Helictite

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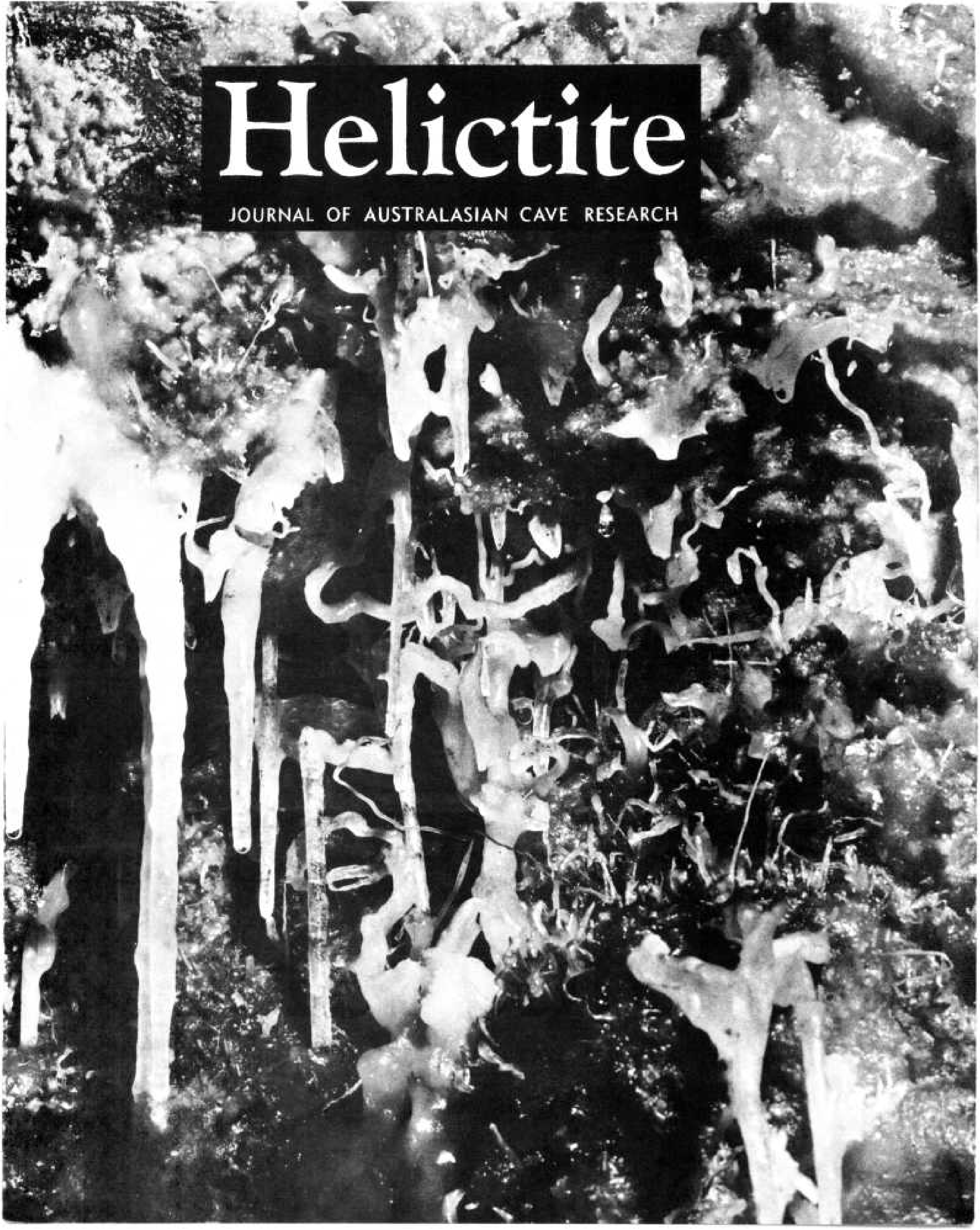

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BOOK REVIEW

Biospéologie. La Biologie des Animaux Cavernicoles. By A. Vandel. Gauthier-Villars Editeur, Paris. 1964 : pp 619.

This is by far the most comprehensive book on the subject of cave biology yet written, and it will probably remain the definitive text on the subject for many years to come. It is a book for the student and specialist rather than for the layman.

The author is Professor of Zoology in the Faculty of Sciences at Toulouse, and Director of the Underground Laboratory of the National Centre of Scientific Research at Moulis. He is also a Member of the Institute. He is well known for his researches on the Isopoda of the world. No one could be better qualified to undertake the task of writing a volume of this scope.

The book is divided into six major parts of biospeology covering such topics as a general section outlining the subject; an account of the different groups of animals and plants found in caves up to the end of 1962; geographic distribution and ecology; physiology; behaviour patterns and sense organs; and evolution. Each sub-section within each of the 31 chapters is completed with its own bibliography, making the volume invaluable as a reference, apart from the general information that it contains. There are many excellent line drawings and illustrations, plus photographs of a more general nature.

"Biospéologie" is written in French. It is understood that an English translation will be printed in London in the near future. The present edition is extremely well produced and printed, but deserves a more substantial binding.

The book concludes with a comprehensive 27-page systematic index, plus a 13-page index of authors mentioned in the text. Dr. A. Richards (co-editor of "Helictite") is included among the special acknowledgements in the Preface.

MORPHOLOGY AND DEVELOPMENT OF CAVES IN THE SOUTHWEST OF WESTERN AUSTRALIA

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Abstract

Caves in the coastal aeolian limestone of Western Australia show two major types of morphology due to different groundwater conditions. The first type comprises linear caves with streams, and develops on a watertable which has pronounced relief because of an undulating impervious substratum. Cave systems of this type are thought to start developing as soon as coherence begins to appear in unconsolidated dunes, and develop rapidly by collapse while the dunes are still weakly cemented, to assume more stable mature forms when the rock is strongly cemented.

Systems of the second type are more irregular in plan and typically develop caves with the form of inclined fissures. These systems are developed on a watertable which has little relief, but which may slope appreciably in one direction. They are thought to start much later than the first type in the history of dune consolidation.

Because of the porous rock, development of each type occurs in levels of permanently water-filled pores in a true watertable. When systems are well established, solutional attack is concentrated at the watertable where drainage is easiest, while at greater depths the groundwater tends to stagnate. A third type of cave is developed in shallow phreatic conditions near Augusta.

Local groundwater conditions cause important modifications to these types. The best cave development in any area is found in the more easterly older dunes, and decreasing rainfall from south to north corresponds with a decrease in cave sizes and numbers. Strong development occurs in many localities where drainage from inland country adjacent to the limestone belt passes underground in its passage to the sea.

Introduction

Caves of the southwest of Western Australia have received virtually no attention from scientists as regards their morphology and development. Dr. E.S. Simpson, in the Year Book of Western Australia for 1902, discussed the origin of caves in "coastal limestone," but his comments were not based on intimate knowledge and were very brief. Generally speaking, it seems that their origin has been taken for granted and geologists have assigned to them theories that apply to other regions. Admittedly the basic essential of cave formation still holds, namely, the corrosion of calcium carbonate by percolating water, but the author's observations over the past nine years have shown the mode of operation to be vastly different from that seen elsewhere. The reason for this lies in the unusual origin and character of the coastal limestone. The bearing of these factors upon cave development will be the main topic dealt with here.

Location

"Coastal limestone" is the popular name for a limestone composed of cemented calcareous dune sands found in coastal belts along much of the western and southern coastline of Australia. Such a name is applied to a great diversity of coastal formations around the world, and it is better to refer to it by the term "aeolianite", or better still, "aeolian calcarenite." In Western Australia, the rock is known from Shark Bay in an almost continuous belt southwards, and then eastwards almost to the South Australian border, a distance of about 1,400 miles. Figure 1 shows the portion of it which comes under the author's experience - about 200 miles north and south of Perth. Although in this area it is broken only by river mouths and inlets, and in the vicinity of Busselton by a strip of emerged strandlines, caves are not developed continuously, and there are long distances of limestone with no recorded caves. Reasons for this variation will be presented in the course of this paper. In fact, there is great variation in the numbers and size of caves and amount of karst development from area to area.

The main cave areas (Figure 1) are, from north to south: Arrowsmith River, Jurien Bay, Namban River, Moore River, Yanchep, Mandurah, Yallingup, Margaret River and Augusta. The last three form an almost continuous belt between Cape Naturaliste and Cape Leeuwin. On the other hand, there are almost 150 miles between Perth and Yallingup with very few known caves.

Origin of Limestone

The origin of the limestone is well-known, but is still subject to controversy in some aspects. The limestone is made up of a cemented, fine, calcareous sand composed mainly of shell fragments and foraminiferal tests, plus minor clastic detritus. The sand is fine and easily blown, and the resulting dunes are extensive and quite high. In places where successive incursions built the dunes one above the other, they have reached as much as 700 ft. above present sea-level.

The widespread occurrence of aeolianite in the Pleistocene Epoch doubtlessly links its origin with the eustatic sea level changes associated with glaciation. Fairbridge (1954) gives a comprehensive review of ideas on the coastal formations, mostly aeolianites, around the Australian coastline and has suggested (Fairbridge and Teichert, 1952) that the dune lines now preserved were probably laid down during interglacial arid periods, which were times of high sea level. This contrasts with the older popular idea that it was necessary for the glacials to cause sea levels to drop so that extensive areas of sand could be laid bare, thereby allowing it to be blown into dunes. The same conclusion had been reached by Hossfeld (1950) and Sprigg (1952) for aeolianites of South Australia, and Bretz (1960) came to an identical conclusion for the periods of emplacement of Bermudan aeolianites.

A few Western Australian dune lines are now partly or completely submerged, which suggests that they were emplaced not only at sea level maxima, but also at lesser stillstands during lower sea levels. Hossfeld (1950) noted this also for South Australian dune lines. Contrasting with all these ideas is a paper by Butzer and Cuerda (1962) on Mallorcan aeolianites in which the older idea is assumed, apparently without question. Hossfeld also suggested that numerous inland dune belts in South Australia were younger than belts nearer the coast, the sea having for a time encoached over the older belts and turned them into islands. While this condition is actually seen today in the Rottnest and Garden Island dune lines west of Perth, the main cave areas are developed in a strip in which up to four dune lines can be distinguished in close juxtaposition, even overlapping considerably in many places. Thus, for these dunes at least, there must be a regular progression in age from oldest in the east to youngest in the west.

One feature which can be an important factor in later cave development is the ease with which these dune belts, migrating northwards by the action of the prevailing winds, threw barriers across smaller river systems which lacked water flow in summer. This is discussed more fully in the paper at a later stage.

Consolidation is caused by water seeping downwards to the watertable. During its movement the water dissolves out small amounts of calcium carbonate, and then reprecipitates it as a cement around sand grains at lower levels. Presumably, if this process carried on for a long time, a tough and impermeable limestone might be formed eventually, but it seems that the age of the material is so low that the cementation has done little more than to impart coherence to the material, often barely enabling it to be called "rock" instead of "sand."

The limestone still retains a high porosity, a feature which is important in that a true watertable is developed, unlike most limestones. The high porosity is general throughout, even in well-consolidated rock, with the possible exception of the strongly cemented "caprock" zone. This caprock is developed in a zone of maximum precipitation; its control and development is not discussed here.

Cave Origin in Aeolianite

Very little has been written about cave development in aeolianites, although the caves are commonly mentioned in passing by writers. Bretz (1960) has made a valuable contribution on the origin of caves in Bermuda, presenting an interpretation differing markedly from views advanced by Swinnerton (1929). Western Australian aeolianiteshas some differences from Bermudan aeolianite, and these are reflected in its cave morphology.

1. Rapid growth of caves.

The Yallingup-Augusta belt has the biggest cave sizes. Giant's Cave, Crystal Cave, Jewel Cave, and other caves in this region, attain ceiling heights of about 100 ft. and ceilings around 40 to 60 ft. are common. Collapsed caverns in this area indicate that much greater dimensions have been attained. Cave formation in most other regions is generally initiated along joint planes or bedding planes, and occasionally on faults, as these are the only fissures penetrable to water in hard impermeable limestone. Dissolution is particularly active at the intersection of two joints, but the process is slow nevertheless. Given sufficient time, a large cave may develop eventually. If we allow that caves are not initiated in a marine limestone until it has reached a suitable elevation in a rejuvenated landscape, that is in a landscape that has not been in existence very long, a substantial period must normally be envisaged for caves of these dimensions. Yet here the time available for cave development must be less than the age of the oldest aeolianite, which itself is no older than earliest Pleistocene, and possibly much less.

