involved the replacement of the upper branch passage as the cave outlet by the present entrance fissure and the cutting down of the main passage by as much as 5 ft. Free surface vadose flow is implied except in the vicinity of the watertrap and the upper passage ceased to function, except perhaps as an occasional flood overflow. Secondary calcite ornamentation would begin here and also on the benches and roof of the main passage. The bench at the back of the entrance chamber indicates that this chamber had been roughed out by this time.

The level of the threshold in the entrance fissure matches that of the top of a river terrace on the opposite side of the North Branch valley. The entrance fissure outlet represents a short cut to the river rather than a lowering of the outlet level from that of the upper branch passage so that the latter also seems to be adjusted to the terrace surface. This terrace surface lies about 5 ft above banktop of the present river bed, which itself varies between 2 and 4 ft in depth. Thus both the first and second phases probably relate to the time when the North Branch was flowing at the flood plain level represented now by the terrace top. As the terrace is aggradational at least in part, there must have been incision of the river prior to the terrace formation.

A third phase of cave development, accompanying fresh incision which completed the formation of the terrace in the valley, saw the substitution of the entrance fissure outlet by the lower branch passage, and the gullying to a depth of 2-3 ft of parts of the floor of the main passage inward of the junction with the lower branch. When the lower branch came into use, it would have been frequently, if not permanently, water-filled along much of its length, as it is today infrequently. The outflow during this phase was to the present river bed level.

This inferred evolution does not explain why the front part of the entrance chamber lies below the threshold of the entrance fissure. A possible explanation is that there was a phase of flow from the entrance chamber directly into the distal part of the lower branch passage and that in this phase part of the entrance chamber floor was lowered as a consequence. It is to be noted in this connection that the flowstone floor in the north-west corner of this chamber rings hollow and voice connection with people in the lower branch, which lies below, is easily established. Such a phase, if it occurred, interposed between the second and third phases.

Subsequently to the whole of the lower branch passage becoming the outlet of the cave, there has been a phase of sapping by frost shattering of the roof of the entrance chamber partially to fill the lower part of its floor with chips of rock.

The final phase of the cave history has been one of declining use of the cave by the underground artery, which previously fed it as part of normal flow. In this phase flowstone and stalagmite construction extended over more of the floor of the main passage. The consolidation of the cemented gravels and their lateral erosion may well have taken place now, though one or both of these processes could also belong to the previous phase when the entrance fissure was the outlet.

A full discussion of the age of the cave would involve consideration of the geomorphological history of the Plain as a whole. Suffice it to say this here. The frost shattering of the entrance chamber probably belongs to a Pleistocene cold period, when periglacial solifluction was common on Cooleman Plain and when glaciers formed in the Snowy Mountains. So only the final phase of the cave history, that of partial abandonment as an outlet, belongs to the Holocene. Aggradation in various valleys on Cooleman Plain seems to be of periglacial - fluvial nature so the probable association of the early phases of the cave with the aggradational terrace in the North Branch valley suggests that the beginnings of the cave may also belong to the Pleistocene.

Appendix

Morphoscopy of the Murray Cave Gravels

The gravels in the main passage were described above as well rounded and it is known that they must have come up the watertrap under hydrostatic pressure. Other inverted siphons are known in River Cave so that these gravels may have suffered much pressure passage flow. Siffre (1959) has described a case where pebbles, which have undergone such treatment, acquired special shape characteristics. These consist of very high flatness and smoothness values as measured by A. Cailleux's indices:

$$\text{Flatness} = \frac{L + l}{2e} \qquad \text{Smoothness} = \frac{2000R}{L}$$

where L is the greatest dimension in the principal plane, l is the maximum width at right angles to L in the same plane, e is the greatest thickness at right angles to the principal plane, and R is the greatest radius of curvature of the surface of the pebble.

Siffre used very small limestone pebbles, which cannot be matched in Murray Cave. Instead a sample of 171 pebbles of fine grained igneous rock, ranging between 4.2 and 10.5 cm in L, and with a median value of 6.8, was employed.

A median value of 2.7 for flatness was obtained, the lower quartile being 2.0 and the upper 3.6 (Figure 2a). For smoothness the median was 222, with a lower quartile of 140 and an upper of 295 (Figure 2b).

