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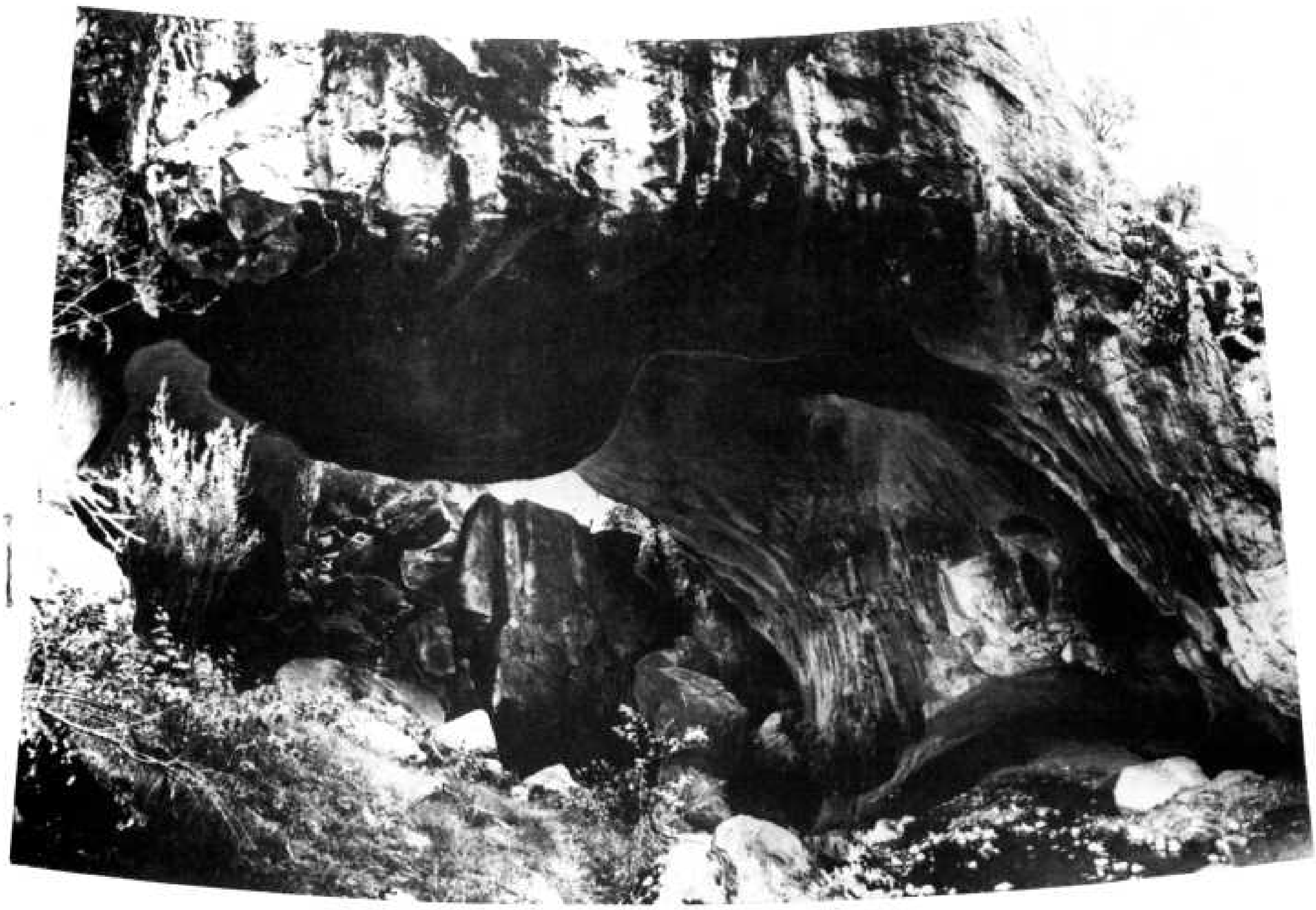

The Borenore Arch looking down-stream.

A composite photograph from seven negatives by Andrew Pavey and prepared by J. N. Jennings.

" H E L I C T I T E "

Journal of Australasian Cave Research

Editors

E.A. Lane, Aola M. Richards, J.N. Jennings, J.R. Dunkley

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ABSTRACTS AND REVIEWS

THE TAXONOMIC STATUS OF SMALL FOSSIL THYLACINES (MARSUPIALIA, THYLACINIDAE) FROM WESTERN AUSTRALIA. By Jacoba W.J. Lowry. J. R. Soc. West. Aust., 55, 1972 : 19 - 26.

