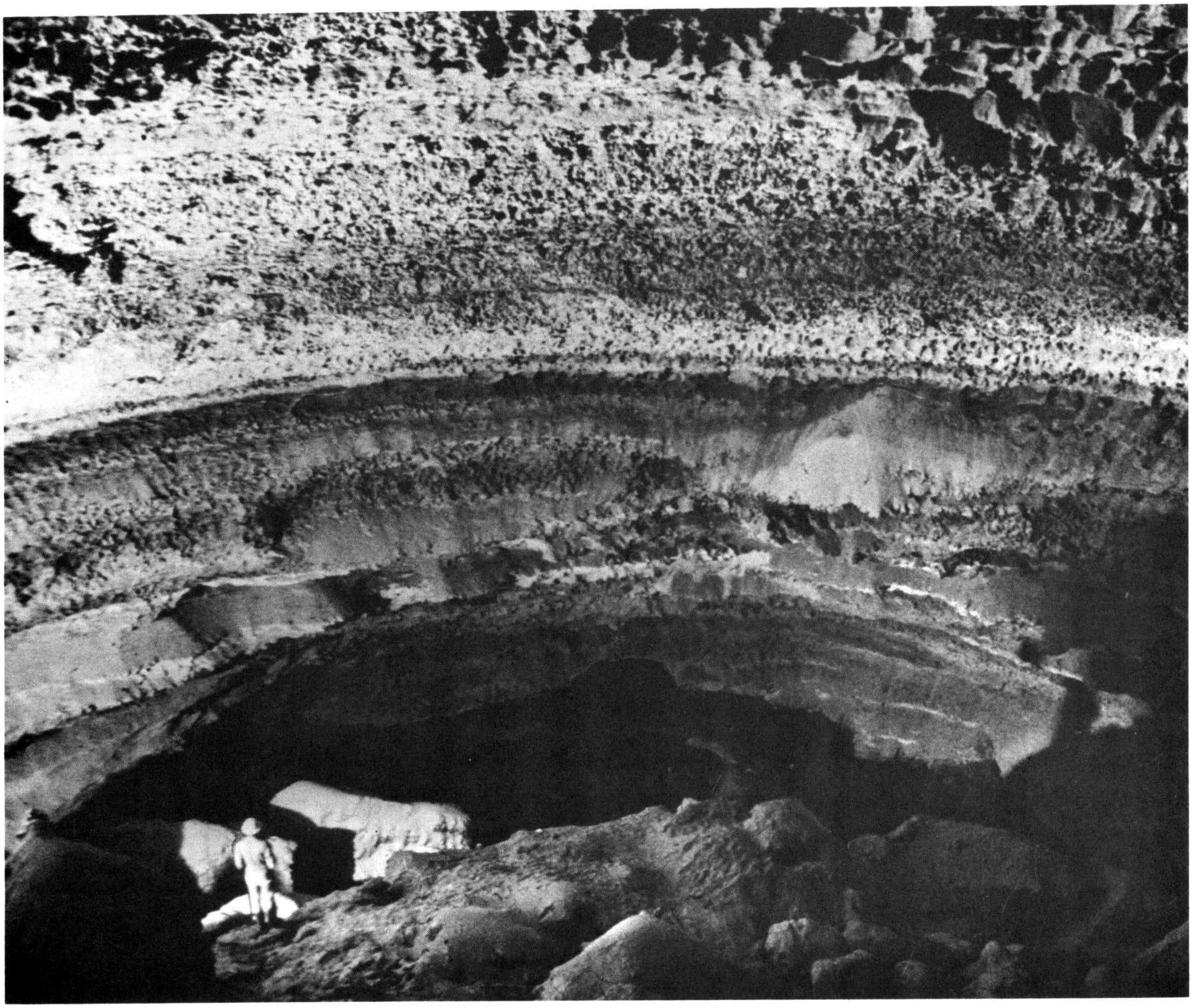
Vol. 8, No. 1 JANUARY, 1970 PRICE 60c.

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



The Powder Room, Mullamullang Cave N37, Nullarbor Plain, Western Australia. Note tafoni weathering on roof and accumulation of rock-flour on ledges and floor. Photo.: E.G. Anderson.

"HELICTITE"

Journal of Australasian Cave Research

Edited by Edward A. Lane and Aola M. Richards

VOLUME 8, NUMBER 1 Published Quarterly JANUARY, 1970

CONTENTS

Price of this issue: To non-subscribers, A$1. Additional copies to subscribers, 75c. Included in annual subscription, 60c. Annual subscription A$2.40, post paid Australia. All foreign subscriptions, A$2.60, post paid. All subscriptions taken on basis of full volume of four issues. Correspondence, contributions and subscriptions to "Helictite", Post Office Box 183, Broadway, New South Wales 2007, Australia. "Helictite" is printed and published by E. A. Lane.

THE ORIGIN AND DEVELOPMENT OF MULLAMULLANG CAVE N37, NULLARBOR PLAIN, WESTERN AUSTRALIA

G. S. HUNT

School of Zoology, University of New South Wales, Sydney

Abstract

Mullamullang Cave N37 is the longest and most complex cave on the Nullarbor Plain, Southern Australia. Unlike the other caves, it possesses extensive levels of phreatic solution tube passages which permit stronger inferences to be made on the development of the collapse passages constituting the bulk of Mullamullang Cave and other deep Nullarbor caves. These passages have been formed by collapse through overlying belts of solution tube networks along an elongated zone of cavitation in the limestone. Massive breakdown was probably initiated at depth within the zone, at least 50 feet below the present watertable level. Upward stoping of the collapse would have been facilitated by the higher network levels in the zone, such as the Ezam and Easter Extension.

Channelling of groundwater flow under the Plain is suggested by the belt-like nature of the networks. An epiphreatic origin is proposed for the network levels though convincing morphological evidence is wanting. Eustatic changes in sea level have been of fundamental importance in the development of the multiple levels. Wetter periods in the past were probably important as little development is taking place under present-day dry conditions. Correlation of wetter periods with Pleistocene glacials would help explain the development of huge collapse passages, but such correlation cannot be assumed on present evidence. Massive collapse and doline formation were followed by subaerial weathering and vadose activity which modified the cave - especially near the entrance.

Correlation of levels in Mullamullang with those in other Nullarbor deep caves is attempted. However, Mullamullang Cave is unique probably due to the lithology of the Abrakurrie Limestone in which it is developed.

Introduction

Mullamullang Cave N37 was discovered during the 1963-64 expedition to the Nullarbor Plain organised by the Sydney University Speleological Society (Anderson, 1964). Further expeditions were organised by the Cave Exploration Group (South Australia), the Sydney University Speleological Society and the Western Australian Speleological Group. Many significant discoveries were made and the original map of Anderson and Wood was extended. Most notable were the CEG(SA) Nullarbor Expedition 1965-66 and two follow-up expeditions during 1966 which resulted in the publication of a revised map (Hill, 1966). Some general observations on the geomorphology were included in various expedition reports. A review edited by Dunkley and Wigley (1967) outlines much of the work done on the Nullarbor up to that date.

The theories on the origin of the deep caves of King (1949), Jennings (1961, 1963) and Lowry (1964b) were based on studies of previously known caves which are of comparatively simple form, having long straight halls with lofty arched or domed roofs. They usually have apse-shaped endings where the roof slopes more or less abruptly beneath the level of the floor or watertable. Jennings (1965, 1967b) indicated the importance of Mullamullang - its great length and varied form which enable observations to be made on features that might only exist as traces, if at all, in other deep caves. These features, and their relevance to the development of Mullamullang and other deep caves, form the basis of this paper. Many of the points were discussed in a paper (unpublished) presented at the Sixth Conference of the Australian Speleological Federation (Hunt, 1967).

A complete discussion of the geomorphology of Mullamullang is not possible as recent data are not yet available and considerable work remains to be done. Much can be learned from Mullamullang, although it is necessary to exercise some restraint in applying the ideas to problems of the genesis of Nullarbor deep caves in general. Many features of Mullamullang may be peculiar to its geological setting.

Geomorphological Setting

Factors important to a discussion of the geomorphology of the Nullarbor deep caves have been discussed by Jennings (1961, 1963, 1965, 1967a, and 1967b). Lowry (1968a) has summarised the stratigraphical work he recently completed on the Plain.