Both flatness and smoothness are much less than in Siffre's case. Even if the difference and size and composition of the two samples is allowed for by referring to samples of comparable size and rock type to the Murray Cave lot from Cailleux (1961) and Tricart and Schaeffer (1950), these shape characteristics are far from exceptional in comparison with surface fluviatile gravels. The smoothness value is such as is usually achieved after two to three miles of travel in rivers and the distance involved here is probably comparable. The flatness value is rather large for river gravels and similar to those given for beach gravels. Pressure passage flow is very different from wave action so it is unlikely that similar hydrodynamic conditions explain this. In addition, Siffre's explanation for the flatness of his pebbles, namely plate-like detachment from the bedrock in constrictions in pressure passages due to implosion effects, cannot apply to these allogenic gravels in Murray Cave. However, the shape of weathering blocks of igneous rocks on the plain is very compact and the flatness of the cave gravels does not seem to be due to inherent characteristics of the rock either. The flatness value thus remains difficult to explain.

Acknowledgments

I thank Messrs. T. Bain and I. Nankivell of the Canberra Speleological Society for their help with the survey of Murray Cave. I am also indebted to Mrs. J.Q. Ewens, who is writing a biography of Sir T.A. Murray and has contributed the biographical note on him to the Australian Dictionary of Biography, Volume 2 (in press), for help with the historical background.

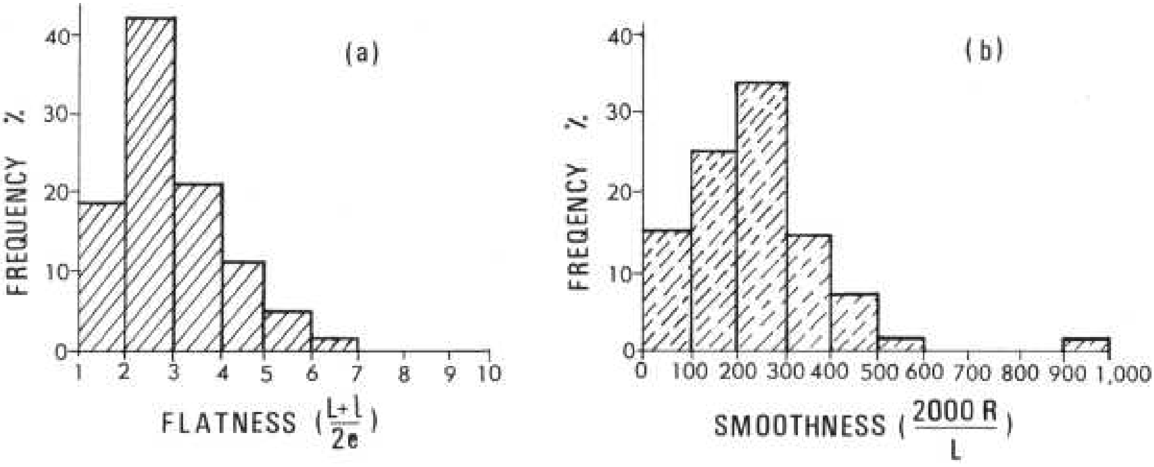

Figure 2. Histograms of Cailleux's indices of flatness and smoothness for a sample of 171 pebbles from Murray Cave, Cooleman Plain, N.S.W.

References

CAILLEUX, A. 1961 : Application à la géographie des méthodes d'étude des sables et des galets. Rio de Janeiro.

CLARKE, W.B. 1860 : Researches in the Southern Goldfields of New South Wales. Sydney.

CULLINGFORD, C.H.D. (ed.) 1953 : British Caving. London.

LEIGH, W.S., ETHERIDGE, R. jun. 1894 : Report on the Caves in Cooleman Creek, Cooleman Plains. Dept. Mines N.S.W. Ann. Rept. for 1893 : 134.

PERRY, T.M. 1963 : Australia's First Frontier. Melbourne.

SIFFRE, M. 1959 : Alluvions souterraines. Stalactite, 4 : 1 - 7.

TRICART, J., SCHAEFFER, R. 1950 : L'indice d'émoussé des galets. Rev. Géom. Dyn., 1 : 151 - 179.

TROMBE, F. 1952 : Traité de Spéléologie. Paris.

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SPELEOCHRONOLOGY

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Introduction

Speleochronology is the study of the age of caves and their contents. At the present time the International Commission for Speleochronology is collecting data, and as the Australian representative on the Commission, the author would like to hear from anyone with any information that may be relevant to speleochronology in Australia or in neighbouring countries. This paper shows some of the aims and methods of the subject and indicates the type of information that may be useful.