Karst development is taking place rapidly today in the most cavernous areas. Some examples from Yanchep and Margaret River will illustrate this. A small grotto with a gently flowing stream at Yanchep, about 30 miles north of Perth, has been known to the author since 1949. In 1954, the grotto suffered a roof fall and several blocks fell into the stream. By 1960, these had disappeared completely and the grotto was more than twice its size of eleven years earlier. Another large grotto with a stream at Yanchep fell in about ten years ago - a source of some consternation to the would-be explorer! One caver of the 1930's records in his notes a visit to the collapse basin of a fallen-in cave near Margaret River which old residents recalled as being formerly a pretty cave with a lake. With longer experience in that area we shall undoubtedly have more examples of cave falls.

While this speedy development obviously characterises both Yanchep and the Yallingup-Augusta belt (and presumably other areas as well), there is a vast difference between typical cave sizes in the two areas. The latter area has a higher rainfall but hardly enough to account for the difference. Some added mechanism seems to be demanded.

2. Cave initiation before consolidation.

Such a mechanism is available and will be described here. It leads to satisfactory answers, not only to the great variation in extent of karst development, but also to the variations in cave forms and types of karst topography.

An important feature of the aeolianite is that, because of its sub-aerial deposition, it has been above sea level from the beginning, when it was soft sand. Minor submergences during interglacial times have only affected the seaward fringes.

Water, doubtlessly, was draining through it while it was still sand and hence, where groundwater conditions were favourable to the concentration of drainage into underground streams, these must have developed. While they were active the major part of the material was hardening gradually by cementation. Thus, as soon as it became coherent enough to hold together above even small cavities, the streams could begin to carve out free channels - embryo caves. Therefore it was not necessary for the dunes to have been converted to solid limestone before caves could be started.

For such a mechanism there must be a precipitation of carbonate to harden the rocks, and simultaneously dissolution along stream lines to create caves. The coincidence of these opposed processes depends on the differing nature and rate of water flow in different parts of the dunes. Water seeping downwards from rainfall is moving very slowly and becomes saturated with carbonate. This is reprecipitated at greater depths when the seasonal summer desiccation occurs. An underground stream, on the other hand, is moving many times faster, is being continually replenished, and as a result is usually undersaturated, except perhaps in times of stagnation due to drought. The result is a regular annual cementation in the body of the dunes, while carbonate bathed by stream waters suffers continual solution.

In the initial stages of cave development outlined here we see a curious departure from the normal sequence of events. In old marine limestones, the lithification of material must come first and caves later, after the limestone has been raised above sea level to a suitable elevation. In these aeolianites the streams are beginning to develop caves even when the sand is barely coherent. Cave development can, in fact, begin a very short time after deposition of the material itself.

The concentration of early drainage into definite streams in some areas will be dealt with later; this is important, for in areas lacking this type of drainage the mechanism cannot be applied for reasons which will be elaborated.

3. Enlargement by collapse.

This idea points logically not only to an early start, but also to rapid growth of caves in areas that have watercourses.

In the early stages of cementation, cave development can be very rapid, the major enlargement of cavities taking place by repeated collapses of barely coherent rock into streams. Fallen blocks, lying in the water, are then open to attack by the streams which also widen by continually undermining their walls. Meanwhile the bulk of the rock is steadily hardening and thus becomes stronger. As a result, collapses gradually decrease in frequency until finally the caves reach fairly stable mature forms.

Cave development thus shows three general phases:-

(i) A period preceding rock coherence, when material removed along streams is immediately replaced by settling of sand from above and growth is nil.

(ii) A period when rock is poorly coherent, sufficient to support small cavities only, and cavern enlargement by collapse is rapid.

(iii) A final period when rock is strongly coherent and collapses very infrequent.

The third phase does not necessarily lead to a final cave form, for as long as there is stream action the sides of a watercourse are corroded wherever wall-rock is in contact with flowing water. So a cave must periodically increase the size of its stable arch to fit the widening base. Cave development can only cease if the stream is diverted from the course it has created. This may occur as a result of a massive collapse damming back the water upstream. Such dammed water usually finds its easiest route through the collapsed material, but if alternative routes are available, it may use these and abandon a downstream section of cave. The section of cave abandoned in this manner becomes permanently stabilised, excepting perhaps for a few minor collapses from weakened parts of the ceiling. A series of lesser collapses may also lead to abandonment by sufficiently impeding the flow of water for the stream to use an alternative route.

There are examples of caves that have been permanently stabilised by collapses, still retaining their original linear form as created by the streams that once flowed through them. Giant's Cave is one of the best. Stream piracy is also a feasible mechanism for diversion of a watercourse, but no examples are known in these areas.

The cave history outlined here is almost entirely a vadose one, but not vadose in the original manner proposed by early cave theorists. These theories either picture water entering at the surface, or percolating waters

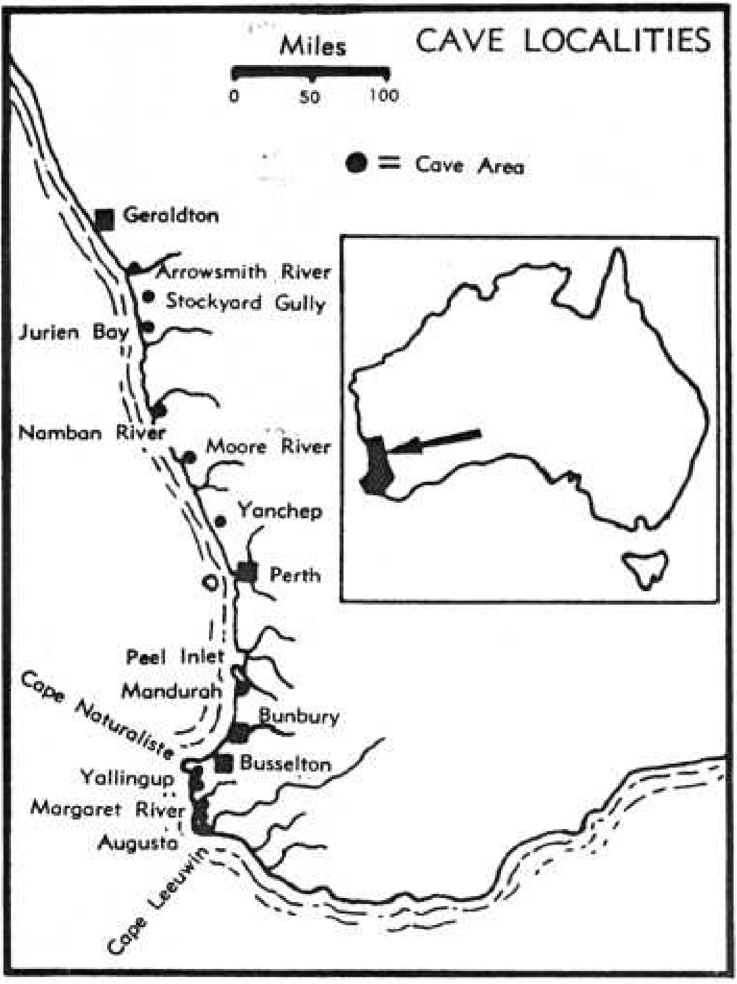
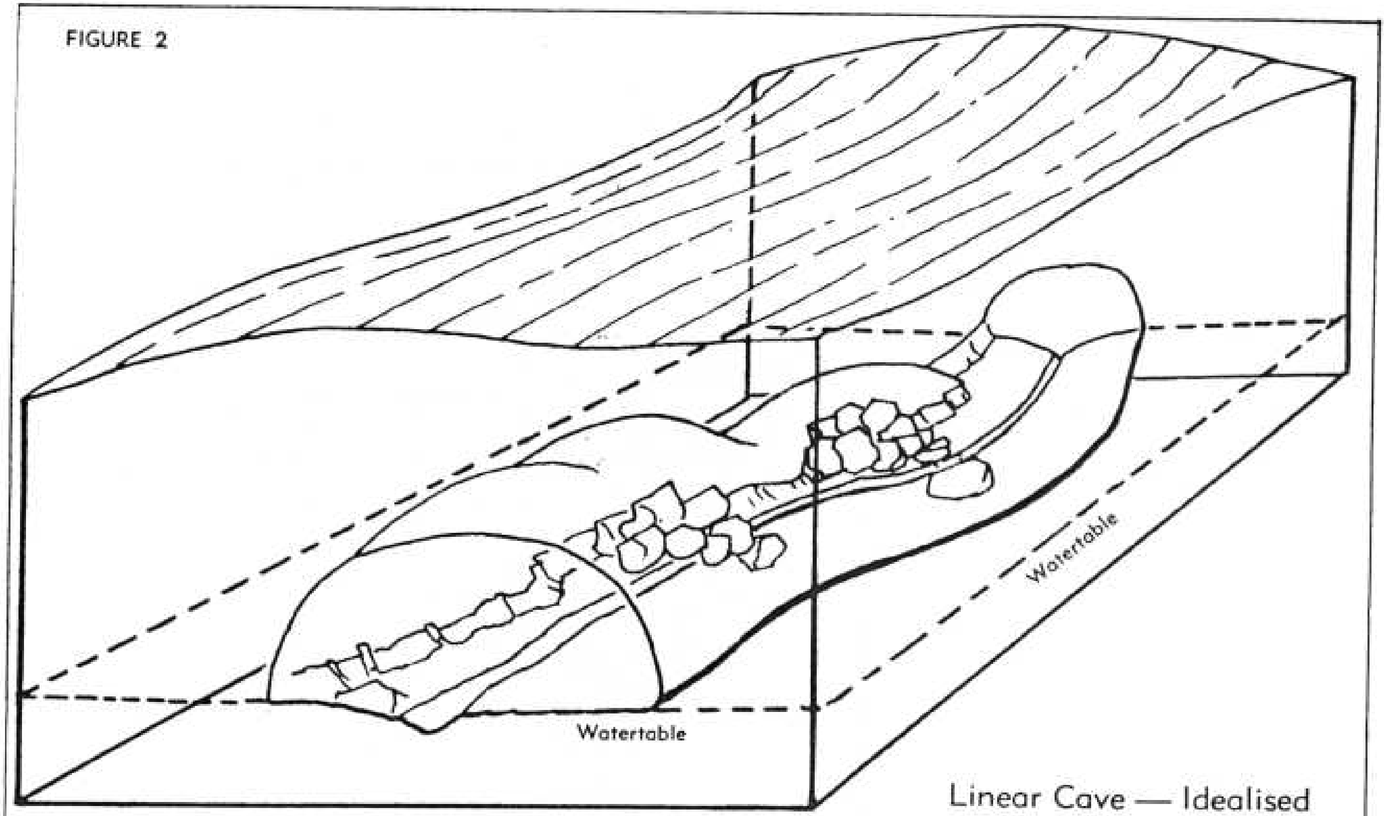

CAVE LOCALITIES
Miles
0
50
100
● = Cave Area
Geraldton
Arrowsmith River
Stockyard Gully
Jurien Bay
Namban River
Moore River
Yanchep
Perth
Peel Inlet
Mandurah
Cape Naturaliste
Bunbury
Busselton
Yallingup
Margaret River
Augusta
Cape Leeuwin