The known limits of Mullamullang penetrate two limestone formations - virtually all horizontal development occurs within the older Abrakurrie Limestone with only the doline penetrating the Nullarbor Limestone above. Lowry (1968a) describes the Abrakurrie Limestone as a medium to coarse grained, yellowish, bryozoal calcarenite. The lower parts are porous and friable, but weathering has made the upper parts hard and tightly cemented. The Nullarbor Limestone is a hard, tightly cemented calcarenite. Fifty-eight feet are exposed in Mullamullang, with the bottom 21 feet belonging to the Mullamullang Limestone Member, a biostromal algal limestone (Lowry, 1968a). Mullamullang lies within the top 322 feet of the Abrakurrie Limestone. This limestone, however, thins out eastwards and many of the deep caves penetrate the older Wilson Bluff Limestone, a white chalky bryozoal limestone. The lower, submerged parts of Mullamullang may also penetrate this formation. Lowry assigns the Wilson Bluff Limestone to the Upper Eocene and the two over-lying formations to the Lower Miocene.

The limestones of most importance to the development of the deep caves are the Abrakurrie and Wilson Bluff Limestones. The differences between the two may have important consequences. Anderson (1964) and Jennings (1965) have commented on the variability of the Abrakurrie Limestone in Mullamullang and hinted that this might have had morphological consequences in the development of the cave. Lowry (1966b, 1968a) notes that some beds are rich in echinoids, brachiopods and pectinid molluscs and that current bedding is common. This bedding and the presence of overturned pectinid valves suggests a shallow water depositional environment characterised by frequent currents. Beds therefore could vary much in thickness and may often be completely truncated. A knowledge of the lateral extent and thickness of beds is important for a fuller understanding of the development of solution tube levels in the cave.

The parts of the Wilson Bluff Limestone and Abrakurrie Limestone in which the majority of caves have developed are regarded as being mostly very porous and permeable (Jennings, 1961; Lowry, 1968a). A porosity of 26 percent has been given by King (1949) for the former limestone. No direct measurements of permeability have been made, though Wigley (1967) believes that the results of his cave breathing studies indicate that the permeability of the wall limestone in Mullamullang is high. Even though parts of the limestone are highly cemented, the general picture of a virtually continuous and planar watertable under the Plain is probably acceptable.

Uplift of the limestones probably occurred at the end of the Lower Miocene (Lowry, 1968a). The relatively weak jointing and absence of folding or major tilting suggests that the region has remained relatively stable since.

With only one exception, the deep caves are confined to the better-watered coastal scrublands of the Hampton Plateau portion of the Plain where joint-controlled ridge and trough systems occur. This hot, semi-arid coastal region has a higher and more effective rainfall than the inland hot arid regions of the Plateau (about ten inches compared with six inches per annum). Jennings (1961) believes the distribution of caves is probably due to the wetter climate of the coastal region.

Present conditions do not appear to favour cave development by solution (Jennings, 1961; Lowry, 1964b) and it seems necessary to postulate wetter periods during the Tertiary and/or Pleistocene to explain the large dimensions of the deep caves.

Most evidence gathered to date relates to climates in comparatively recent times. Lundelius (1960, 1963) cites paleontological evidence, relating to the extinction of many marsupials on the Plain, which he believes points to the onset of unfavourable arid conditions. However, Merrilees (1968) stresses the need for caution against inferring too much from paleontological data without other local evidence in support.

Jennings (1967b) believes that "The Dip", a string of depressions near Hughes on the Trans-Continental Railway, is what remains of a fossil river course which entered the Plain from the north. As no stream flows on the Plain today this is strong evidence for wetter conditions in the past (or conditions of more effective precipitation). On the other hand, Jennings believes that surface karst development has been retarded and past conditions were not very much different from those of today.

Jessup (1961) presents evidence pointing to wetter and drier periods in the past. He believes that soils were blown to the east from the Nullarbor as the vegetation became sparse after the onset of drier conditions and that soil formation occurred under a thicker vegetation cover during wetter periods.

Lowry (1967) has produced evidence suggesting recent climatic change on the Plain. In Thylacine Hole N63 the older generation stalactites are of calcite. New generation stalactites are halite which may possibly be explained by more-arid conditions in recent times.

Ingram's (1969) palynological studies of the same cave do not contradict, nor support, this conclusion. Conditions similar to the present seem to have occurred at some time between 2,000 and 5,000 years BP. Pollen from the desiccated gut contents of mammal remains suggest a flora similar to that of today.

It has not been established for the Nullarbor that wetter conditions accompanied Pleistocene glacials. Indeed, Galloway (1965) argues that such a correlation may not be valid and suggests that, on present evidence, an interglacial-pluvial correlation is more likely. He also believes the desert belt of Australia expanded rather than contracted during the glacial. If this were so, the Nullarbor would have been relatively dry and not wet as has previously been suggested.

The detailed study of cave sediments, including those in the initial parts of Mullamullang (discussed below), should provide more-definite evidence. R.M. Frank has recently studied sediments from the Gallus archeological site in Koonalda Cave N4 and results of this work are to be published shortly.

The balance of evidence to date suggests that wetter periods than at present occurred on the Nullarbor since uplift of the limestones, but this must still be regarded as inconclusive. There is little or no evidence to suggest that wetter periods accompanied Pleistocene glacials.

General Description of Mullamullang Cave

Entry to the cave is by a large collapse doline similar to those leading into other deep caves and large enough to be clearly visible on air photographs (Jennings, 1964).

More than six miles of passage has been explored and mapped (Hill, 1966), and the cave shows an overall trend of about 045 degrees magnetic (Figure 1). About 17,500 feet is due to major collapse, while the remainder comprises small solution tube passages which have been little affected by collapse. All known solution tube development must have preceded massive collapse as the tubes have been breached by the collapse. The Easter Extension series can be entered at Oasis Valley (at 4,000 feet*). The Extension "re-enters" the main passage near Frank's Station (at 4,800 feet) but this has yet to be shown on the map (A.L. Hill, pers. comm.). A short section, the J.B. Maze, can be entered from the western wall at Oasis Valley and is presumably a continuation of the Easter Extension. The higher Ezam series of passages is entered from the Dome (at 15,500 feet) (Figure 2). The major collapse passage itself branches, forming the Smoko Junction Loop (at 2,300 feet) and two branches, the Left Branch and the Right Branch, at just over 12,000 feet. The Left Branch is the major one, but is blocked by a huge mass of breakdown blocks at the Dome. Attempts to extend beyond this have failed. The Right Branch is slightly longer than the Left but becomes progressively smaller and lower beyond the second lake. A few minor, though morphologically significant side passages occur at points along the main passage (at 2,000 feet; at 2,800 feet off the Smoko Junction Loop; at 4,800 feet; at 5,200 feet; at 11,200 and 11,700 feet).

Lakes occur at intervals along the cave and are separated by collapse passage which reaches various heights above lake level. The lakes indicate that the watertable is at a depth of 390 feet below the Entrance (Hill, 1966). The watertable was calculated by Hill to be about 20 feet above mean sea level giving a gradient to the sea of approximately six inches in the mile.

Entrance Doline

The Entrance Doline (Plate 1a) has been described by Anderson (1964). Jennings (1967b) refers to it as a double of "dumb-bell" doline, collapse having perforated the surface at two closely spaced points leaving a median saddle of little-disturbed bedrock (Figure 3d). The northern doline leads into the cave. Cave undoubtedly continues in a south to southwest direction, but entry via the southern doline has yet to be achieved. The

---

* Distances are measured from the Entrance (Figure 1) and are approximate.

northern doline descends rapidly. The initial descent, the daylit Entrance Amphitheatre, reaches a depth of 160 feet. The twilight Powder Room amphitheatre descends to 330 feet where predominantly horizontal development of passage begins. A thick blanket of rock flour from subaerial weathering of the roof covers the breakdown block material on the floor of the Powder Room (see photograph on cover).

The double doline acts as a focus for surface drainage. Most water entering the southern doline seems to drain into the northern along a rift between solid bedrock and the eastern periphery of the collapsed material. The western periphery can also be followed for some distance via the Refrigerator Blowhole, but carries no significant stream bed. Much of the water draining into the double doline discharges at the foot of the talus in the Powder Room. Large bodies of water can pond beyond here after sustained downpours, though this has not been witnessed.

Major Collapse Passages

A description of the main collapse passages follows.

1. The lateral and vertical dimensions of the main passage are highly variable. The average width is about 100 feet and in many sections, especially deep within the cave, it is commonly 150 feet wide and occasionally reaches 200 feet. The main passage is commonly about 50 feet high, but often reaches 70 feet or more. The initial sections of the cave tend to be narrower and lower, however, the passage in the Sail and Camp 1 areas reaches much larger dimensions. Lengths of collapse passage also occur in the Easter Extension, but generally the dimensions are much less than the main passage.