Caves usually take a very long time to develop and many are still actively growing. Unless otherwise stated here the age of a cave means the age of its origin. In dry, dead caves it may also be possible to determine the time at which development ceased. Caves formed over a long period of time can have parts of different ages. Even within one active passage, the upper part may now be dry while the lower part is still enlarging by solution. So, in one sense, the lower part of the passage is younger than the upper.

Underground streams may change route along fissures, and the younger passage will normally be lower than the older. A cave may also extend headwards by progressive engulfment of a drainage system, in which case the more headward caves are younger than the downstream parts. On the other hand, there may be abandonment of caves in the lower reaches of a system at the same time as headward extension, so caves of different age occur in all parts of the system. This is shown in Figure 1. Analysis of such caves has been attempted for G.B. Cave in the Mendips, England (Ford, 1964), and for Punchbowl Cave, New South Wales (Jennings, 1964).

Events may be dated either absolutely or relatively. The most accurate dates depend on radioisotope analysis and are stated in years. We can also give more approximate dates such as "pre-glacial", "Lower Pleistocene", and so on, which do not have the exactitude of isotope dates but give some limits to possible absolute age. Relative dating merely places events in a sequence relative to each other, but when sufficient events are utilised quite elaborate sequences can be elucidated.

Speleochronology endeavours to determine the sequence of events in the history of individual caves, with as many actual dates as possible. When