FIGURE 1

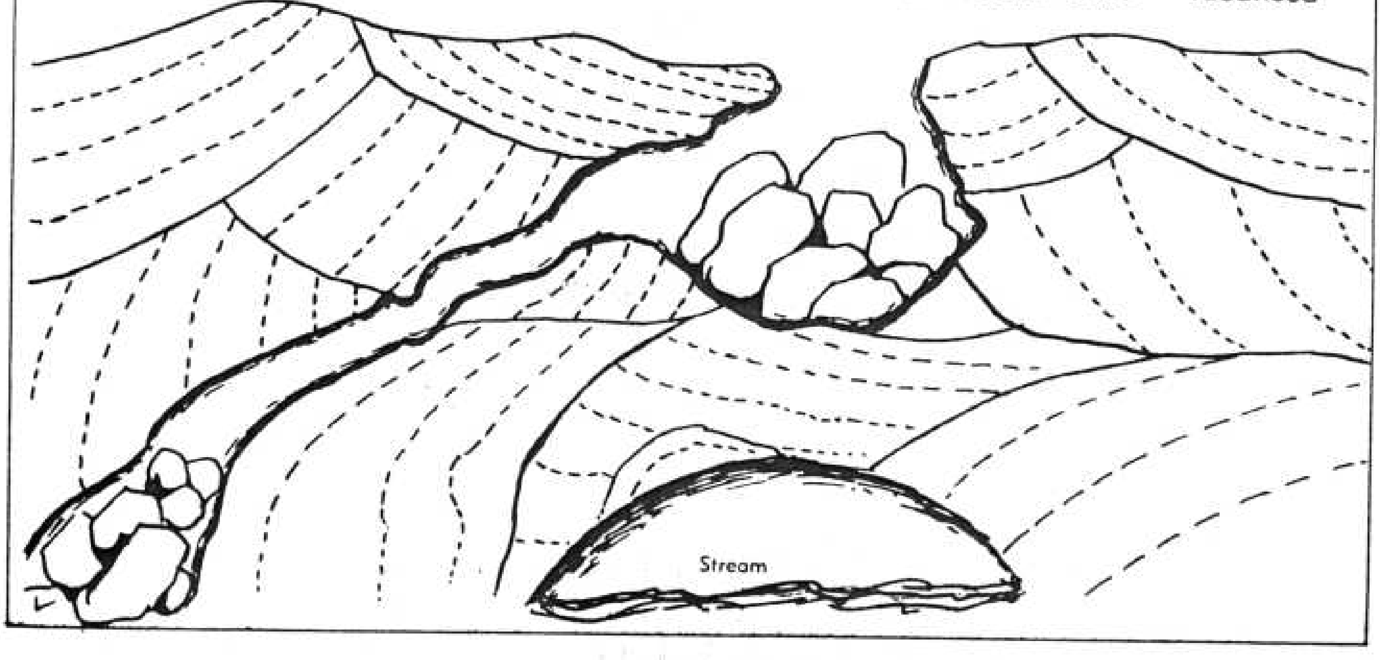
FIGURE 2



Linear Cave — Idealised

FIGURE 3

Inclined Fissure Cave — Idealised



gathering above levels of completely water-filled passages. Such underground streams may be at different levels which are not related to a watertable. On the other hand, in the aeolianite, streams run at the true watertable level and, but for the collapses, would be completely water-filled passages. It is only when free air surfaces are created above the streams with the very first collapses that the passages become vadose caves in the broad sense.

It must be noted nevertheless that there is, ultimately, a stage reached of fully coherent rock when collapses are not the rule. If new caves were then to be initiated, there is no reason why a normal phreatic history might not ensue. Such, in fact, appears to have taken place in the Augusta cave area where an extensive system of small cave passages shows abundant evidence for a shallow phreatic history. This system will be the subject of further study.

4. Cave form types.

Cave forms in aeolianite differ markedly from area to area due to the different growth histories resulting from the particular drainage characters of each area. All, with the exception of the Augusta system mentioned above, are essentially secondary forms due to collapse. Two main types can be distinguished:-

(a) The linear cave form with arched roof outlined above is very common. Even in cases where the cave is very "tumble-down" and does not reach watertable, it is usually sufficiently long and sinuous to indicate that a stream once flowed underneath. A fairly common variation is an isolated cavern without extensions. Such caves have high, domed ceilings and jumbled masses of roof blocks making up the floors, often partly blanketed by sand and soil washed in from the surface. The rubble piles have merely blocked off access to the main stream courses. Such caverns are not really different in any essentials from the linear type. Often a small passage may be found connecting with the parent cave and the origin of such an isolated cavern becomes clear. In Crystal Cave, 14 miles south of Margaret River, there are two large domed caverns which open off by small tunnels onto a watercourse which has obviously bypassed them.

(b) The second type is seen in small caves having the general form of an inclined fissure, often with floor and roof neatly matching. These again are the result of collapses upon an active cavern at watertable level. If an inclined fissure cave leads into a linear stream cave at a lower level, its origin becomes obvious, but more commonly such fissures close up at their lower ends because the original cave development was directly beneath the part of the fissure showing the greatest length of fall; the closed end of the fissure is off to the side of the original cave. The two cave types are depicted in Figures 2 and 3.

5. Relationship of drainage to cave forms.

From area to area the relative proportions of linear caves and inclined fissure caves varies widely. In the Yallingup-Augusta belt the linear type predominates, and fissures when found can often be related to fall-outs on a linear cave nearby. Yanchep area has good examples of both types, but inclined fissures predominate and the great majority do not lead to a linear controlling system. Namban River area has extensive caves made up wholly of ramifications of connected inclined fissures having the general form of many broad intersecting low-roofed domes.

The linear type, it has been noted, is formed by collapses onto a well-defined stream. It is characteristic of these caves that the streams vigorously corrode the bases of their rubble piles which continually settle until, in the absence of fresh falls, high and spacious caverns are created. The streams are apparently not easily diverted.

On the other hand, the broad systems of fissure caves, with their collapsed material lying virtually untouched, indicate that concentrated attack by streams has not taken place. Watercourses in such oblique fissure systems are apparently easily diverted by collapses.

It is evident that the inclined fissure systems represent collapses upon very broad and ill-defined waterways. These waterways apparently began as complicated systems of wide, but very low, cavities at the watertable. These collapsed gradually in sections, each section at a different time. Because of this, alternative routes were always available in a system of this type. Since the water was not limited to the necessity of attacking directly through a collapsed section, the rubble remained relatively untouched. Nambibby Cave at Yanchep is a good example of such a well-developed fissure cave system.

The two cave types point to two distinct watertable conditions:-

(i) Linear types indicate a watertable with strong relief carrying defined streams along its lowest parts; the streams are obviously restricted to these valleys and this explains why they must attack through any collapses that land upon them for they cannot be diverted to the flanks, which are upslope. This undulating watertable is controlled by an impervious stratum which itself has strong relief.

(ii) Inclined fissure cave systems indicate a watertable which has very subdued relief, even if an appreciable fall in one direction is present. Water flows in broad belts because it is not affected by an undulating impervious substratum.

Originally there are no defined streams in areas with a watertable of subdued relief, but it is as a result of extensive collapses in the cave systems that water becomes temporarily confined to streams. Such a stream, however, is typically small, easily accommodated in whatever route is available, and obviously not forced to maintain that course. It tends to cut off its temporary meanderings by eventually finding a shorter course through another part of the collapse system. Thus these streams follow many courses within the broad limits of a cave system at various times. The final state of such a system is a broad area of settled ground within which are scores of oblique fissures, small collapse dolines, and occasionally a sight of a stream here and there.

It follows that only caves built along definite stream lines could have the early start outlined in this paper, as concentrated solution along a definite stream line is required to create cavities in poorly consolidated sands. Broad flow, by dissolving throughout the breadth of a dune, would only cause the whole mass to settle slightly, and so caves cannot get started in this case until the dunes have hardened considerably. Inclined fissure cave systems are indeed much smaller than linear caves. Since they also lack concentrated follow-up attack upon collapsed material, one may wonder that within the short time available they were anywhere ever developed to the extent that man could enter and penetrate far. In fact, it seems apparent to the author that they are never developed to this extent unless substantial amounts of water are added to the dune belts from outside sources. Dune belts lacking such added volume of drainage are exceedingly poor in caves.

Causes of Local Variation in Cave Development

1. Effect of bedrock.

The Yallingup-Augusta cave belt differs from other areas in having a bedrock of igneous rocks upon which an appreciably hilly topography had been developed before the dunes were emplaced. This impermeable basement, by creating the undulating watertable outlined above, appears to have imposed its old stream patterns upon the limestone above so that underground streams today follow similar lines to the original surface watercourses. An excellent example is the Mammoth Cave system, where a surface stream continues directly into the limestone barrier, obviously following its original valley. As has been outlined above, this area has through its concentrated drainage attained much bigger cave dimensions than elsewhere.

In other limestone areas there are only flat-lying alluvial beds of the old coastal plain beneath the limestone. The watertable is consequently much nearer to the horizontal and the broad, sheet-like water movement produces systems of the second type.

2. Rainfall.

The average annual rainfall of the region ranges from about 50 inches in the Karridale area near Augusta, to 10 inches around Shark Bay. This is a considerable variation and has a direct bearing on the rate of growth of caves and there is a decrease in both size of caves and amount of decoration from south to north. Since there are several other factors at work the trend is, of course, a very rough one.

3. Age of the limestone.

Aeolian calcarenite ranges right through to Recent in its age and shows progressively poorer cementation and less cave development in younger occurrences. The caprock is very early to develop and gives no idea of the degree of coherence of the main body of the limestone beneath. Limestone belts beneath Fremantle and Mandurah have tough caprock, but the material beneath is friable, and caves are almost unheard of in this belt. Likewise at Yanchep, the numerous caves are all seen in an old dune belt several miles inland, whereas younger dune belts nearer the coast have no known caves, even though drainage passes through them.

4. Height above watertable.

In some areas, such as Yanchep, the dunes did not reach a great height and the watertable may commonly be as little as 30 ft. below the surface. Caves can never attain impressive dimensions; they have only to reach a ceiling height of 20 ft. or so for the next collapse to take a cave right to the surface. There tend to be a great number of fissures, open collapses and insignificent rubbly chambers without extensions, which elsewhere might never open to the surface. On the other hand, the Yallingup-Augusta belt has areas with a watertable more than 200 ft. deep, and its depth is mostly over 100 ft. Here caves have room to grow larger before collapses reach the surface, and minor changes of stream path have space to rejoin, to enlarge and simplify the systems. When a collapse does reach the surface, the result is often an impressive pit. Lake Cave and Bride's Cave, about eight miles south of Margaret River, are excellent examples. Such pits are common in spite of the depth to water because of the additional factors here.

5. Drainage from back country.

Whereas in many areas rainfall on the limestone belt is the only source of drainage water, there are some in which drainage from inland country, lacking a surface connection with the sea, adds considerably to the volume of water passing through. Such are the localities where dune belts have completely blocked off river outlets, as noted earlier. If an area, otherwise dry, is receiving large quantities of such water, then caves may develop here much faster than in adjoining areas and may even approach in magnitude those of the wettest parts. Perhaps the best example of this is the Arrowsmith caves area which is developed where the Arrowsmith River, draining an area of about 300 square miles in a 20 inch rainfall belt, terminates in a string of lakes a few miles from the sea, some 20 miles south of Dongara. In flood times, the lakes overflow into several caves, the largest (Arramall Cave) being a mile in length before becoming impenetrable. The floods in each cave spread out into systems of distributaries, each taking a fraction of the flow and dividing repeatedly down into a ramification of tiny passages, until finally the drainage is spread through a wide area of limestone and slowly travels the remainder of the distance to the sea.

Twenty-five miles south of this system, Stockyard Gully Cave drains a small belt of inland country, and 40 miles further south the Namban River (sometimes spelt Nambung on maps) is associated with a very extensive system of inclined fissure caves in the vicinity of its blocked downstream end. At Yanchep no proof of added drainage is available, but an area of about 200 square miles between the dunes and the Darling Range is sandy country completely lacking watercourses. Undoubtedly, drainage from a large portion of this area must pass into the limestone. In the Yallingup-Augusta belt there are a number of small streams entering the limestone. The Mammoth Cave system has already been mentioned, and Calgardup and Arumvale Caves are other good examples of caves developed on such streams.

By contrast with all the areas outlined above, there is a long strip of coastline between Perth and Bunbury lacking added water. Swan and Canning Rivers and their associated swamp lines, then Serpentine River, Harvey River, and Wellesley River in turn, drain coastal plain country behind the dune belts, reaching the sea via narrow passages through the dune systems. Caves are virtually unknown in this region, although a few very small caves are recorded on the western side of Harvey Estuary on the inland edge of a dune belt. Springs issuing into the estuary indicate that the caves are developing only by drainage from rain falling onto the limestone itself. The relative friability of rock, and the configuration of Peel Inlet, Harvey Estuary, and the interdune lakes, Clifton and Preston, suggests that many of the dune belts are quite young anyway in this region. A small patch of limestone of very low elevation on the south side of Peel Inlet may be the only dune remnant of comparable age to the main cavernous dunes elsewhere. A cave of reasonable size has been found there.