2. The form of the cave often differs from the simple, rounded structures characteristic of Koonalda N4 and Abrakurrie Cave N3. This is attributable to the variable nature of the limestone in which Mullamullang occurs, simple forms being better developed in more-uniform limestone. Even so, there is still a marked tendency to form arched and domed roofs over much of the cave (Figure 4, a and b).

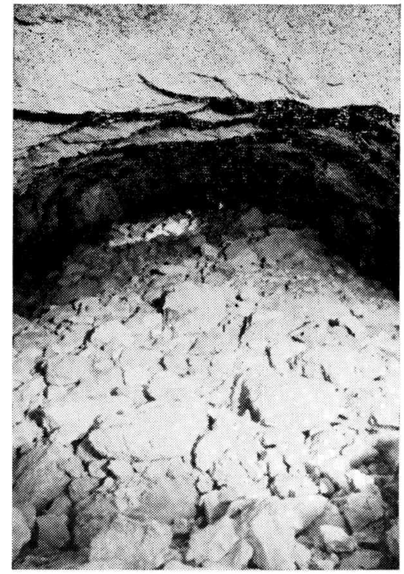
3. The floor is almost entirely covered by roof breakdown material - a jumble of angular blocks of varying sizes (Plate 1b). In the initial section up to the Sandchute, the angular material is covered by alluvium and/or fine roof breakdown products (Figure 4d).

Conical piles of angular material are found beneath collapse domes, whilst lengths of arched passage are commonly floored by median piles of rubble. The floor tends to be flat under lengths of relatively flat roof.

4. Mullamullang is characterised by variation in the degree of upward

PLATE 1

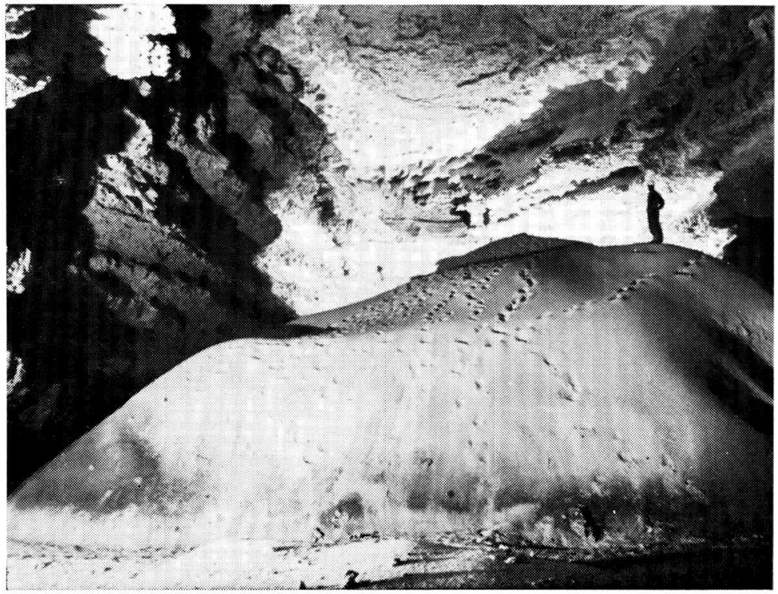
(a) Northern part of Entrance Doline. Photo: E. G. Anderson.



(b) View up rock pile from White Lake. Note person in centre of photograph. Lights in background are 200 feet above and 350 feet from camera. Photo: J. R. Dunkley.

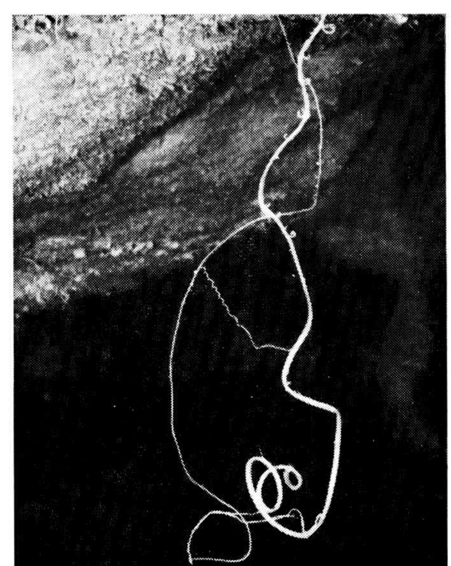
(c) Phreatic passage, the Salt Cellars, showing typical cross-sectional shape and halite crusts on roof and floor. Photo. T. M. L. Wigley.

PLATE 2



(a) The Dune, showing staining of bottom due to mud impregnation of rock-flour during flooding. Photo: E. G. Anderson.

(b) The Clam, Easter Extension. One flake is being wedged upwards (top centre), and another outwards (bottom centre), due to growth of gypsum crystals. Photo: Dr. H. Cohen.



(c) Delicate decoration in the Ezam. Described as halite by Hill (1966) but, unlike similar formations in the Easter Extension, is probably gypsum. Photo: T. M. L. Wigley.

stoping by collapse (Plate 1b). The watertable is not encountered until Oasis Valley after about 4,000 feet of horizontal development. It is again encountered at Yippees Point (between J.B. Maze and Franks Station). Collapse then extends to 250 feet above watertable (AWT) before the Col and to 200 feet before the abrupt drop to White Lake. The watertable is then not reached until Lake Cigalere. Other high points in the cave include the Drop Off (280 feet AWT), above Camp 1 (180 feet AWT) and the Dome (300 feet AWT). Upward stoping, which formed the Entrance Doline, reached to about 390 feet AWT.

Variation in lithology also helps to explain the extent and variability of upward stoping. Stoping would be facilitated where there is much bed-to-bed variation with bedding planes well developed.

5. Detachment along bedding planes is evident through most of Mullamullang, especially in the Left Branch where large flat slabs cover areas of floor. Detachment along joint planes, while less apparent, is also important. It is well illustrated in the initial section of the Right Branch where massive slabs have detached from both walls. Long straight sections of passage, for example the Great Hall (White Lake area), may imply joint-controlled breakdown. This is less evident in other Nullarbor deep caves examined by the author.

Phreatic Passages

Solution tube levels or their remnants are found in many parts of Mullamullang. Entry is only possible in those above the present watertable though further phreatic passages probably occur below it. As mentioned above, the variable degree of upward stoping by collapse has permitted access into two main series of solution tube levels - the Easter Extension and the Ezam.

The tube levels exhibit features of definite phreatic origin, similar to those described in other parts of the world (Bretz, 1942; Davies, 1960; Ewers, 1966; Halliday, 1960; Pinchemel, 1954; Sweeting, 1950; White, 1960).

1. Spongework occurs in isolated pockets adjacent to smooth-walled solution tubes. The Cheese in the Ezam is an extreme example of this development. Tubes up to six inches in diameter ramify in all directions and penetrate the wall past observable limits (R.A. Heffernan, pers. comm.).

2. Bedding plane anastomoses are developed in parts of the Easter Extension.

3. The floor profile is often irregular and is covered by varying thicknesses of clay and iron oxide residual material.

4. The walls and roof are generally quite smooth. No traces of current fluting (scalloping) occur, though smoothed irregularities of the wall produced by differential solution (presumably along bedding planes) have a superficial likeness.

5. The solution tubes are characteristically elliptical in cross section, having, on an average, a width of about six feet and a height of four feet. They are mostly straight and horizontal and are often parallel to similar passages. These features indicate joint and bedding plane control. The majority of passages have a recumbent elliptical cross section (Figure 5a; Plate 1c), but some are upright ellipses in section (Figure 5, c and d). These forms may be due to preferential solution along bedding planes and joint planes respectively. Passages with roof and/or floor slots (Figure 5e) sometimes occur.

6. Occasionally, passages are developed along closely spaced parallel joints and become confluent along much of their length; the partition between having been perforated and largely removed as solution continued. Good examples are found in the Easter Extension (Figure 5b). The Ezam is an extreme case where a large low area, the Rumpus Room (Figure 2),has been formed. The original solution tubes can be traced, as pillars, and ridges on floor and roof still remain. The formation of areas like this would help in initiating collapse, especially if similar cavities occurred above or below.

In places in the Ezam the limestone between closely overlying tubes has been perforated by solution, forming small irregular chambers. Again, this type of development on a larger scale might initiate substantial collapse.

Quite large solution tube passages, by Nullarbor standards, are common in the Easter Extension. They are relatively broad and low and have formed presumably along particularly suitable beds or bedding planes. There is little or no morphological evidence to suggest development along a watertable..