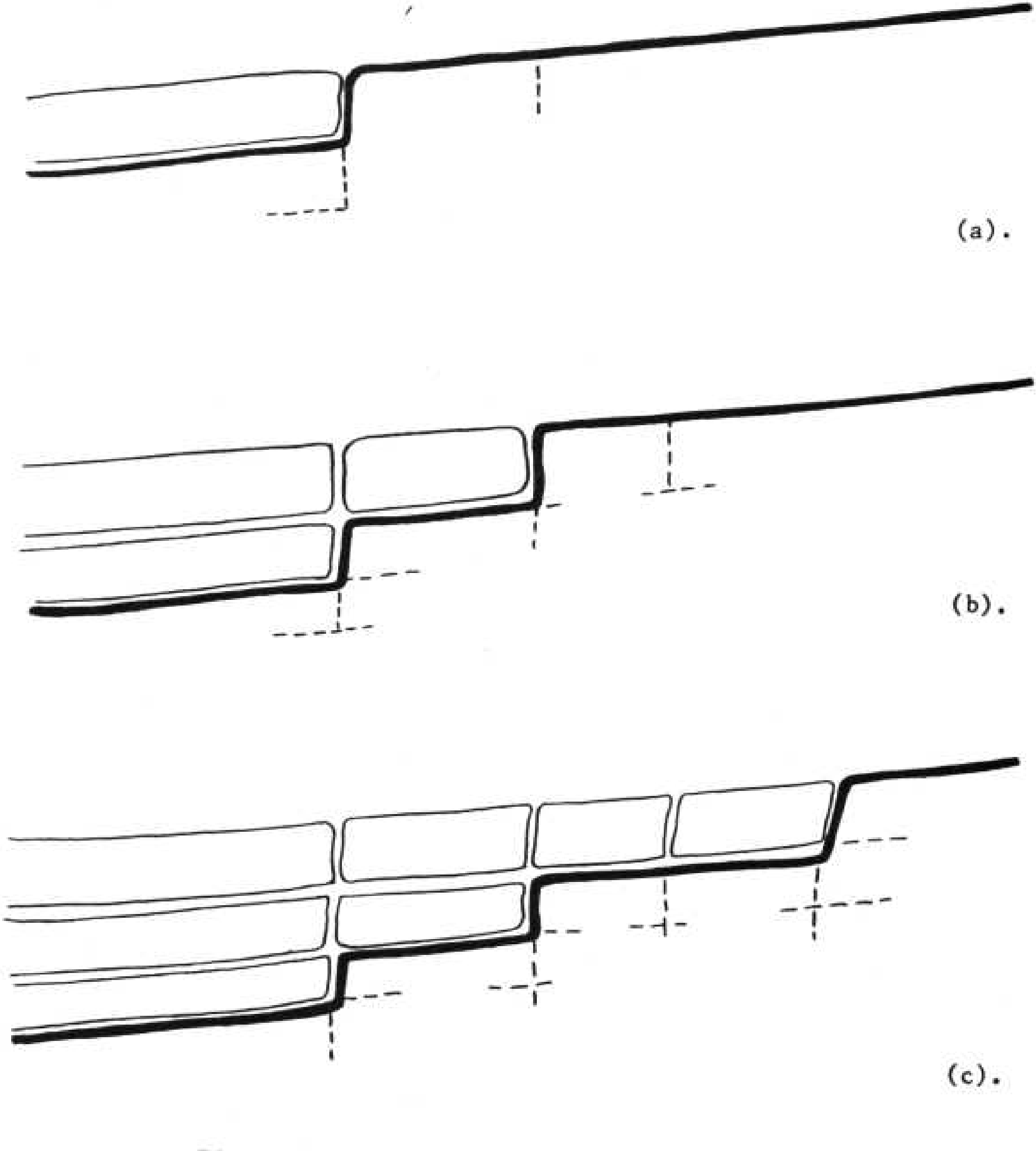

Figure 1: Development of a diachronic cave system.

sufficient caves have been studied correlation becomes possible and more general conclusions may be drawn.

Age of Enclosing Rock

A cave is obviously not older than the rock that encloses it, and if the age of the rock is known, this serves as a maximum possible age for the cave. Thus McEchern Cave, Victoria, is in Oligocene limestone and is therefore not older than Oligocene; the cave in Kelly Hill, Kangaroo Island, South Australia, is in Pleistocene limestone, and is not older than Pleistocene. The weakness of this method is that many caves are in very old limestone, and the maximum date is so far from the probable real age that it is almost useless. The fact that Buchan Caves, Victoria, are in Middle Devonian limestone (360-370 million years), is of little value in dating them though in cave accounts the age of the enclosing rock should always be given.

The method is sometimes useful in non-limestone caves. For example, the Mount Eccles volcanics, Victoria, are about 6,000 years old, and the Eccles caves are therefore this age too. This is a speleochronological result of some precision. With a little less precision it can be stated that the nearby Byaduk lava caves are older because the lava flow is older, but an actual date cannot be given. By throwing away any semblance of precision, the best informed guess at present is that the Victorian lava caves were formed in the following order (Table 1):

TABLE I

Age of Victorian Lava Caves

Cave	Age
Eccles	c. 6,000 years old
Byaduk	
Mt. Hamilton	
Porndon	
Panmure	
Skipton	
Parwan	over 1,000,000 years old

Age of Cave Contents

The age of a cave must be greater than that of its contents. Cave fill may be any age from the initial opening of the cave to the present day, and the oldest date from cave fill gives the most reliable minimum possible age for the cave.

(a) Human. Human artefacts in the form of stone tools, hearths and cave paintings give clues to cave age. Such artefacts have long been known in

Europe, but in recent years significant discoveries have been made in Australia, for example, in the Nullarbor area and in the Kenniff Cave of Queensland (Mulvaney and Joyce, 1965). Australian aboriginal remains go back at least 16,000 years (Mulvaney, 1966). Gallus (1966) has reported a radiocarbon (C 14) date of 18,200 + or - 550 years from Koonalda Cave in the Nullarbor which is probably associated with aborigines. Older dates can be expected from here. Overseas, human remains have a much greater range. Neanderthal man ranged from about 150,000 to 30,000 years ago. Australopithecus africanus, found in limestone caves near Taungs in Bechuanaland may be two million years old (Moore, G.W., and Nicholas, 1964).

(b) Animal. Fossil animal finds may help to date caves, especially if they are remains of extinct animals, or of creatures that no longer live in the area. An Australian example is provided by Mt. Hamilton lava cave, Victoria, where remains of 26 species were found, of which three are prehistoric, two are known as modern animals in Tasmania, and ten are no longer present in Victoria. Two species possibly date from an arid period 4,000 to 6,000 years ago, and three others became extinct about the end of the Pleistocene (Wakefield, 1963). The lava cave has therefore been open to the surface since this period, though it may have been in existence for much longer. In European caves there are records of many animals such as lions, bears and elephants which have long since left the area.

In the Mendips, England, some small caves have been found to contain Triassic fossils (190 to 220 million years old) (Green and Welch, 1965). These show that some caves were in existence in the Mendips even then, but do not indicate the age of the present, large, active caves.

(c) Botanical. Barrett (1963) provided microfloral evidence to show that infilling of passages in Kairimu Cave (S.W. Auckland, New Zealand) occurred during a time of high sea level in Upper Pliocene or Lower Pleistocene times, and he suggested that the oldest passages originated in the Upper Miocene.