6. Variations in solutional capacity of groundwaters.

In any one area, even within a single dune, the biggest cave development is seen adjacent to the eastern edge of the dune belt. This is particularly obvious wherever large amounts of drainage from inland country are undoubtedly entering the limestone, as in the examples cited above. Caves may begin large, but invariably become smaller and smaller, in an irregular fashion, westwards through the limestone. In the case of the Arrowsmith system, the trend is obviously due to spreading of the drainage, but this cause is not evident in any other system.

Elsewhere the trend can only partly be attributed to the ages of the dunes. Every area has multiple dune lines showing a progressive drop in age from east to west. Thus one would expect a step-like drop in cave size from dune to dune, but the actual picture is a far more rapid drop in size and, in fact, there is not a single cave known anywhere from the youngest dune line. Much of the cause must be simply credited to increasing saturation, and consequent loss of dissolving power, of the water as it flows westwards.

Conclusions

The caves in Western Australian aeolianite and their origins as pictured here show quite wide differences from the Bermudan caves, due largely to their different groundwater conditions. Bretz described true phreatic caves from Bermuda, but it seems that the main cave development in Bermuda occurred in marine limestone which underlies the aeolianites and would, presumably, have been fairly solid when solutional attack began. The main factor preventing solution much below watertable here is simply that collapses are so rapid and release so much insoluble quartzose sand, that the floors of watercourses just keep filling up. Furthermore, once continuous open passages for water are established at watertable, this would have a further inhibiting effect upon any solution at depth as the easy drainage at watertable level would cause the flow to concentrate there, while flow at greater depths must virtually cease. The picture is of a nearly stagnant body of saturated groundwater topped by a thin layer of under-saturated water draining away easily.

These results of observations carried out over the past decade are necessarily only qualitative. Without experimental work to back them, the conclusions cannot be considered proven, but it is hoped that they will furnish a firm basis for future work.

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ABSTRACTS

VICTORIAN CAVE BATS. By G. George and N. Wakefield. *Vict. Nat.*, *77* (10), 1961 : 294 - 302.

This paper is the first official record of the Bent-wing bat, *Miniopterus schreibersi blepotis*, the Eastern Horseshoe bat, *Rhinolophus megaphyllus* , and the Large-footed Myotis, *Myotis adversus macropus*, occurring in caves in various parts of Victoria. The Bent-wing is the common cave bat of south-eastern Australia, and it has also been recorded from the Naracoorte Caves in South Australia. In Victoria it is widespread and very common. The authors have identified it from caves in the Buchan and Colac districts, from rock crevices along the Yarra River at Warrandyte and from a granitic outcrop near Genoa, East Gippsland. The Eastern Horseshoe bat is plentiful in limestone caves of the Buchan district of eastern Victoria, and the Large-footed Myotis also occurs at Buchan.- A.M.R.

SEASONAL CHANGES IN PELAGE OF *MINIOPTERUS SCHREIBERSI BLEPOTIS* (CHIROPTERA) IN NORTH-EASTERN NEW SOUTH WALES. By P.D. Dwyer. *Aust. J. Zool.*, *11*, 1963 : 290 - 300.

In *M. s. blepotis* of north-eastern N.S.W., the annual moult occurs during the summer and early autumn and lasts about 14½ weeks. Yearlings having their first moult usually initiate this some three weeks after the adults commence. In many adult females the moult is inhibited during lactation and again during the winter, so that some individuals may be found moulting in all months of the year. The importance of considering annual pelage characters when using colour taxonomically in bats is emphasised, and possible relationships between moult and reproductive cycles are indicated. In addition the use of pelage characteristics, in conjunction with reproductive criteria as a means of recognising age groups of *M. s. blepotis* is discussed.

BAT TICKS OF THE GENUS *ARGAS* (IXODOIDEA, ARGASIDAE). 4. *A.* (*CARIOS*) *AUSTRALIENSIS* n. sp. FROM AUSTRALIA. By G.M. Kohls and H. Hoogstraal. *Ann. Ent. Soc. Amer.*, *55* (5), 1962 : 555 - 559.

Argas (*Carios*) *australiensis* is described from a male and a nymph found in a house at Hammondville, New South Wales, in 1960. The hosts are presumed to be bats. The remarkable elliptical outline and large size readily distinguish the new species from *Argas vespertiliones* (Latreille) and *A. pusillus* Kohls, the two other species known in the subgenus *Carios*.

BAT TICKS OF THE GENUS *ARGAS* (IXODOIDEA, ARGASIDAE). 5. DESCRIPTION OF LARVAE FROM AUSTRALIAN AND NEW GUINEA CARIOS-GROUP. By H. Hoogstraal and G.M. Kohls. *Proc. Linn. Soc. N.S.W.*, *LXXXVII* (3), 1962 : 275 - 280.

Surprisingly few *Argas* ticks have been collected from bats in Australia, and none has been reported from these or other hosts in New Guinea. *Argas* (*Carios*) *vespertilionis* (Latreille, 1802) has been recorded from Townsville, and recently a new species, *A.* (*Carios*) *australiensis* was described by the authors from Hammondville, N.S.W. The present paper describes larvae collected from Australia and New Guinea which may belong to the species referred to as *A.* (*C.*) *vespertilionis* by previous authors. Very slight differences between these and Egyptian samples of the species are noted, but it is suggested that populations from Africa and from Australia and New Guinea may nevertheless differ taxonomically, and that in this subgenus, adults rather than larvae may be more lucid indicators of separate species. It is impossible at this time to state whether these larvae are *A.* (*C.*) *australiensis*, *A.* (*C.*) *pusillus* Kohls 1950, as yet definitely known only from the Philippines and Malaya, or an undescribed species. Hosts are a variety of insectivorous bats (Microchiroptera).- A.M.R.

RECORDS AND DESCRIPTIONS OF NYCTERIBIIDAE AND STREBLIDAE (DIPTERA). By T.C. Maa. *Pacific Insects*, *4* (2), 1962 : 417 - 436.

The author records Nycteribiidae and Streblidae collected from bats, from various parts of the world, but particularly from Southeast Asia. Several new species are described. Of special interest to Australians are a new species of Nycteribiid, *Eremoctenia vandeuseni* Maa off *Miniopterus* sp. from West New Guinea; the Nycteribiid *Cyclopodia* (*Cyclopodia*) *inflatipes* Speiser sensu Theodor off *Miniopterus* sp. from West New Guinea; and the Streblid *Nycteribosca amboinensis* (Rondani) off *Miniopterus* sp. and *M. schreibersi* from New Guinea, Queensland and New South Wales.- A.M.R.

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NULLARBOR EXPEDITION 1963-4

By Edward G. Anderson

Commonwealth Department of Supply, Sydney

Introduction

The Nullarbor Plain, Australia's most extensive limestone region, consists of about 65,000 square miles of almost horizontal beds of Tertiary limestone. The Plain extends from near Fowlers Bay, South Australia, approximately 600 miles west across the head of the Great Australian Bight into Western Australia. However, for its size, the Nullarbor appears to be deficient in caves compared with other Australian cavernous limestones. The vastness of the area, isolation, and complete lack of surface water, makes speleological investigation difficult. Some of the most important caves are more than 100 miles apart.

The 1963-4 Nullarbor Expedition was organised by members of the Sydney University Speleological Society (SUSS). Two major caves, as well as a number of smaller features were discovered in the western part of the Plain. One cave contains what is believed to be the longest single cave passage in Australia.

Previous Expeditions

Although various individuals and groups have previously investigated caves on the Nullarbor, the first major speleological expedition was made in December/January, 1956-7. It was organised by the Cave Exploration Group (South Australia) and followed the Inaugural Conference of the Australian Speleological Federation (A.S.F.) which was held in Adelaide. The expedition included cavers from most Australian speleological societies. In 1959-60, a smaller expedition was organised by CEGSA and led by a member of SUSS. A third expedition was organised by CEGSA for the summer of 1960-1. These trips carried out extensive exploration and surveying, mainly in the South Australian part of the Plain. Up to this time little speleological work had been done in the Western Australian sector.

Objectives of the 1963-4 Expedition

The basic purpose of the 1963-4 expedition was the exploration of the surface and caves of the Hampton Tableland area, near Cocklebiddy and Madura in Western Australia. A proper survey was to be made of each of the caves already known in the area, as well as any new discoveries.

Many of the Nullarbor caves exhibit notable air movements, particularly at or near entrances. To evaluate theories on the cause of these, preliminary observations were to be conducted at several blowholes. Simple chemical analyses of the natural groundwater found in caves and the continuation of zoological investigations were also included in the program.

Planning and Organisation

The expedition left Adelaide on December 28, 1963, and returned on January 18, 1964, after 16 days actually spent on the Plain. The party travelled 2,300 miles in the period and investigated a total of 22 caves, blowholes and dolines.

Most of the planning was done in Sydney by a committee consisting of N. Campbell (leader), E. Anderson (assistant leader), G. Hunt (treasurer) and J. Steele (quartermaster). The remainder of the planning was contributed by members of CEGSA in Adelaide. Of the 41 persons who joined the expedition, 21 were SUSS members, and the other 20 came from the following groups - University of New South Wales S.S., Illawarra S.S., Tasmanian Caverneering Club, Brisbane Cave Group, University of Queensland S.S., and CEGSA. The expedition, which cost about £A1,200, was financed by the participants. An additional amount was subscribed for future publication of the expedition results.

A passenger bus and a five-ton, four-wheel drive truck were hired in Adelaide and about 3,100 lbs of food purchased. Perishable food was stored in a 22 cubic feet refrigerator on the truck. Air temperature in the shade reached 118°F (48°C) on several occasions, but the food remained in good condition. As fresh water is obtainable at only a few places, 400 gallons were carried in tanks on the truck.

In view of the isolation of groups working the Nullarbor Plain, a portable radio transceiver is advisable as a safety precaution. This expedition established regular contact with the Flying Medical Service's base at Ceduna, South Australia, and, on one occasion, obtained important medical advice when a member of the party became seriously ill at Cocklebiddy and had to be moved 300 miles by vehicle to the nearest hospital at Norseman, Western Australia.

Exploration and Surveying

The 22 caves, blowholes and dolines visited by the expedition are placed in one of the following groups. See Figures 1 and 2 for locations.

Group 1 : Those visited previously by speleological expeditions and mapped in whole or part.

Group 2 : Those which had not been visited by any of the previous major expeditions, but had been explored by other speleologists at various times in the past.

Group 3 : Those believed not to have been previously investigated by speleologists.

Group 1	Group 2	Group 3
Koonalda C. N4	Madura C. NN	Bobobogol Doline N35
Unnamed Blowhole N32	Murra-el-elevyn C. NN	Erosion Blowhole N36
Unnamed Blowhole N33	Firestick C. NN	Mullamullang C. N37
Bunabie Blowhole N21	Kestrel Cavern No. 1. N40	Walpet C. N38
Chowilla Doline N17	Kestrel Cavern No. 2. N42	Joe's C. N39
Abrakurrie C. N3	Unnamed Doline N41	Parritappa Doline N43
Weebubbie C. N2		Kutowalla Doline N44
Clay Dam Doline N16		Winbirra C. N45

NOTE: Cave references less than and including 34 have been allocated by CEGSA and published in its Checklist of South Australian Caves, June, 1963. Those greater than 34 have been proposed by the expedition and have yet to be confirmed by the speleological societies concerned.

GROUP 1

Descriptions and maps of these caves have been published in other reports (e.g. Jennings, 1961), so will not be considered here.

GROUP 2

Madura Cave

Lat. 32°00'S. Long. 127°00'E. Photo Co-ords.: 8/5101, A2.3/0.0.*
A small party visited this cave to collect entomological specimens.

Murra-el-elevyn Cave

Lat. 32°00'S. Long. 126°00'E. Photo Co-ords.: Burnabbie 1/5418, ---.
Because of its proximity to the Eyre Highway, this cave has been known for a considerable time and referred to locally as Cocklebiddy Three Mile Cave. A precipitous collapse doline leads to several large chambers, the first of which contains a lake. The cave can be classified as "deep"(Thomson, 1950) and is one of the larger Nullarbor caves. As is the case with some other caves on the Plain, equipment is being installed by the owner of

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* Latitude and Longitude are to the nearest 5 minutes. Photo Co-ordinates, plotted by Jennings, refer to Madura 4-mile sheet unless otherwise indicated. Aerial photographs are from the National Mapping Office, a section of the Department of National Development.

the property to pump water from the lake to the surface. The expedition surveyed the entrance doline and the first large chamber to CRG Grade 6. The lake in the cave was approximately 289 feet below the surface of the Plain.