7. In the case of the Ezam and Easter Extension, the joint controlled solution tubes are integrated into loose and rather ill-defined networks. The trends of the joints involved vary considerably. For example, the trends of 038°, 060°, 015° and 095° (in order of decreasing importance) are involved in the Ezam. The form of the network differs from that of the classic network systems where two sets of regularly spaced joints are usually involved. Both the Easter Extension and the Ezam networks have a general linear form.

Previous Theories on the Development of the Deep Caves

Previous theories on the development of the Nullarbor deep caves were based on observations in a small number of relatively short and uniform caves where little remains of primary passage.

King (1949), studying Nullarbor deep caves of comparatively simple style, thought that phreatic solution excavated the large halls of the caves to their present form. Jennings (1961, 1963), however, has shown that their morphology can only be explained by collapse, with sub-aerial weathering and recent stream action superimposing their effects to varying extents. Lowry (1964b) and Anderson (1964) share this view for other deep caves on the Plain.

The problem is to explain the formation of a single primary cavity or zone of cavitation large enough to initiate and absorb collapse of the massive scale involved. Jennings attempted to infer the nature of the primary cavity from the morphology of the collapse passage it produced, though realising the limitations of this.

He favoured application of the master cave theory of Glennie (1954). On morphological grounds, however, the application of this theory rather than a more general one depends strongly on his assumption that the apse-like endings of collapse passages studied marked the ends of the large elongated primary cavities envisaged by the theory. Evidence from Mullamullang and other caves now indicates that primary cavitation extended well below the present level of accessible cave and thus assumptions about its nature at lower levels are dangerous. It is now certain that collapse passage persists at lower levels. Owing to a rise in the watertable, such passage is now flooded in many caves, including Koonalda N4 and Weebubbie N2. Lowry (1964b) has suggested that this is the case for Cocklebiddy Cave N48.

Jennings (1965, 1967b) has departed from his earlier views. He admits that the apses were probably formed in another way. Evidence indicates that the apses are stable collapse-produced forms, representing abrupt changes in roof level controlled by lithology, structure or changes in the width or trend of the primary cavity (or zone of cavitation). It is not necessary to postulate that the apse ending represents the end of a primary cavity which caused the collapse. In Mullamullang, high level halls ending in abrupt changes in roof level occur along the cave and are morphologically similar to halls ending in apses at or near the watertable in other Nullarbor caves. A comparison between the plans of Abrakurrie Cave N3 and the Sail Hall in Mullamullang emphasises this point.

Jennings (1961) also attempted to explain the development of halls at more than one level by postulating the existence of at least two levels of primary passage (formed at different watertables) into which collapse occurred. He had some support for this as primary remnants do occur on separate levels. Different phreatic levels also occur in Mullamullang but are more extensive. The highest of any consequence, the Ezam, lies between 80 and 100 feet above the present watertable. Even so, if the size of known parts is any indication, it is not large enough to initiate major collapse at that level. It seems more likely that collapsed material extends from the present floor level to 50 or more feet below the present watertable (discussed below) over the whole length of the cave. The level that collapse reaches is not only controlled by the level of the primary cavity (or zone of most intense cavitation), but also by the dimensions of the cavity and lithological and structural considerations. The paucity of solution tubes above the watertable in other deep caves suggests that collapse was probably initiated below the watertable over the whole length of these caves.

Lowry (1964b) postulated the development of a large cavern along a vertical joint as the first stage in the development of Cocklebiddy Cave N48. He favoured development close to the watertable, implying a more general epiphreatic origin than Jennings (1961) proposed.

Development of Nullarbor Deep Caves in Light of Evidence from Mullamullang

The existence in Mullamullang Cave of the Ezam and Easter Extension allows stronger inferences about the formation of the major collapse passages and origin of primary solution passages. The extensions are belts of small penetrable solution tubes on several levels up to 100 feet above the present watertable. The fact that the Ezam (80 - 100 feet AWT) occurs directly over a long section of collapse passage (part of the Left Branch) (Figure 2) strongly suggests a relationship between the formation of collapse passage and the distribution of belts of solution tubes.

It appears likely that the collapse passages were formed by collapse through overlying belts of solution tube networks along an elongated zone of cavitation in the limestone.

Further evidence supports this theory. In the Right Branch, above the first lake, a short length of joint-controlled primary passage remains intact above the collapse passage. In this case, both the Right Branch and the remnant passage have the same joint-controlled trend (about 045^{o}). There is also evidence that a level corresponding to the Easter Extension existed below the Ezam but has been virtually destroyed by collapse. Remnant tubes occur high in the wall between Grotto and Shbula Lakes and, at points along the Left Branch, solution-rounded blocks and patches of red residual material, similar to that found in existing phreatic passages, occur amongst the breakdown.

Unlike the initial part of the Right Branch, the collapse passage of the Left Branch and the Ezam above do not follow a dominant joint trend. The trends of the networks, and thus those of the collapse passages formed by them, depend on the relative importance of various joints in forming solution passages. This accounts for the variability in the trend of the main collapse passage in Mullamullang. The belief (Hill, 1966) that the cave is largely controlled by two major parallel joints, 1,700 feet apart and trending SW-NE, is an oversimplification. What is involved is a main SW-NE joint system, but other systems are also present.

Lowry (1964b) pointed out that the size of the single primary cavity which he envisaged for Cocklebiddy Cave N48 would have been of enormous dimensions to absorb all the collapse material and create a large air space, even allowing for the removal of some material by solution after collapse. The network levels in Mullamullang also help to explain this. Several relatively small overlying cavities had the same effect as a single large one, a situation more easy to visualise. Integration of primary cavities above one another by solution and minor collapse could produce a string of large cavities along the zone of cavitation before the event of massive collapse.

The origin of the primary phreatic networks is more difficult to explain. Their belt-like nature seems to be explained by applying Pinchemel's (1954) view of the hydrology of the chalk country of France (and Zötl's (1957) similar view of the hydrology of the Dachstein massif in Austria) to the Nullarbor situation. Jennings (1961, 1967b) realises the possible significance of Pinchemel's ideas. As well as a continuous (regional) watertable, localised currents occur within the body of groundwater along major joint systems. Cave development would occur along suitable joints and enlargement would further channel groundwater flow and localise cave development. The overall trend of Mullamullang approximates to that of the dominant ridge and trough system on the surface. The troughs are thought by Jennings (1961) and Lowry (1968a) to be due to solution along major joints. This evidence further supports application of Pinchemel's views.

Both Jennings (1961) and Lowry (1964b) favour a shallow phreatic origin for the primary cave. The author supports this, though evidence is inconclusive. The Ezam appears to be isolated by about 30 feet of limestone from any levels below. This may indicate solution about a separate watertable but, alternatively, it may indicate solution along a particularly favourable set of beds at any level below a watertable. The problem will be difficult to resolve as Mullamullang is developed in horizontal beds of limestone. The possible lateral variation and truncation of beds in the Abrakurrie Limestone may provide a means for resolving this question, however.

Theoretical considerations point to development of the Ezam (and other levels) not too far below the watertable of the time. The virtual restriction of the deep caves to the wetter coastal strip is taken by Jennings (1961) to indicate the importance of rainfall. There is no surface stream run-off and the influx of water with different physical and chemical properties from that of the groundwater, down joints and fractures, was probably of great importance in cave development during wetter times. The addition of relatively fresh solutions along the path of flow, Mischungskorrosion effects, addition of carbon dioxide along the path of flow, etc., would be expected to have more effect near the watertable.

Depth of Cavitation Below the Present Watertable

As mentioned above, the zone of cavitation probably extended 50 or more feet below the present watertable and that collapse was initiated at these depths. Lowry (1964b) believes this to be so for Cocklebiddy Cave N48 : "The longitudinal section shows that the present lake level has little or no effect on the general shape of the cave. The roof descends in a series of steps until it passes beneath the surface of the lake, whilst the irregular sloping floor of fallen blocks continues on beneath the water...It seems that the original cavern space into which collapse occurred lies submerged beneath the lake."

Evidence from other caves supports Lowry's observations. The map of Tommy Grahams Cave N56 (Lowry, 1966a) shows that the roof and floor of the collapse passage similarly descend below lake level. In Winbirra Cave N45, the walls, roof and floor of the doline descend steeply to and beyond the watertable with virtually no horizontal development of collapse passage. The lake in Weebubbie Cave N2 is up to 40 feet deep and its bottom is formed of breakdown blocks.