(d) Sediments and Stratigraphy. Layers of sediments may be deposited in caves. The study of these sediments can give clues to chronology. The basic principle of stratigraphy - the study of strata - is the law of superposition, which simply means that the lower layers are older than those above (neglecting such complications as burrowing animals). Thus, if two types of stone knives are found in several layers, the lowest layer contains the oldest implements. Any one cave is likely to have only a fragmentary record of changes through time, but from many studies a succession of faunas or cultures may be built up. When this has been achieved and proved reliable, the discovery of unstratified tools or fossils may be used for dating by correlation with the known sequence elsewhere. Archaeological correlation is well established in the Northern Hemisphere. In Australia, Mulvaney has possibly started such work by his distinction between hafted and non-hafted tools at Kenniff Cave (Mulvaney and Joyce, 1965).

Even barren sediments with no tools or fossils may give clues to chronology if studied by appropriate techniques. In different environments, different kinds of sediments are deposited, and sedimentologists strive to work out past conditions from the sedimentary record. It may be, for instance, that a cave accumulates clay in moist periods, but in an arid period receives wind-blown sand. A layer of sand in the strata may be taken as evidence of an arid period. (This is, of course, only an example. Not every layer of sand indicates an arid period.) On the other hand, a cave may be dry in an arid period and produce layers of calcite dust, while hard layers of flowstone may be deposited in a moist period. Quite commonly in limestone caves, the stratified fill is spaced by flowstone bands which possibly have some such significance. King (1951) has described a sequence of red wind-blown sand with Australopithecus followed by a dripstone period and then more red sand with a Middle Stone Age assemblage. He correlates deposits from caves in various parts of southern Africa with this sequence. Stratigraphic methods thus enable the construction of a relative time scale on which cave formation and fill may be recorded.

In caves close to present or past glaciation there may be glacial or periglacial deposits in the cave, especially near the entrance, in which case the cave may be tied to the local glacial chronology. In many of these studies it is apparent that the cave study is partly relying on, and partly contributing to, studies of past climate.

For absolute dating there are a number of methods based on radioisotope analysis. Radiocarbon dating (referred to earlier) enables absolute dating of material as far back as 50,000. The method can be applied to charcoal, bone or even to the carbonate of stalactites.

Amount of flowstone may give a rough indication of cave age, for bigger stalactites take longer to grow than small ones. The rate of growth cannot be stated accurately, but rough estimates may be made. The use of isotopes can help here, but assumptions have to be made about the derivation of the carbon, i.e. whether it comes from atmospheric carbon dioxide or from ancient carbonate in the limestone. Radiocarbon analyses of stalagmite material from a cave in California enabled Broeckner *et al*. to work out its rate of growth - 3.5 in. in 1,400 years (Broeckner, Olson and Orr, 1960). Other natural radioactive decay systems, such as potassium-argon, eventually may prove useful in speleochronology.

Rate of Solution

Another possible approach to cave dating is through the rate of solution of limestone. Drainage waters are analysed to determine their calcium content, and if a reasonable average figure can be obtained, and the total run-off from a region can be determined, then the amount of calcium lost can be calculated. This in turn could be expressed as degree of lowering per thousand years, or some such figure. Sweeting (1966) has calculated that in limestone areas of northern England there is a total lowering of 0.083 mm per year, and 0.043 mm per year lowering by solution underground. Such rates of lowering are sufficient to form caves in post-glacial times. In some areas the chemical evidence has been used to support other evidence for the post-glacial origin, as in County Clare, Ireland (Ollier and Tratman, 1956), and Norway (Renwick, 1962).

Cave Biology

Animals that live in caves may have special adaptions to suit them to their environment. The time scale for biological evolution may, in some cases, be comparable with the scale of cave age. One of the best-known examples of a cavernicolous animal is the glow worm, *Arachnocampa luminosa* (Skuse), of Waitomo Caves, New Zealand, described in detail by Richards (1960, 1964).

Cave dwelling animals tend to become blind, like the eyeless fish, shrimps and eels of the caves of North West Cape, Western Australia (Richards, 1963). The only known troglobic beetle in Australia, the Tasmanian *Idacarabus* (Moore, B.P., 1964), has very reduced eyes and vestigal wings. Moore considers that distributions of troglobic beetles in New Zealand and Tasmania suggested a linkage with the Pleistocene glaciations.