Firestick Cave

Lat. 31°45'S. Long. 127°00'E. Photo Co-ords.: 7/5059, C1.6/2.67.

Another deep cave, Firestick consists of a moderately degraded, but quite deep doline, which leads to a spacious cavern containing a steeply tiered talus slope. A survey was made by D. Lowry and M. Davis, of the Western Australian Speleological Group, in November, 1963 (Lowry, 1964a). Investigation revealed a small horizontal passage showing no signs of previous entry, which was developed at a higher level than other similar passages at the bottom of the cave.

Kestrel Caverns (N40, N42) and Doline N41

Kestrel 1. Lat. 31°40'S. Long. 127°10'E. Photo Co-ords.: 6/5755, C1.1/2.12. Kestrel 2. Lat. 31°35'S. Long. 127°15'E. Photo Co-ords.: 6/5755, C2.7/1.4. Doline N41. Lat. 31°40'S. Long. 127°10'E. Photo Co-ords.: 6/5755, C1.85/1.85. A description of these features and their discovery was published recently (Lowry, 1964b).

Kestrel No. 1 is similar to Murra-el-elevyn although its entrance doline is much more deeply undercut and its single main chamber is not as deep and is blocked at the far end by a rockpile. A grade 6 survey gave the floor-level depth of the main cavern as approximately 229 feet. Although there are many deeper holes in the floor, the cave does not reach the watertable.

Doline N41 is degraded and relatively shallow with a sufficient soil coverage on the floor to support a substantial amount of vegetation. The small holes among boulders at its deepest end do not lead to any cave. Kestrel No. 2 has a single chamber, similar in size, depth and general structure to that of Kestrel No. 1, but its entrance doline is not so precipitous.

GROUP 3

The discovery of the eight components of this group can be attributed directly to the use of tracings prepared by J.N. Jennings (Jennings, 1964) from a series of vertical air photographs of the Plain. The tracings give the location, relative to vehicular tracks, of all the surface features of this group except Erosion Blowhole. On the Plain, each of the features was found by compass traverse from an identifiable point, usually the nearest track. Often it was necessary to come quite close to a doline before it could be detected (see photo Kestrel No. 2), so that care was required in

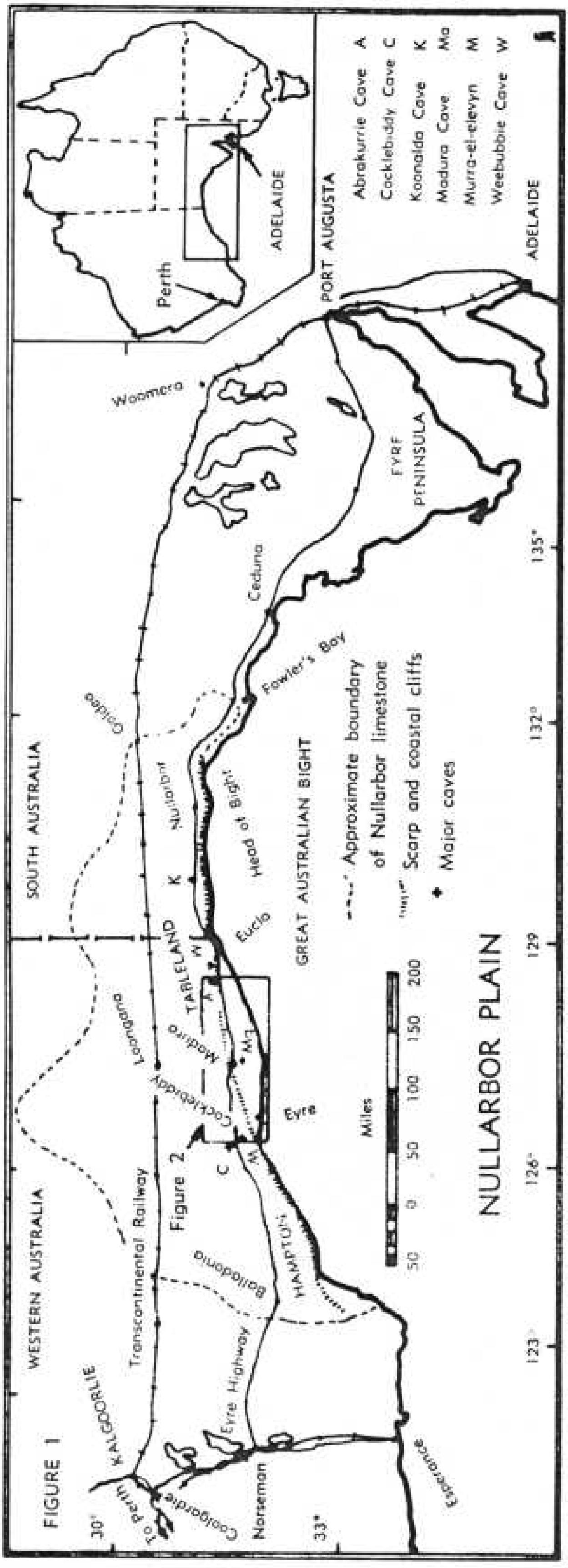


FIGURE 1

NULLARBOR PLAIN

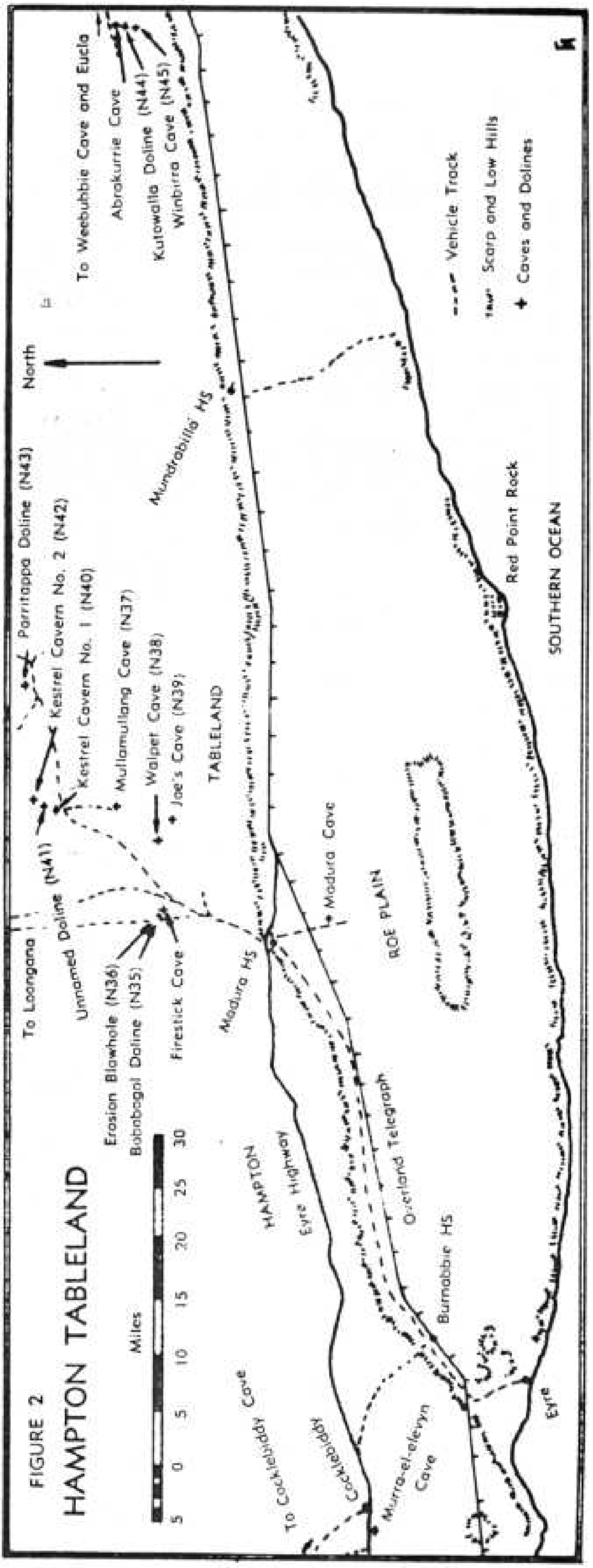


FIGURE 2

HAMPTON TABLELAND

making the traverse, which might amount to a distance of five miles over remarkably uniform country.

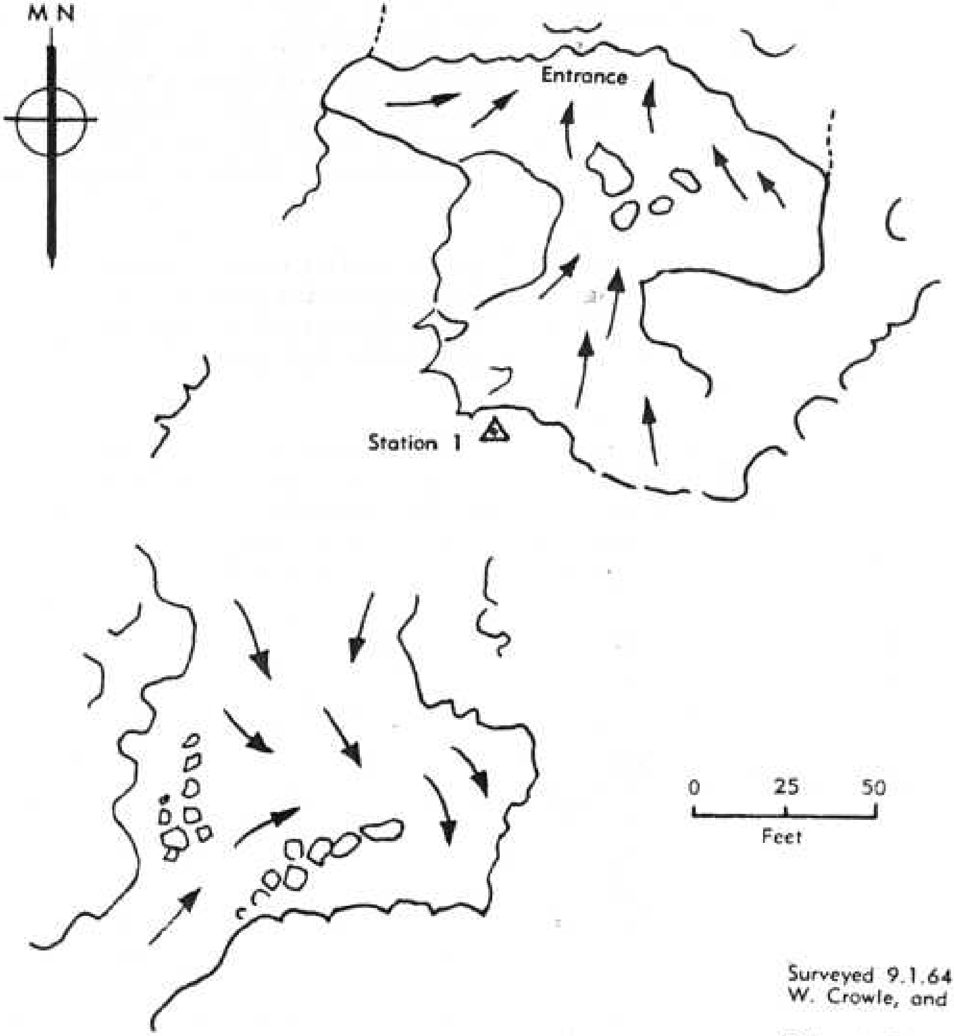
Mullamullang Cave, N37

Lat. 31°45'S. Long. 127°10'E. Photo Co-ords.: 7/5061, C3.7/1.3. This is undoubtedly the longest cave discovered on the Nullarbor Plain, and is probably the longest single cave passage in Australia. Slightly more than 1.6 miles were surveyed by a team of eight during the 25 hours available. Cave extends for approximately ½ mile beyond the end-point of the survey. It terminates in a rockpile.