This evidence is further supported by the details of the Shbula-Grotto Lakes area in Mullamullang (Figure 4c). The cross section of the passage here is atypical, departing from the usual symmetrically arching form. Closer study provides an explanation. On the NW side of the passage a huge block, rather than many relatively small ones, has become detached as a result of solution undermining. Grotto Lake occupies the rift between the detached block and bedrock. It is estimated that the block reaches to more than 50 feet below the surface of the lake although the depth of the lake has not been plumbed. Therefore, most intense cavitation responsible for the phase of massive collapse probably occurred at similar, or greater, depths.

Existence of Solution Tubes in Other Deep Caves

Solution tubes are found in some other deep caves but do not appear to form part of an integrated system of the scale found in Mullamullang. There are at least two possible explanations for this.

1. Caves including Koonalda N4, Abrakurrie N3 and Weebubbie N2 are developed in more-uniform limestones which do not show the conspicuous bed-to-bed variation seen in Mullamullang. Solution tube development above the present watertable may not have been favoured, especially if arid times correlated with interglacial higher sea levels.

2. In Mullamullang, much of the groundwater flow appears to have been concentrated along a vertical zone of cavitation in the limestone, no matter what the watertable level. Collapse along this zone produced the main passage of the cave. However, the presence of the Easter Extension, the J.B. Maze and the Smoko Junction Loop away from the main passage suggests some variation in groundwater flow. In Koonalda N4, Weebubbie N2, and others, the scarcity or absence of solution tubes might indicate that network levels did not occur at higher levels in the immediate vicinity of the known parts of the caves because of variation in the pattern of groundwater flow.

The author favours the former explanation although in some cases the latter could have a supplementary role. Most of the solution tube developments above the present watertable probably occurred during interglacial times of higher sea levels and higher watertables. The effective precipitation may have been about the same or less than present, not favouring cave development at these higher levels.

Intense cavitation did occur at depth, however, enough to initiate massive collapse forming caves of the dimensions of Abrakurrie N3 and Koonalda N4 (and Mullamullang). The greater solution at depth may be due to glacial times of lower sea level when effective precipitation may have been higher. Alternatively, of course, it may simply be due to more-sustained solution at lower levels.

Correlation of Solution Tube Levels in Mullamullang and Koonalda N4

In Koonalda Cave N4, a high-level solution passage, the Squeeze, occurs about 80 feet above the watertable and connecting the West and Northwest Passages. Also, remnants of solution tubes occur up to 30 feet above the watertable at the end of the Third Lake, at the end of the West apse of the Second Lake, and also towards the end of the West Passage (lying beneath the high-level solution passage). The two levels may have been formed under watertable regimes corresponding to those which may have been responsible for the Ezam (80 - 100 feet), and the Easter Extension and J.B. Maze (10 - 50 feet). Further evidence is needed in support, however.

The solution tubes in Firestick Cave N70 and Kestral Cavern No. 1 N40 (Lowry, 1964a) are probably higher above the watertable than the Ezam and the Squeeze.

Surface geomorphic evidence supports the hypothesis that a watertable just above 100 feet was responsible for the Ezam and possibly the Squeeze in Koonalda N4. The Hampton Range escarpment is almost certainly an emerged cliffline which Jennings (1961, 1963) attributes to a submergence to + 100 - 200 feet during a Pleistocene interglacial. The sea, and consequently the watertable, remained at this level for a considerable time;

the Roe Plain is presumably what remains of an extensive marine erosion and depositional surface of the Pleistocene which would have required an extended period for its formation. Some cave development would be expected with this prolonged sea-level stand and the Ezam and Squeeze might well be remnants.

Recent Solution in Mullamullang

Both Jennings (1961) and Lowry (1964b) have emphasised that there is very little solution going on near the present watertable. Jennings (1961, 1963) cites chemical and geomorphological evidence in support, attributing the lack of solution to the semi-arid surface conditions.

Observations in Mullamullang, in general, support this view. However, some evidence points to a little solution above the present watertable level - at least in isolated parts of the cave. An incut at watertable level occurs at Grotto Lake on its SE edge which extends laterally into the limestone for at least 15 feet, but is too low for entry. Because it seems unique to the cave, it might be an earlier feature not attributable to present solution activity.

Gurgle Lake derives its name from "gurgles" produced when surface ripples lap under an undercut in the wall at lake level (Figure 4a). Whether this undercut is due to solution or collapse is not known. Also, Gurgle Lake can be followed for more than 100 feet under the breakdown material along the edge of the passage. This may mean sapping of the breakdown from below due to solution, with that above the watertable remaining relatively intact, possibly stabilised by the secondary deposition of gypsum between the rocks. In general, however, breakdown and bedrock surfaces around the lakes show little sign of solution

Vadose Stream Activity

The effects of recent stream action are evident in the initial part of the cave, between the bottom of the initial talus slope and the end of the Southerly Buster. Water entering the doline discharges at the foot of the talus. The floor beyond has been graded and sediments, which are generally fine, have been deposited (Figure 3d). The thickness of these sediments is not known, but could be quite substantial. An excavation could yield clues as to the age of the lowest sediments and hence a minimum age for the Entrance Doline. A small excavation by the author and R.A. Heffernan near the foot of the Dune revealed alternating layers of fine alluvial silt and rock flour from subaerial weathering of the roof. Recent floodings of the cave are therefore infrequent as the subaerial weathering appears to be slow. Any changes with depth in the nature or relative thickness of these alternating alluvial and rock-flour beds may give clues to past climatic conditions.

Jennings (1965) commented on the intense pocketing of the roof in the low section up to the Southerly Buster. He suggested that this is spongework, a relic of primary solution activity before collapse occurred. He noted, however, that it was similar to forms produced by tafoni weathering further into the cave.

Study by the author revealed that material covering the bottom ten feet or so of the Dune (Plate 2a) was consolidated due to the effect of flooding. Higher up, consolidated material gives way abruptly to unconsolidated rock-flour. A thin layer of this fine, unconsolidated material also covers the bottom of the Dune, being the accumulation since the last major flooding.

This flooding is enough to submerge the roof of the initial part of the cave completely. The spongework could be produced therefore by subaerial weathering, with solution during flooding having a modifying effect.

Processes of Cave Breakdown

The cave breakdown processes fall into two main groups - massive collapses which destroyed much of the primary cave, and subaerial weathering which is modifying to varying extent existing primary cave and the collapse passage.

The former process has been discussed above and corresponds to the method of mass collapse in bedded limestone described by Davies (1951). Lowry (1964b) believes a drop in watertable level, due to sea level drop in glacial times, was necessary for general collapse. This would remove hydrostatic support for the walls and roofs of primary cavities. The author agrees, though much collapse could have occurred below the watertable as solution undermining and cavity integration proceeded.

Breakdown is also proceeding on a smaller scale in Mullamullang. Growth of halite and gypsum crystals is responsible for wedging flakes and chips off the roof and walls in the Easter Extension (Plate 2b). Crystal wedging also occurs at the granular scale in the Extension. In places, the crystals, along with wedged-off products, still remain matted on the roof. Convection currents set up by carbide lamps are enough to dislodge this material as a fine rain.

Crystal wedging is known in other limestone caves. Pohl and White (1965) stress its importance in the breakdown of caves of the Sinkhole Plain in central Kentucky. Lowry (1968b) has also suggested that crystal wedging plays a major role in the development of the shallow blow-hole caves on the Nullarbor and that it operates in deep caves including Cocklebiddy N48 and Mullamullang. Crystal wedging has been cited by various authors to explain cavity and tafoni formation in non-calcareous rocks, and it is likely that it is responsible for the tafoni weathering in Mullamullang.

The tafoni weathering in Mullamullang is most intense, especially on the roof of the Powder Room (see photograph on cover), above the Dune and in the Sandchute area. Much of the large-scale breakdown on the floor in the low initial parts of the cave up to the Sandchute is covered with fine rock-flour and small chips. Weathering may have been more intense in these parts because of the proximity of the Entrance.

Summary of Main Events in the Development of Mullamullang

1. Uplift of the Eocene and Miocene limestones at the end of the Lower Miocene. Solution of limestone begins. (Figure 3a).

2. Perforation of the limestone at different levels, probably at different watertable levels corresponding to glacial and interglacial low and high sea levels. Groundwater drainage concentrated along definite pathways. A multi-level elongated zone of cavitation was formed in the limestone, largely along a NE-SW joint system. (Figure 3b).

3. Enlargement and integration of levels by solution, probably accompanied by limited localised collapse. A string of relatively large cavities probably produced along the zone of cavitation.

4. Enlargement reaches critical point. Massive collapse initiated at depth along the zone, possibly during the last glacial period. (Figure 3c). Formation of Entrance Doline. (Figure 3d).