In the northern hemisphere troglobic animals seem more prolific and have been studied in considerable detail, enabling construction of reliable distribution maps (e.g. Vandel, 1963). Troglobites appear to be restricted to temperate regions, and their distribution controlled by glaciation and climatic change during the Quaternary. It also seems that the present troglobic faunae comprise groups of differing degrees of antiquity, whose ancestors entered caves in different epochs (Moore, B.P., 1964). All living troglobites appear to be descended from species that originated before the last Ice Age (about 70,000 years), and very few live in caves that were covered by ice.

It can happen that caves are continually formed and destroyed through a long period of time in the same area, and a blind fish, for example, may now occupy a modern cave though its ancestors evolved in a long-destroyed cave system. For example, the troglobic animals of North West Cape, Western Australia, live in caves in a coastal platform not more than 5,000 years old. It is inconceivable that the animals could have evolved their present morphology in such a short period, and Mees (1962) has suggested that the fauna developed in late Tertiary or Pleistocene times in the Cape Range caves, and colonised the caves of the platform in Recent time.

Geomorphic Methods

From an examination of the shape and erosional features of caves, geomorphologists try to work out how they were formed, and also when. Some caves are formed under phreatic conditions, that is below the watertable in saturated rock, and, if the caves are now above the watertable, a study of why and when the watertable fell may indicate something about cave age. Other caves appear to be formed above the watertable (vadose conditions), or at, or just below the watertable (epiphreatic conditions). Caves forming along the watertable will have extensive near-horizontal development of cave levels.

Watertable level is controlled by rivers, and as a river cuts down, the watertable falls. In some caves it is possible to correlate cave levels with the levels of terraces cut by rivers on the surface which controlled the water level in the caves. In Punchbowl and Signature Caves, Wee Jasper, N.S.W., Jennings (1964) reported four periods of epiphreatic flow separated by three periods of vertical incision with intervals of 45-50 ft, 20-25 ft and 10-20 ft. The evolution of the system was controlled by downcutting of Wee Jasper Creek, and it is likely that some cave levels are related to the valley bench remnants above the Goodradigbee River, although no close correlation seems possible.

Buchan Caves, Victoria, also have a marked relationship to river terraces (Sweeting, 1960) and it seems likely that they have originated during a period of rapid erosion and are of relatively recent age. In the Ingleborough area of England, Sweeting (1950) found caves related to much older erosion surfaces, going back to Tertiary times (several million years).

Occasionally more complex geomorphic methods may be used to work out ages of caves, as in the following examples. Paviland Cave, South Wales, opens onto a raised beach (Sollas, 1931). The lower part of the cave fill is marine shingle, overlain by terrestrial deposits. In this area the raised beaches, and therefore also the cave, can be related to sea level changes during the Pleistocene.

In County Clare, Ireland, some active caves have the form of long stream passages, which follow closely the lines of dry valleys on the ground surface. The obvious conclusion is drawn that the caves are made by the stream that once flowed in the valley going underground, so the caves are younger than the valleys. The area is covered by glacial drift which the dry valleys cut through, so the valleys are younger than the drift, which is thought to be about 20,000 years old. The caves are younger than the drift, so it is concluded that the caves are not more than 20,000 years old, and some may be considerably younger (Ollier and Tratman, 1956).

In New Mexico, the area of the Carlsbad Caves was uplifted in Late Pliocene or Early Pleistocene times. Before uplift, thick layers of overlying formations extended across the area of the caverns. Only after uplift and denudation was extensive cave development possible (Moore, G.W., 1960). In the Mt. Hoyo caves of the Congo, it was found that the caves have all the signs of phreatic formation, but they occur on a steep fault escarpment where phreatic conditions are impossible to attain (Ollier and Harrop, 1964). It is therefore concluded that the caves were formed before faulting brought them to their present position. From very rough correlations the fault is guessed to be about a million years old, and the caves are therefore older than that.

Information from Cavers

The detailed study of speleochronology calls for the work of numerous experts. It is a new science and its methods are still evolving. There is ample scope for commonsense, keen observation and new discovery. Cavers can make valuable contributions by describing caves in such a way that the chronologist may draw useful inferences. Observations are sought and should include the following points:

1. Is the cave in limestone? If not, what sort of a cave is it (e.g. sea cave, lava cave, sandstone rock shelter)?

2. What is the age of the enclosing rock?

3. What shape is the cave? Are there any distinct levels in it?

4. What is the relationship between the cave and surface topography (e.g. cave follows a valley; cave runs diagonally under a ridge)?