The direction of overall trend is about 060° magnetic. The pattern of the better-defined collapse surfaces of the cave's entrance doline, which appear to evidence fairly strong structural control (Figure 3), hints at the liklihood of structure being a factor in shaping the rest of the cave as well. Based on this possibility, an examination of the plan indicates that the trend of the cave might be the result of development in a combination of several structurally governed directions, which are clearly defined in the doline. In most cases, evidence of such control presented by inspection of the plan, is insufficient to allow further consideration without more precise observation in the cave itself. One of the more obvious examples is the common alignment, in a direction of approximately 015° magnetic, of the following lineaments: parts of both the more easterly and westerly sides of the doline, the cave wall immediately before and beyond the Southerly Buster, the side passage at section 13 (which appears to be collinear with the wall of the doline), and the side passage between Yipees Point and the 1 mile cairn.

The vertical features of the cave, which are clearly illustrated in the developed longitudinal and transverse sections, reflect the typical pattern of most of the deep Nullarbor caves. Smooth, level roofs and medial detritus piles including large roof-collapse slabs, combined with high-domed chambers and their associated rockpiles, are common. An exception is the depth of the cave. Real horizontal development is not reached before a depth of 300 feet; while the watertable level - represented by several small pools in Oasis Valley, water in a slot in the wall near Yipees Point, and the much larger White Lake - is at a depth of approximately 370 feet. The highest domed chamber (section 31) reaches to within 135 feet of the surface, and the top of the rockpile below it is about 200 feet above the watertable.

The Entrance Doline. See Figure 3. The doline is divided by a narrow medial saddle of weathered bedrock into two distinct collapse depressions. The more northerly one, containing the main entrance, is the deeper and less degraded. Its north wall is a high cliff overhanging a rock-strewn talus slope which leads down into the main entrance chamber. On the opposite side of the saddle, the more southerly depression has been degraded to a greater extent. Consisting of well consolidated material, its grass-covered



Surveyed 9.1.64 by I. Wood,
W. Crowle, and G. Wilson.

Prismatic Compass, Steel Tape.

C.R.G. Grade 4.

FIGURE 3. PLAN OF COLLAPSE DOLINE OF MULLAMULLANG CAVE, NULLARBOR PLAIN, W.A.

floor slopes gently to the foot of a low cliff at the south side. Here shallow undercutting provides access to a passage which was extended under the doline by digging, to emerge on the eastern side of the cave at the bottom of the main entrance chamber.

Details of the cave. Around the toe of the talus slope in the main entrance chamber, the roof converges with the floor to form a slot which is almost filled by huge boulders. Here there is an almost vertical drop of 40 feet into another chamber very similar to the main chamber of Firestick Cave. Predominantly horizontal development of the cave begins at the bottom of this chamber. The shape of the remainder of the cave is clearly shown in the plan and sections, but the following features require further description.

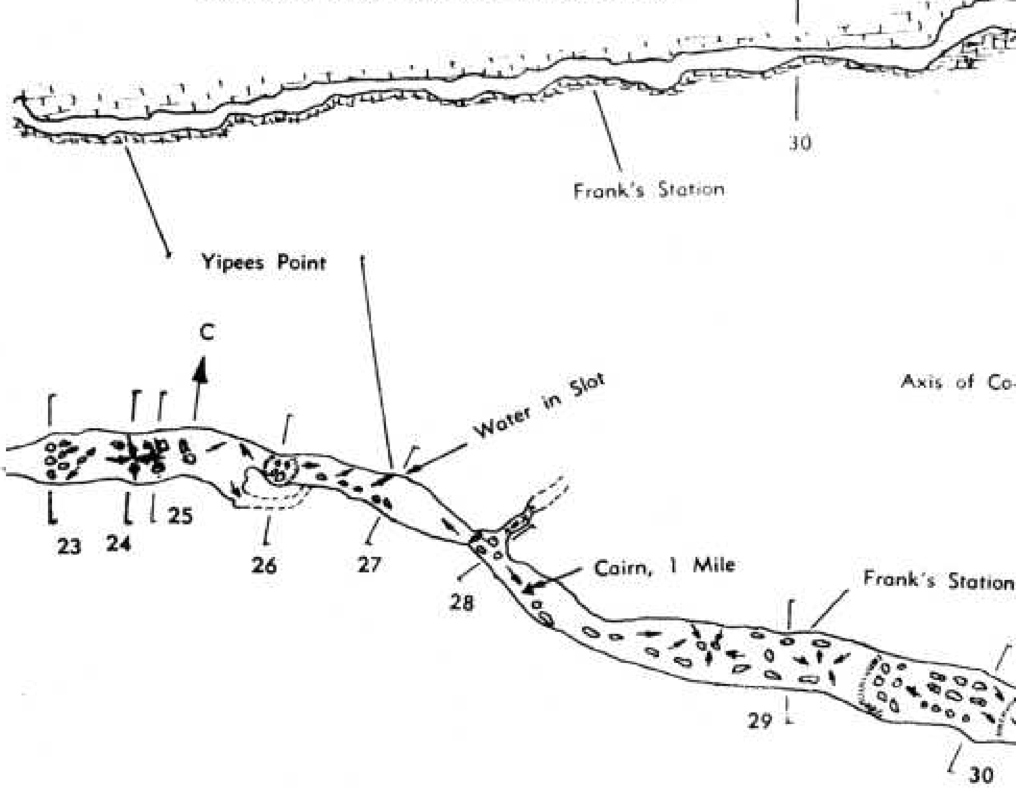
The Southerly Buster is a constriction in the cave produced by a lowering of the roof and convergence of the walls. Its minimum height is about two feet, but there are channels in the roof as much as one foot in depth. A strong wind was observed at this point which has probably been partly responsible for the erosion of the roof.

At Smoko Junction (section 10) a large cavern is formed by the confluence of the main passage and a similarly proportioned but lower side passage. Exploration of this side passage showed it was connected to the main passage again, further on, by a small almost sand-filled squeeze (section 13). In the main passage at section 12, a shelf across the full width of the cave, combined with a lowering of the roof, forms a horizontal slot about three feet high. A strong wind was observed here also.

The Sandchute (near section 17) is the result of a roof collapse which almost blocks the passage. A penetrable space remains, however, between the steeply sloping roof and floor. A copious cover of loose sand down the slope gives the whole formation its name. Just before Yipees Point at section 26, a small side passage loops back under a rockpile in the main passage. Between Yipees Point and the 1 mile cairn, is a small side passage containing numerous small pools of water.

Cave deposits. Virtually the entire floor of the cave consists of detrital material and large collapse blocks or boulders. Although all this material has resulted from breakdown of the surrounding rock, it can be classified into one of two very distinct forms: 1. Relatively fine-grained material, ranging from coarse sand to dust, and 2. Larger component material ranging from huge collapse blocks to rubble. Each of the two forms predominated in a particular part of the cave. Deposits of sand, particularly in mounds (an unusual formation in the Nullarbor caves) are common in the forward part of the cave, between about sections 3 and 19. The 25 feet high, almost circular pile of sand called the Dune (section 4), which is developed in a fairly high domed chamber, is a fine example of this formation. In the remainder of the cave, larger collapse material predominates. Notable

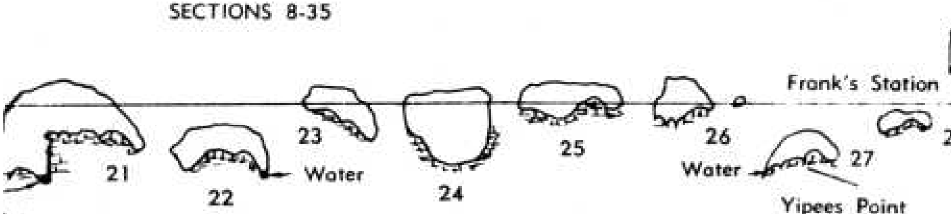
DEVELOPED LONGITUDINAL SECTION B-C-D



Feet

Note: The reduction factor of Sections 1-35 is double that of the other elevations

SECTIONS 8-35



- Rim of Doline
- Cave Outline
- Unsurveyed Outline
- Limestone (Schematic)
- Rock Detritus
- Sand
- Rockpile or Sand Dune
- Standing Water
- Dry Watercourse
- Gypsum Flowers
- Downward Slope

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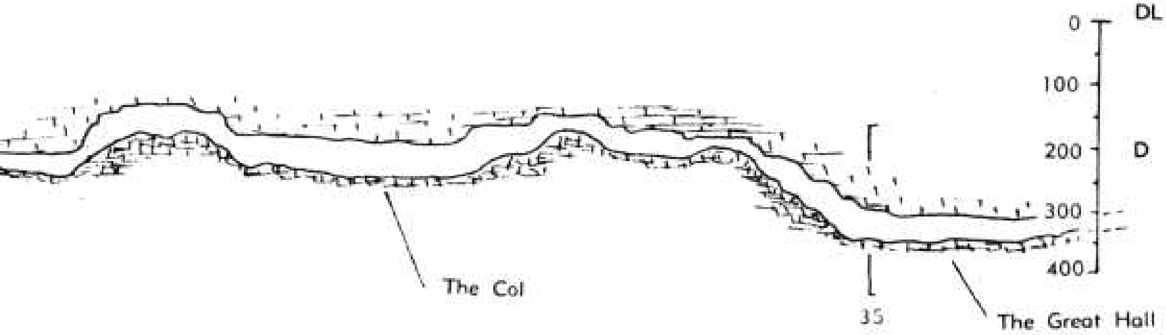
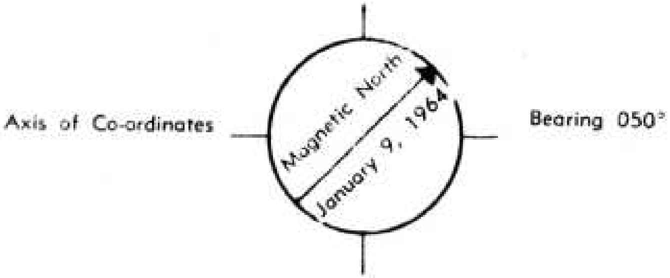
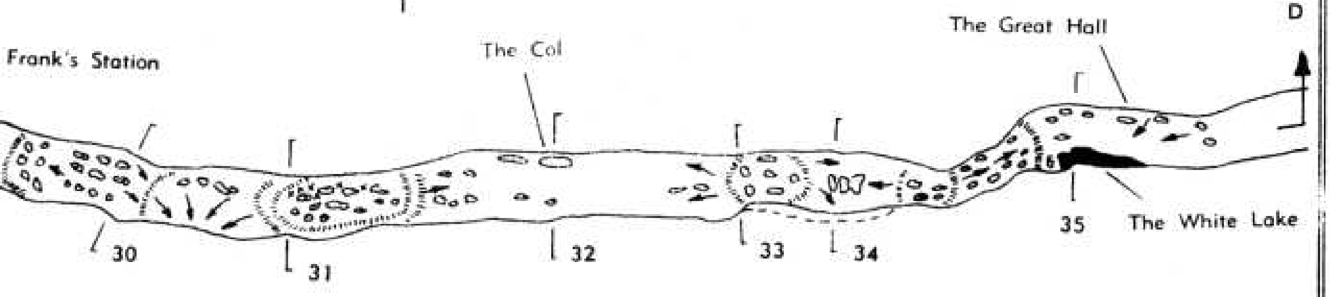
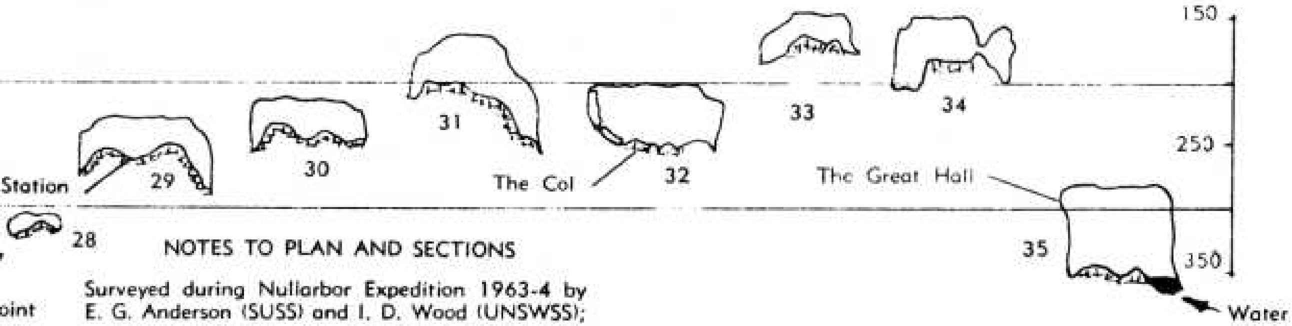