5. Vadose activity and subaerial weathering commence. Stream alluviation, accumulation of rock-flour and chips, and limited solution in initial parts of cave. (Figure 3d).

6. Watertable rose to present level. Lower levels of cave flooded, but little solution activity evident. Deposition of gypsum crusts and other minerals around the edges of the lakes. The time of deposition of minerals in other areas of the cave (Plate 2c) is not known.

7. Vadose activity, subaerial weathering and isolated collapse continuing to present time.

The above summary is intended to give as complete a picture as possible of the development of Mullamullang Cave. Much, however, is based on limited evidence and a definite chronology remains to be worked out. Further surface and sub-surface evidence is required, especially concerning levels within various caves, the horizontal extent of beds in the Abrakurrie Limestone, relative land and sea movements, and past climatic conditions.

Acknowledgments

I am grateful for the assistance of members of the Nullarbor expeditions in which I participated. I am indebted to E.G. Anderson and J.R. Dunkley for the help and encouragement they have given me, and to Dr. A.M. Richards and J.N. Jennings for their advice in the writing of this paper. E.G. Anderson, T.M.L. Wigley, J.R. Dunkley and Dr. H. Cohen have given permission for me to use their photographs. The Speleological Research Council Ltd., of the University of Sydney, loaned the blocks for Plates 1 and 2. The outline for the plan and extended profile of Mullamullang Cave, Figure 1, are based on Jennings (1968b).

References

ANDERSON, E.G. 1964 : Nullarbor Expedition 1963-64. Helictite, 2 : 121 - 134.

BRETZ, J.H. 1942 : Vadose and Phreatic Features of Limestone Caverns. J. Geol., 50 : 675 - 811.

DAVIES, W.E. 1951 : Mechanics of Cave Breakdown. Bull. Nat. Spel. Soc., 13 : 36 - 43.

DAVIES, W.E. 1960 : Origin of Caves in Folded Limestone. Bull. Nat. Spel. Soc., 22 : 5 - 18.

DUNKLEY, J.R., WIGLEY, T.M.L. (Eds.). 1967 : Caves of the Nullarbor. A Review of Speleological Research on the Nullarbor Plain. The Speleological Research Council Ltd., U. of Sydney : 61 pp.

EWERS, R.O. 1966 : Bedding-plane Anastomoses and their Relation to Cavern Passages. Bull. Nat. Spel. Soc., 28 : 133 - 140.

GALLOWAY, R. 1965 : Late Quaternary Climates in Australia. J. Geol., 73 : 603 - 618.

GLENNIE, E. 1954 : The Origin and Development of Cave Systems in Limestone. Trans. Cave Research Group Gt. Brit., 3 : 75 - 83.

HALLIDAY, W.R. 1960 : Changing Concepts in Speleogenesis. Bull. Nat. Spel. Soc., 22 : 23 - 29.

HILL, A.L. (Ed.). 1966 : Mullamullang Cave Expeditions 1966. Cave Exploration Group (S. Aust.) Occas. Pap., 4 : 1 - 47.

HUNT, G.S. 1967 : The Geomorphology of Mullamullang and its Significance for the Deep Caves of the Nullarbor. Unpub. paper presented at the 6th Conf. Aust. Spel. Fed., Mirboo North, Vic., December 1966.

INGRAM, B.S. 1969 : Sporomorphs from the Desiccated Carcases of Mammals from Thylacine Hole, Western Australia. Helictite, 7 : 62 - 66.

JENNINGS, J.N. 1961 : A Preliminary Report of the Karst Morphology of the Nullarbor Plain. Cave Exploration Group (S. Aust.) Occas. Pap., 2 : 1 - 45.

JENNINGS, J.N. 1963 : Some Geomorphological Problems of the Nullarbor Plain. Trans. Roy. Soc. S. Aust., 87 : 41 - 62.

JENNINGS, J.N. 1964 : Air Photographs and the Nullarbor Plain Caves. Newsl. Aust. Spel. Fed., 23 : 4 - 5.

JENNINGS, J.N. 1965 : A Note for the CEG(SA) 1965-6 Nullarbor Expedition. In Handbook for CEG(SA) 1965-6 Nullarbor Expedition. Cave Explor. Group (S. Aust.), 1965 : 1 - 5.

JENNINGS, J.N. 1967a : Some Karst Areas of Australia. Chapt. 12, p. 279, in Landform Studies from Australia and New Guinea, Eds. J.N. Jennings and J.A. Mabbutt. Canberra, Aust. Nat. Univ. Press, 1967.

JENNINGS, J.N. 1967b : The Surface and Underground Geomorphology. In Caves of the Nullarbor. Eds. J.R. Dunkley and T.M.L. Wigley. The Spel. Research Council Ltd., U. of Sydney, 1967 : 13 - 31.

JESSUP, R.W. 1961 : A Tertiary-Quaternary Pedological Chronology for the South-Eastern Portion of the Arid Zone. J. Soil Sci., 12 : 208 - 213.

KING, D. 1949 : Geological Notes on the Nullarbor Cavernous Limestone. Trans. Roy. Soc. S. Aust., 73 : 52 - 58.

LOWRY, D.C. 1964a : Kestrel Caverns Number One and Two, Madura. Western Caver, 4 : 10 - 14.

LOWRY, D.C. 1964b : The Development of Cocklebiddy Cave, Eucla Basin, Western Australia. Helictite, 3 : 15 - 19.

LOWRY, D.C. 1966a : Tommy Grahams Cave N56. Western Caver, 6 : 3.

LOWRY, D.C. 1966b : (Note on) Stratigraphy (in) Mullamullang Cave Expeditions 1966. Cave Exploration Group (S. Aust.) Occas. Pap., 4 : 32.

LOWRY, D.C. 1967 : Halite Speleothems from the Nullarbor Plain, Western Australia. Helictite, 6 : 14 - 20.

LOWRY, D.C. 1968a : Tertiary Stratigraphic Units in the Eucla Basin in Western Australia. Ann. Rept. for 1967, Geol. Surv. W. Aust. : 36 - 40.

LOWRY, D.C. 1968b : The Origin of Blow-Holes and the Development of Domes by Exsudation in Caves of the Nullarbor Plain. Ann. Rept. for 1967, Geol. Surv. W. Aust. : 40 - 44.

LUNDELIUS, E.L. 1960 : Post-Pleistocene Faunal Succession in Western Australia and its Climatic Interpretation. Proc. Internat. Geol. Congr., 21st Session, Copenhagen, 1960, Part IV : 142 - 153.

LUNDELIUS, E.L. 1963 : Vertebrate Remains from the Nullarbor Caves, Western Australia. J. Proc. Roy. Soc. W. Aust., 48 : 75 - 80.

MERRILEES, D. 1968 : Man the Destroyer : Late Quaternary Changes in the Australian Marsupial Fauna. J. Roy. Soc. W. Aust., 51 : 1 - 24.

PINCHEMEL, P. 1954 : Les Plaines de Craie. Paris.

POHL, E.R., WHITE, W.B. 1965 : Sulphate Minerals : Their Origin in the Central Kentucky Karst. Amer. Mineral., 50 : 1461 - 1465.

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

WHITE, W.B. 1960 : Terminations of Passages in Appalachian Caves as Evidence for a Shallow Phreatic Origin. Bull. Nat. Spel. Soc., 22 : 43 - 53.

WIGLEY, T.M.L. 1967 : Non-steady Flow Through a Porous Medium and Cave Breathing. J. Geophys. Res., 72 : 3199 - 3205.

ZÖTL, J. 1957 : Neue ergebnisse der karsthydrologie. Untersuchungen im Dachsteingebiet mit hilfe der sporentriftmethode. Erdkunde, 11 : 107 - 117.

****

ADDENDUM

Since the above paper went to press, a further paper by D.C. Lowry (1969) has been published. Lowry places the phreatic passages in Firestick Cave N70 and Old Homestead Cave N83 at 220 feet below the surface and those in Kestrel Cavern No. 1 N40 at 160 feet below the surface - about 250 feet above the present watertable. Contrary to what has been stated above, Lowry believes the Abrakurrie Limestone is relatively weakly bedded. Because the limestone is quite porous, he believes this points to an epiphreatic origin of the solution passage levels rather than control by bedding. This is a little difficult to reconcile, perhaps, with the bedding plane control which he states is important in passage development. He supports the theory that past sea levels have been of fundamental importance in determining the level of the watertable under the Plain and, therefore, the level of epiphreatic solution.