5. Is the cave active now? Is water flowing through it? Are stalactites wet?

6. Is there any cave fill? How much? Is it stratified?

7. Are there any fossils or artefacts?

8. Any other notable features.

References

BARRETT, P.J. 1963 : The Development of Kairimu Cave, Marakopa District, S.W. Auckland. N.Z. J. Geol. Geophys., 6 : 288 - 298.

BROECKNER, W.A., OLSON, E.Z., ORR, P.C. 1960 : Radiocarbon Measurements and Annual Rings in Cave Formations. Nature, 185 : 93 - 94.

FORD, D.C. 1964 : On the Geomorphic History of G.B. Cave, Charterhouse-on-Mendip, Somerset. Proc. Univ. Bristol Spel. Soc., 10 : 149 - 188.

GALLUS, A. 1966 : Comments on 'Transition from Mousterian to Perigordian' by L. Pradel. Current Anthropology, 7 : 39 - 40.

GREEN, G.W., WELCH, F.B.A. 1965 : Geology of the Country around Wells and Cheddar. H.M.S.O., London : pp. 84.

JENNINGS, J.N. 1964 : Geomorphology of Punchbowl and Signature Caves, Wee Jasper, New South Wales. Helictite, 2 : 57 - 71.

KING, L. 1951 : The Geology of the Cango Caves, Oudtshoorn, C.P. Trans. Roy. Soc. S. Africa, 33 : 457 - 468.

MEES, G.F. 1962 : The Subterranean Fauna of Yardie Creek Station, North West Cape, Western Australia. J. Roy. Soc. W. Aust., 45 : 24 - 32.

MOORE, G.W. 1960 : A Guide Book to Carlsbad Caverns National Park. Nat. Spel. Soc. Guide Book Series, No. 1.

MOORE, G.W., NICHOLAS, G. 1964 : Speleology. Heath, Boston.

MOORE, B.P. 1964 : Present-day Cave Beetle Fauna in Australia. Helictite, 3 : 3 - 9.

MULVANEY, D.J. 1966 : The Prehistory of the Australian Aborigine. Scientific American, 214 : 84 - 93.

MULVANEY, D.J., JOYCE, E.B. 1965 : Archaeological and Geomorphological Investigations on Mt. Moffatt Station, Queensland, Australia. Proc. Prehist. Soc., 31 : 147 - 212.

OLLIER, C.D., TRATMAN, E.K. 1956 : The Geomorphology of the Caves of N.W. Clare, Ireland. Proc. Univ. Bristol Spel. Soc., 7 : 138 - 157.

OLLIER, C.D., HARROP, J.F. 1964 : The Caves of Mount Hoyo, Eastern Congo Republic. Bull. Nat. Spel. Soc., 25 : 73 - 78.

RENWICK, K. 1962 : The Age of Caves by Solution. Cave Science, 4 : 338 - 350.

RICHARDS, A.M. 1960 : Observations on the New Zealand Glow-worm Arachnocampa luminosa (Skuse) 1890. Trans. Roy. Soc. N.Z., 88 : 559 - 574.

RICHARDS, A.M. 1963 : The Subterranean Freshwater Fauna of North West Cape, Western Australia. Helictite, 1 : 78 - 82.

RICHARDS, A.M. 1964 : The New Zealand Glow-worm. Studies in Spel., 1 : 38 - 41.

SOLLAS, W.J. 1931 : Paviland Cave: An Aurignacian Station in Wales. Huxley Memorial Lecture, R.A.I., London.

SWEETING, M.M. 1950 : Erosion Cycles and Limestone Caverns in the Ingleborough District. Geog. Journ., 115 : 63 - 78.

SWEETING, M.M. 1960 : The Caves of the Buchan Area, Victoria. Zeit. f. Geomorph., Supp 2 : 81 - 91.

SWEETING, M.M. 1966 : The Westhering of Limestones. In "Essays in Geomorphology", ed. G.H. Dury. London.

VANDEL, A. 1963 : La repartition des cavernicoles et la paléogéographie. Actes 2me Cong. Int. Spel., 2 : 31 - 42.

WAKEFIELD, N.A. 1963 : Sub-fossils from Mount Hamilton, Victoria. Vict. Nat., 79 : 323 - 330.