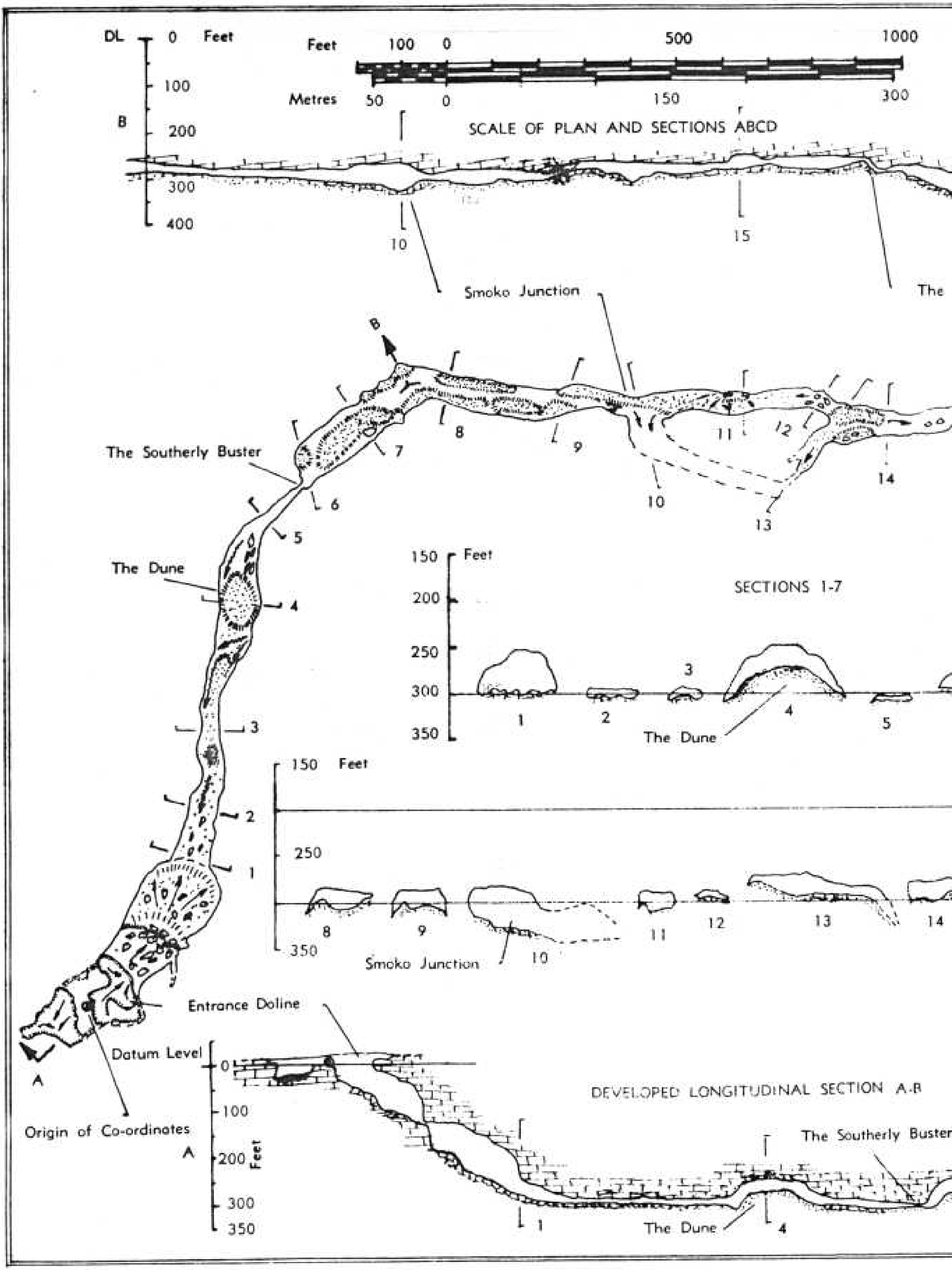
NOTES TO PLAN AND SECTIONS

Surveyed during Nullarbor Expedition 1963-4 by E. G. Anderson (SUSS) and I. D. Wood (UNSWSS); with the assistance of W. A. Crowle, D. Perkins, J. L. Steele (SUSS), R. Richardson (ISS), F. R. Brown and G. Wilson (TCC). Drawn by E. G. Anderson. Type and plates by "Helictite."

Origin of Co-ordinates and Datum Level arbitrarily chosen as the position of Station 1 on the median saddle in the Entrance Doline. Vertical scales give depth, in feet, below Datum.

Surveyed with Miner's Dial and Steel Tape to C.R.G. Grade 6. Roof and floor outlines of Longit. Section C-D drawn in cave, but Longit. Section A-B-C prepared later from roof heights and cross-sections and thus less accurate.

Plan and Sections of
MULLAMULLANG CAVE (N37)
Nullarbor Plain, Western Australia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Entrance Doline
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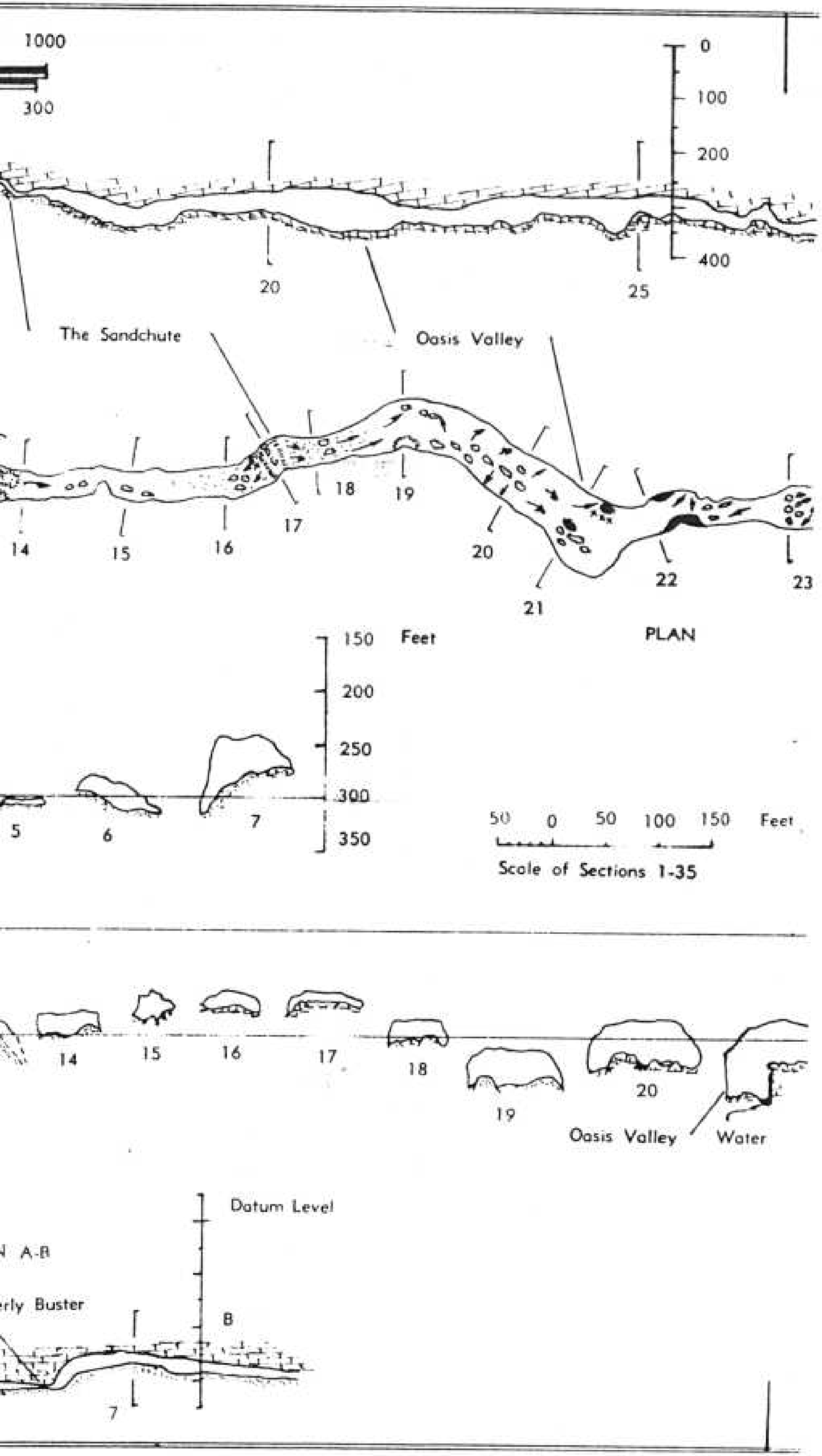
DEVELOPED LONGITUDINAL SECTION A-B
The Southerly Buster
The Dune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examples of this are the talus near the entrance, the collapse slabs in and near the Col (section 32) and the high rockpiles on either side. Thus rocky collapse material occurs mainly further into the cave where vertical development (or degradation?) is greater, while the sandy material is restricted to the forward part of the cave at a lower level. The inference that the two types of cave deposit are the result of breakdown of different parent rock cannot be disregarded. This difference in lithology could be due to variations in thickness of the Nullarbor Limestone, or due to facies change in the Wilson Bluff Limestone.

Decorative deposits in the cave are meagre. Small gypsum flowers were seen in many places beyond the Sandchute, and calcite encrustation appears around the pools in Oasis Valley and the White Lake. A few pieces of wood and charcoal discovered near section 34 remain unexplained.

Water action. Possible indications of a former substantial flow of water were observed along the horizontal passage between section 1 and 5. Near the forward part of the passage they appeared in the rubble which completely covers the floor, while further in ripple marks (indicating flow towards the present entrance) could be seen in channels on either side of a medial sandbank (section 3). A broad, water-carved channel, about 18 inches deep, traverses the sand floor at the foot of the entrance side of the Dune. No current markings were seen on the walls, but the crumbly nature of the limestone would not be conducive to preservation of these in any case. The only water in the cave at present is contained in static pools and lakes.

Winbirra Cave N45

Lat. 31°45'S. Long. 128°45'E. Photo Co-ords.: Eucla 6/5180, ---. Winbirra was the second deep cave visited by the expedition. It had been discovered previously by a local property owner, but this was the first investigation by speleologists. A survey was made by E. Anderson - surface, grade 3; underground, grade 1.

The entrance doline has precipitous cliffs on the north, west and south sides. A very steep and unstable talus slope transverses the doline from the east down to the cave mouth at the foot of the western cliff. Continuing in this direction it leads underground, where it fans out to form a level platform at the bottom of a spacious domed chamber. Behind this platform a narrow, almost vertical slot is formed between the steeply descending toe of the talus slope and the most westerly perimeter of the chamber wall. About 200 feet below the level of the platform, a lake extends almost around this slot. The talus slope can be seen continuing down under the water.

Bobobogol Doline N35

Lat. 31°45'S. Long. 127°00'E. Photo Co-ords.: 7/5059, C1.6/3.0. This is a small, shallow, circular doline. Its soil floor supports a good grass coverage and a few trees. There is no cave.

Erosion Blowhole N36

Lat. 31°45'S. Long. 127°00'E. No photo reference. This blowhole was discovered while searching for Bobobogol and is only a short distance from it. It is developed in the side of what appears to be a typical erosion gully, about 100 feet long. A strong air flow into the blowhole was observed in the late afternoon.

Walpet Cave N38

Lat. 31°45'S. Long. 127°10'E. Photo Co-ords.: 7/5061, C1.15/4.0. This large doline was found to lead to only a small cave. A maze of shallow passages among the boulders of a rockpile were explored without further discovery.

Joe's Cave N39

Lat. 31°45'S. Long. 127°10'E. Photo Co-ords. 7/5061, C0.3/2.9. The doline associated with this cave is severely degraded. However, a low horizontal passage leads off from the flat floor of the depression and extends for an estimated distance of 600 feet before being blocked by a rockfall. It might be possible to penetrate this rockfall.