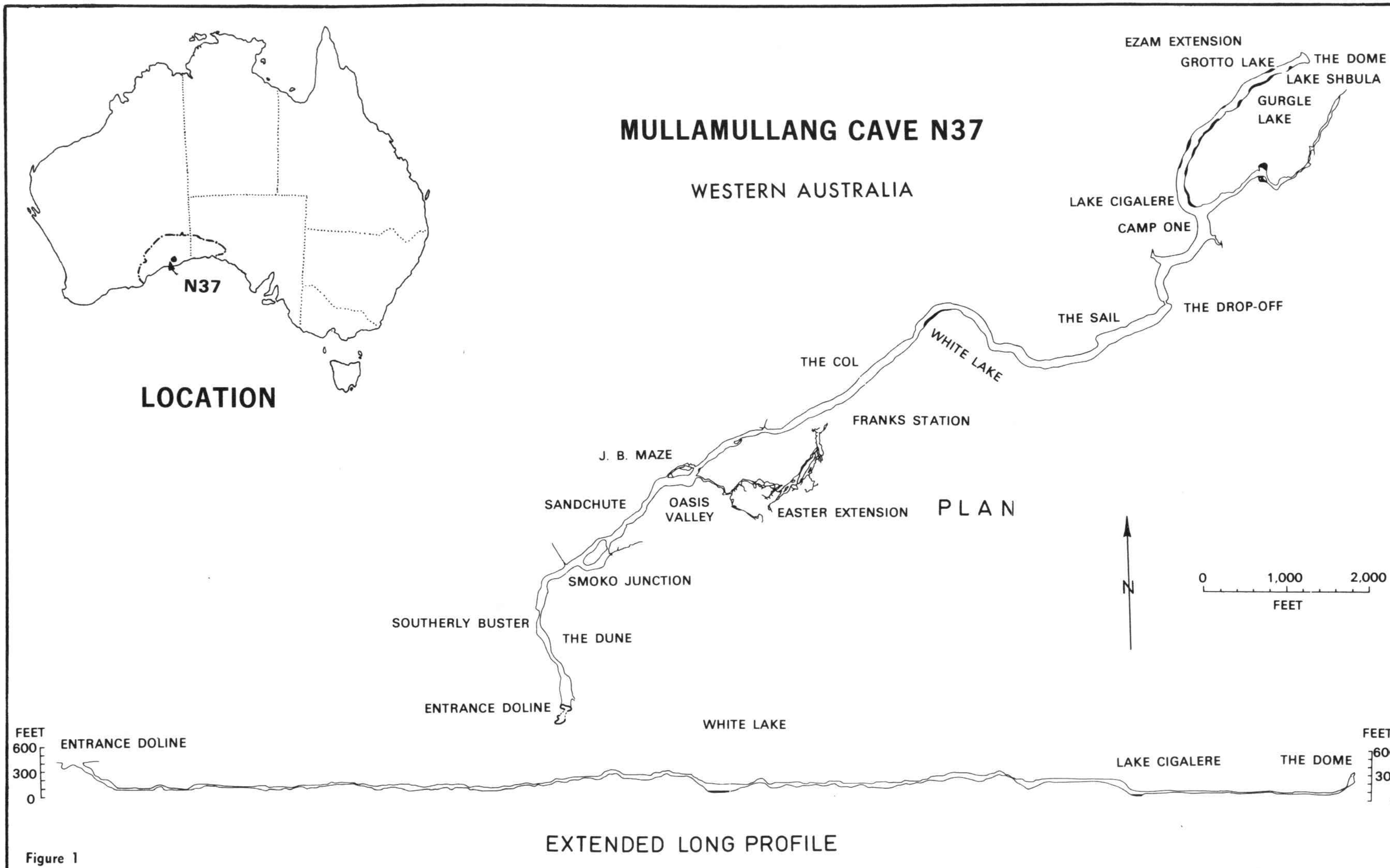
Lowry mentions the existence of two levels in the Ezam and three in the Easter Extension. He has apparently taken this from the sections drawn by Hill (1966). The situation is probably more complex, however. Compass and tape were used to survey both extensions with no attempt at fixing vertical levels. Accurate levelling needs to be done before the levels in the Ezam and Easter Extension can be defined with confidence.

A new figure for the watertable level in Mullamullang is given. Lowry places it at only five feet above mean sea level, compared with Hill's figure of 20 feet. If this is so, then the gradient of the watertable between Mullamullang and the coast, 42 miles away, is a very low 1.5 inch in the mile.

Additional Reference

LOWRY, D.C. 1969 : The Origin of Small Cavities in the Limestone of the Bunda Plateau, Eucla Basin. Ann. Rept. for 1968, Geol. Surv. W. Aust. : 34 - 37.

****


MULLAMULLANG CAVE N37
WESTERN AUSTRALIA
LOCATION
N37
PLAN
EZAM EXTENSION
GROTTO LAKE
THE DOME
LAKE SHBULA
GURGLE LAKE
LAKE CIGALERE
CAMP ONE
THE DROP-OFF
THE SAIL
WHITE LAKE
THE COL
FRANKS STATION
J. B. MAZE
SANDCHUTE
OASIS VALLEY
EASTER EXTENSION
SMOKO JUNCTION
SOUTHERLY BUSTER
THE DUNE
ENTRANCE DOLINE
N
0
1,000
2,000
FEET
FEET
600
300
0
ENTRANCE DOLINE
WHITE LAKE
LAKE CIGALERE
THE DOME
FEET
600
300
0
EXTENDED LONG PROFILE
Figure 1

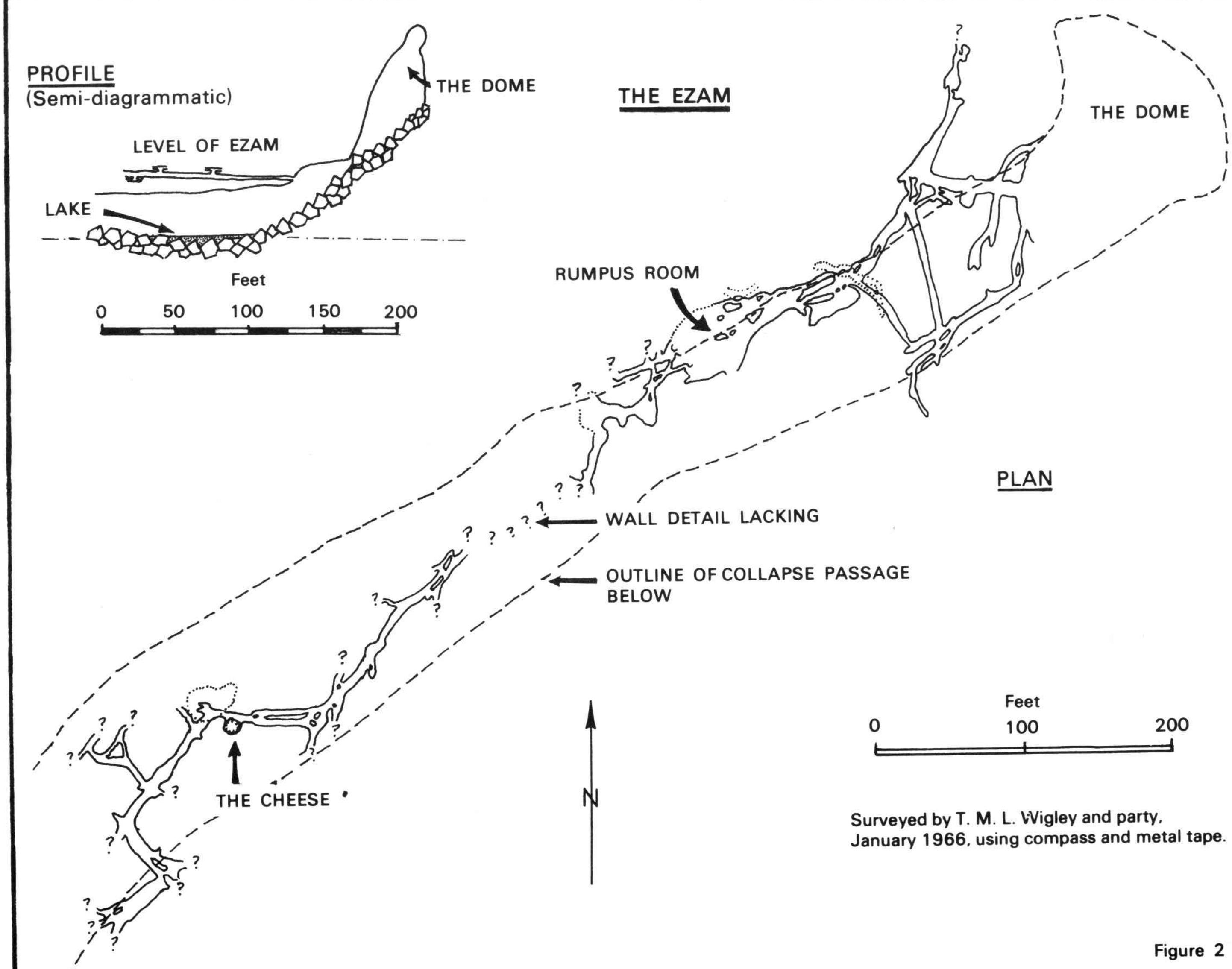

PROFILE
(Semi-diagrammatic)
THE DOME
LEVEL OF EZAM
LAKE
Feet
0 50 100 150 200
THE EZAM
THE DOME
RUMPUS ROOM
PLAN
WALL DETAIL LACKING
OUTLINE OF COLLAPSE PASSAGE BELOW
Feet
0 100 200
N
THE CHEESE
Surveyed by T. M. L. Wigley and party,
January 1966, using compass and metal tape.