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A B S T R A C T S

DESCRIPTION AND BIOLOGY OF AN AUSTRALIAN SPECIES OF CYPSELOSOMATIDAE (DIPTERA), WITH A DISCUSSION OF FAMILY RELATIONSHIPS. By D.K. McAlpine. Aust. J. Zool., 14, 1966 : 673 - 685.

A new species of the genus Cypselosoma Hendel is described in both the adult and immature stages. This is the first record of the family Cypselosomatidae in Australia. Notes on the family, generic and specific characters are given with keys to aid identification. Cypselosoma australis McAlpine is recorded from mountainous areas near the eastern fall of the Northern Tablelands of N.S.W. It has been collected from Carrai Bat Cave, Carrai, c. 50 miles W. of Kempsey, and from a mine shaft at Kingsgate c. 20 miles E. of Glen Innes. The ecology and habits of the insects were studied in an inner chamber of Carrai Bat Cave. Numerous larvae of C. australis were found in moist bat guano and adult flies were seen on the surface of the guano. The flies were observed caught in the webs of spiders on the surface of the guano. It is probable the larvae are eaten by larvae of histerid beetles which also occur in the guano. An unidentified species of Phoridae was also present. In the drier guano of the main chamber C. australis was replaced by the larvae of another fly close to Aphaniosoma nigridorsum Malloch (Chyromyidae). The specimens from Kingsgate were also obtained on guano. The gut of living larvae of C. australis contained guano. Adults must also derive nutriment from guano as all activities including copulation take place there. Thus C. australis occupies an extraordinarily restricted ecological niche. No other nocturnal species are known in any other family of Micropezoidae, and it is thought visual stimuli are probably necessary for copulation and other activities necessary for survival. It is suggested the front tarsi of C. australis may have an olfactory function for finding food and locating the opposite sex. There is no notable reduction of the eyes. It appears that C. australis has only recently become adapted to life in darkness. The closely related species C. gephyrae Hendel from Formosa and Java is not recorded from caves, but from rotting banana plants.- A.M.R.

TIME AND THE MARSUPIAL. By Duncan Merrilees. Wildlife in Australia, 3, 1966 : 20 - 23.

In addition to a general discussion on the distribution of fossil marsupials, Merrilees refers to a mummified skeleton of a thylacine found by the Sydney University Speleological Society in a cave on the Nullarbor Plain in 1964. Until this discovery it had been assumed that thylacines dated back thousands of years, but the Nullarbor specimen suggests a more recent date which it is hoped will be estimated by C 14 dating. Also referred to are a great variety and number of fossil marsupial bones discovered in Mammoth Cave, south-western Western Australia. Charcoal obtained from the deposits has been subjected to radiocarbon analysis, but the deposit proved to be older than the radiocarbon method was capable of estimating at that time, i.e., older than 37,000 years. An artist's impression is given of a scene near Mammoth Cave when the fossils were accumulating. It is based on a study of the deposit. None of the marsupial species represented lives in the area today, and two or perhaps three of the species are extinct. - A.M.R.

FLIGHT PATTERNS OF SOME EASTERN AUSTRALIAN BATS. By P.D. Dwyer. Vict. Nat., 82 (2), 1965 : 36 - 41.

It is thought a knowledge of specific flight patterns in bats may throw light on feeding specialisations and provide some insight into the ecological diversity shown by the species found in a particular area. It may also provide useful clues for field identification. Thus certain morphological flight attributes were measured for 17 species of bats known from New South Wales and Victoria. These include aspect ratio (with and without uropatagium); ratio wing area/uropatagial area; wing loading, and uropatagial loading. Results obtained are discussed in relation to present knowledge of flight patterns and behaviour, and suggested flight patterns deduced for species where this has not been recorded. It is considered that specific flight patterns reflect specific feeding habits, and that future work is required to refine the generalisation that these bats are "insectivorous". - A.M.R.

THE ALLEGED OBLIGATE ECTOPARASITISM OF MYOTYPHLUS JANSONI (MATTHEWS) (COLEOPTERA : STAPHYLINIDAE). By E. Hamilton-Smith and D.J.H. Adams. J. ent. Soc. Qd., 5, 1966 : 44 - 45.

Myotyphlus jansoni (Matthews), previously considered an obligate ectoparasite of Rattus spp., is reported from bat guano in caves at Warrnambool, Victoria, and Jenolan, New South Wales. This finding suggests that the genus Myotyphlus (Fauvel), assigned by Seevers to the tribe Amblyopinini, may need to be replaced in the Quediini. - A.M.R.

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