Parritappa Doline N43

Lat. 31°35'S. Long. 127°25'E. Photo Co-ords.: 6/5757, C4.47/1.57. The major characteristic of the doline is a dry water course leading to the flat bottom of the depression. There is no cave.

Kutowalla Doline N44

Lat. 31°45'S. Long. 128°25'E. Photo Co-ords.: Eucla 6/5180, ---. A particularly large doline which is moderately degraded. It has a level, grassy floor. A dry stream course leads into its eastern side and a cliff about 60 feet high forms its western wall. A few small holes at the foot of the cliff were investigated but no cave was found. Investigation of its northern rim revealed several small rock shelters, apparently the result of aerial weathering.

Cave Meteorology

Large, reversing air movements between the surface and underground chambers are frequently encountered in the Nullarbor caves. This phenomenon is most pronounced in the smaller caves or blowholes. These blowholes are narrow, vertical tubes (usually the result of solution) leading from the surface to either a solution or collapse chamber below, which may or may not have additional passages. As far as can be determined by exploration they are normally less than 100 feet deep, and range in volume from less than 1,000 to about 450,000 cubic feet in the case of Jimmy's Cave (N23), the largest known blowhole.

During the expedition, some quantitative observations were made at Bunabie Blowhole (N21), half way between Koonalda Homestead and Eucla, and an unnamed blowhole (N33), about one mile SSE of Koonalda Cave. In addition, strong air movements were noted in another unnamed blowhole (N32), about three-quarters of a mile SSE of Koonalda Cave, and also at three constrictions in Mullamullang Cave (N37).

The volume of air passing through the blowholes indicates the existance of interconnecting caves of much larger volume than the blowholes and their small associated chambers. The readings taken show a regular, periodic reversal of air flow, with a time frequency approximating sunrise and sunset. This carries a strong inference that temperature variations at the surface are responsible, at least in part, for the phenomenon. The actual meteorology would naturally comprise a much more complex sequence of events.

Water Analyses

Water from static lakes in a few of the caves was analysed for calcium and chloride ions, representing the calcium carbonate and sodium chloride content respectively. Measurements of the calcium give an indication of the rate of solution of the surrounding limestone. When combined with other measurements made in the past (King, 1950; Jennings, 1961), they are useful in comparisons of the different caves of the Plain, and of these caves with those of other limestone areas.

Samples were analysed in the field, almost immediately after being brought to the surface. All samples were taken from approximately 12 inches below the water surface. The pH was determined with a colorimetric comparator; calcium by the EDTA titration method; and chloride by titrating a neutral solution with silver nitrate in the presence of chromate indicator. All measurements were made in accordance with British Standard 1427 : 1962. Calcium is expressed in parts per million (ppm) in terms of its carbonate, and chloride similarly in terms of sodium chloride. The effect of the fairly high cloride (and probably sulphate) content of the water on the measurements of calcium is uncertain at this time.

Samples were taken from the first, second and third lakes in Koonalda Cave, the main lake in Murra-el-elevyn Cave, the White Lake and two lakes in the southern side of Oasis Valley in Mullamullang Cave, and the main lake in Weebubbie Cave. In Koonalda, the first and second lakes are shallow and separated by only a low, rocky island, while the third lake is completely separate and much deeper. See Table on page 132.

Plotting the calcium determinations on Trombe's graph of saturation curves (Trombe, 1952), suggests that all samples but one are saturated with

Table 1 : Results of Water Analyses

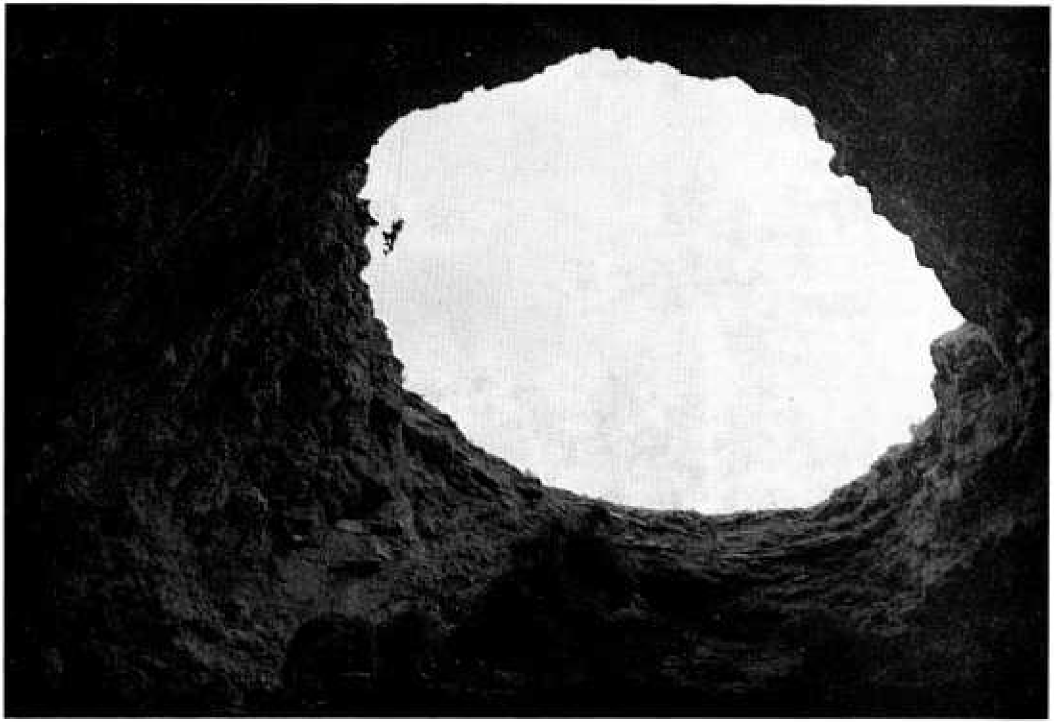
Location	Date	Temp. °C	pH	$CaCO_3$ ppm	NaCl ppm
1. Koonalda 1st. Lake	31.12.63	14.3	7.9	232	14500* *14.1.64
2. Koonalda 2nd. Lake	31.12.63	14.6	8.2	145	n.d.
3. Koonalda 3rd. Lake	31.12.63	16.9	8.0	116	n.d.
4. Murra-el-elevyn	3.1.64	19.2	7.8	249	13500
5. Mullamullang 1st. Lake	9.1.64	n.d.* *16° est.	8.2	326	7600
6. Mullamullang 2nd. Lake	9.1.64	n.d.* *16° est.	8.2	340	6650
7. Mullamullang The White Lake	9.1.64	n.d.* *16° est.	8.1	341	6970
8. Weebubbie	14.1.64	n.d.	8.0	240	10900
9. Port Augusta Sea Water					39600

respect to calcium carbonate. The exception, from Koonalda Third Lake, is almost saturated. All samples from Mullamullang Cave show strong saturation, and this is further demonstrated by the thick calcite incrustation around each lake.

Also worth noting is the relatively low chloride content of the water in Mullamullang as compared with the chloride content of the sea water at Port Augusta, South Australia.

Another interesting aspect of these measurements is the dissimilarity in the water temperatures. As the Second and Third Lakes in Koonalda are only 400 feet apart, the difference in temperature is remarkably large. The lake in Murra-el-elevyn is also at a relatively high temperature for sub-surface water. Water temperatures were not taken in Mullamullang Cave, but are estimated at 16°C.

Plate 10



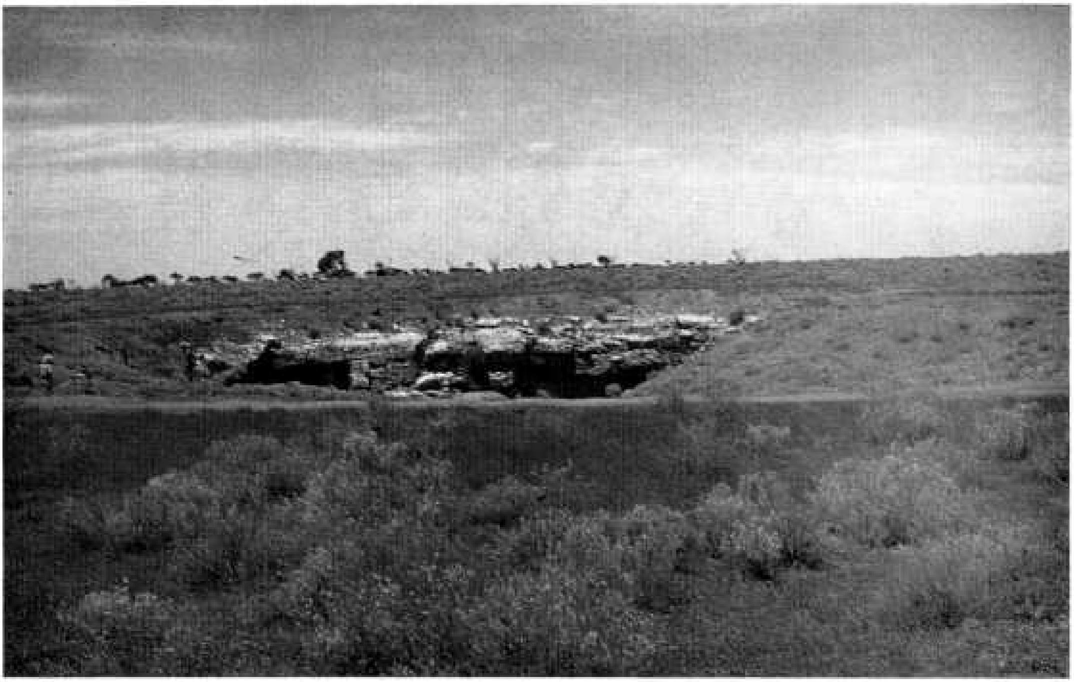


Plate 11

Zoology

Much of the material collected by the expedition has been deposited in the South Australian Museum and specimens have been sent to specialists for identification. Bat specimens were collected from several caves, including Mullamullang.

One important discovery was made in Murra-el-elevyn Cave. Here, Mr. N. Campbell found a skeleton, believed to be that of a new species of *Thylacinus*. The bones, at present, are at the Department of Zoology, Monash University.

Summary

It seems fair to say that the expedition made a worthwhile contribution to the exploration and mapping of caves in the western part of the Nullarbor. The investigation of Mullamullang and Winbirra has brought the number of known deep caves to nine, and the grade 6 surveys and other sketch maps will no doubt be useful in the geomorphological study of the Plain. However, a considerable amount of work remains to be done. The surveys of Murra-el-elevyn and Mullamullang Caves need completing, and the terminal rockpiles in Mullamullang and Joe's Caves should be investigated for possible extensions. The possibility of extending Winbirra Cave by diving is also worth considering. Scope exists for cave meteorology studies. Ground resistivity measurements or some other method might be employed profitably in determining the true extent of the blowholes. Doubtlessly many more caves and blowholes remain to be discovered.

The Sydney University Speleological Society, later this year, proposes to publish a comprehensive report on this Nullarbor Expedition as a special edition of its Journal.

Acknowledgments

The author wishes to thank Messrs. I.D. Wood and J.L. Steele for the information and comments on their work on cave meteorology and water sampling respectively, and for permission to reproduce their photographs. The maps of Mullamullang Cave are as much due to the efforts of Mr. Wood as those of the author, and the assistance of the other members of the surveying team was of course invaluable. Thanks are also due to Mr. J.N. Jennings of the Australian National University for the use of tracings from aerial photographs and general discussion.

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Captions to Plates 10 and 11, between Pages 132 and 133

Plate 10 : Top picture. Entrance doline of Kestrel Cavern Number One, from talus slope inside cavern. Photo: E.G. Anderson.

Bottom picture. Kestrel Cavern Number Two doline, showing typical open surrounding country. Note figure to left of doline. Photo: J. Steele.

Plate 11 : Top picture. Entrance doline to Firestick Cave. Figure can be seen bottom centre. Photo: J. Steele.

Bottom picture. Lake in Mullamullang Cave. Light in background is approximately 350 ft from camera. Lake is 150 ft long. Photo: I.D. Wood.

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END OF VOLUME TWO