Figure 2

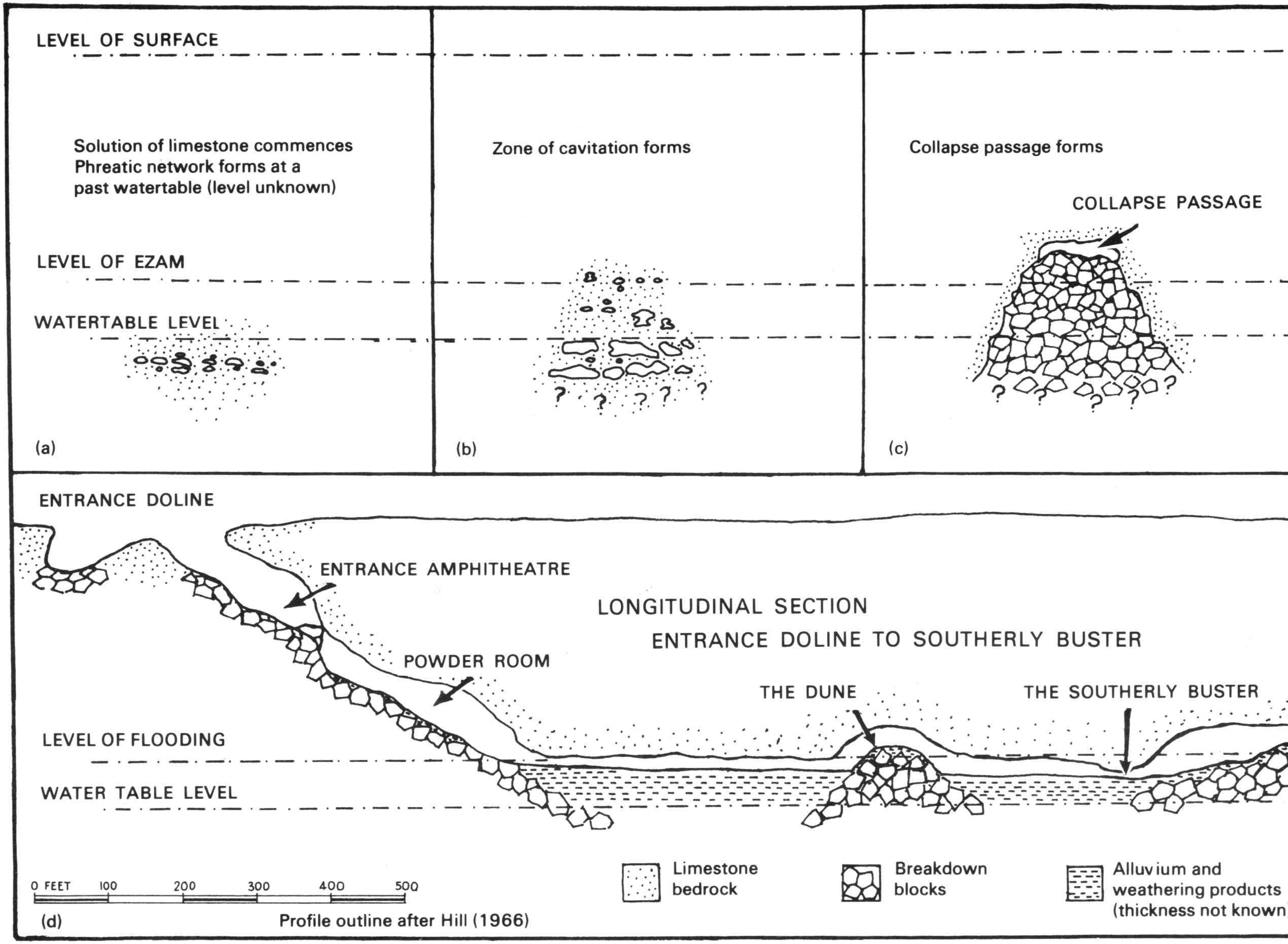


Figure 3

Diagram illustrating aspects of development of Mullamullang Cave

SELECTED CROSS SECTIONS

Collapse Passage Sections

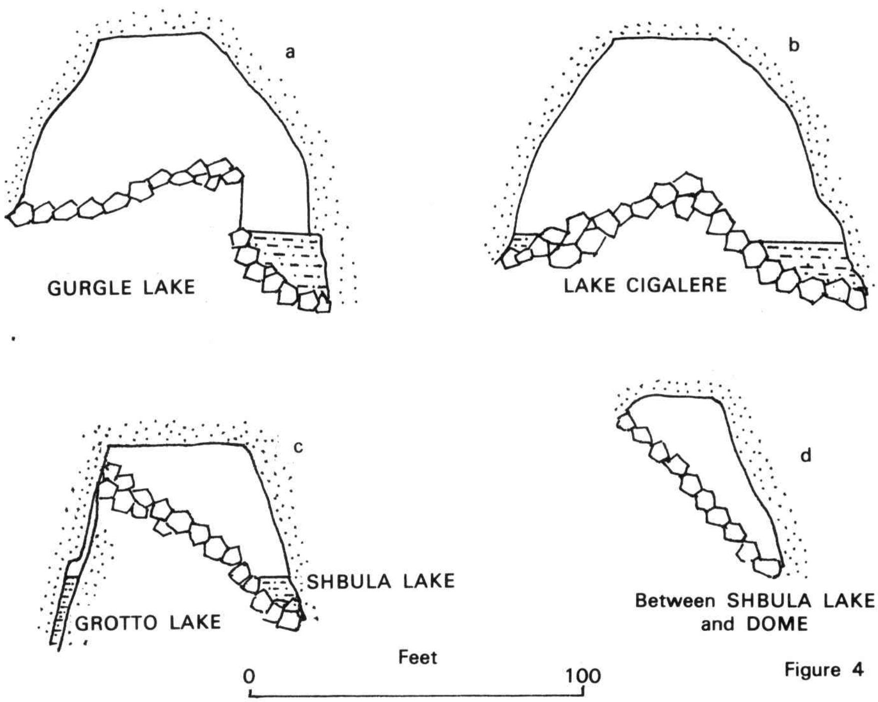


Figure 4

Phreatic Passage Section

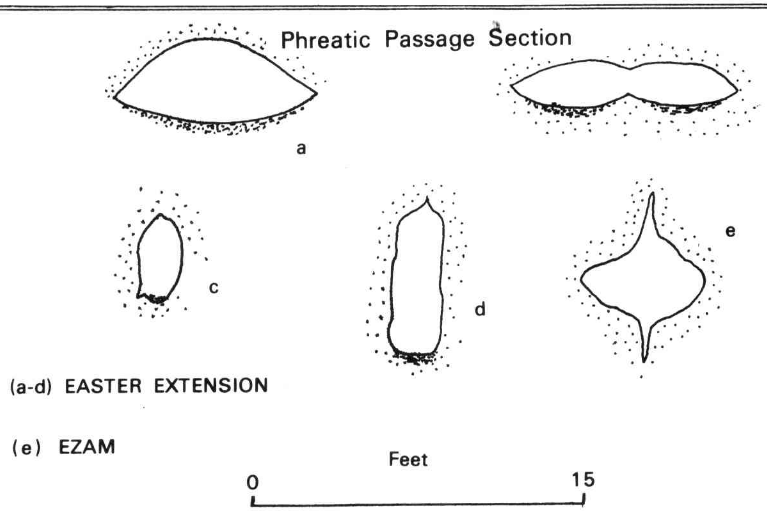


Figure 5