Fossil thylacines have been collected from Thylacine Hole, Murra-el-elevyn Cave, Roaches Rest Cave, Capstan Cave and Webbs Cave on the Nullarbor Plain, Western Australia. These fossils have conspicuously smaller teeth than those of modern *Thylacinus cynocephalus* from Tasmania. With size of teeth taken as the criterion, the taxonomic status of the fossils is assessed by using statistical tests. These show that in the Nullarbor fossil thylacines the requirement of the "75 per cent rule" for subspecies is not met at a 95 per cent level of confidence. As a result, the fossils are referred to *T. cynocephalus*. The re-evaluation of the taxonomic status of fossil thylacines from Yallingup Cave, Mammoth Cave and Jewel Cave in southwestern Australia, using the same tests, confirms W.D.L. Ride's conclusion that there is also no justification for recognizing these fossils as a new subspecies. However, the heterogeneity of the sample leaves the status of those fossils uncertain. Sexual dimorphism is marked in *Thylacinus*, and a statistical method is used to separate some Nullarbor specimens into presumed males and females. - A.M.R.

A NEW CAVERNICOLOUS HARVESTMAN FROM WESTERN AUSTRALIA (ARACHNIDA : OPILIONES : TRIAENONYCHIDAE). By G.S. Hunt. J. Aust. ent. Soc., 11, 1972 : 232 - 236.

A new cavernicolous harvestman, *Calliuncus labyrinthus* Hunt, is described from Strongs Cave and Labyrinth Cave in the Margaret River area, Western Australia. Unlike other harvestmen recorded from Western Australian caves, it is pale in colour with relatively long, thin legs, and has not been collected from surface habitats. Until the surface fauna has been adequately sampled and the biology of *C. labyrinthus* has been studied, it is not known whether it is a troglophile or troglobite. The genus *Calliuncus* Roewer is redefined by Hunt and a key is given for males of its six species. - A.M.R.

A NEW CHTHONIID PSEUDOSCORPION FROM WESTERN AUSTRALIA. By M. Beier. J. Aust. ent. Soc., 10, 1971 : 233 - 234.

A new species of pseudoscorpion, *Pseudotyrannochthonius giganteus* Beier, is described from Calgadup Cave near Augusta, Western Australia. It was found on roots hanging from the roof in the final chamber of the cave. The eyes are very reduced. The species is closely related to *P. gigas* Beier from Victoria. It also has affinities with the South African genus *Afrochthonius*. - A.M.R.

SEDIMENTARY AND MORPHOLOGICAL DEVELOPMENT OF THE BORENORE CAVES, NEW SOUTH WALES, I

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Abstract (of Parts I and II)

The Borenore Caves, west of Orange, occur in a partly metamorphosed Silurian limestone outcrop of about 5.5 km^2 which forms an impounded karst.

Both of the main caves, the Arch Cave and the Tunnel Cave, contain large quantities of clastic sediments. Evidence from the position and kind of sediments and from the bedrock features show that both caves have undergone a predominantly fluvial development by a sequence of stream captures.

The same type of evidence indicates a dry climatic phase for the Borenore area about 28,000 B.P.

INTRODUCTION

The Borenore Caves are about 20 km west of the city of Orange. In the winter of 1830, John Henderson visited the caves (and the Wellington Caves as well) while he was engaged in geological reconnaissance work. Henderson's report (Henderson 1832) includes some ideas on the origin of the caves and on the depositional environment of the bone-bearing sediments. These ideas would be considered anachronistic today since they involved the notion that the caves had originated by the drying up of water masses within the limestone while it was a soft mud and by deposition of the cave sediment in a deluge (albeit a regional, rather than a world-wide one). The famed Australian explorer, T.L. Mitchell, also visited at least one of the caves, Tunnel Cave, in 1836 (Mitchell 1839). He collected fossil bone material from the cave which was probably studied subsequently by Robert Owen along with bones from the Wellington Caves. The Borenore Caves have received additional mention in the literature (for example, Stutchbury 1852; Carne and

Jones 1919) but the only other speleological investigation that has been done is that of Jennings (1970).

General geology

Folded and faulted Ordovician, Silurian, and Devonian sandstones, shales, limestones, and volcanics crop out in the Borenore Caves area (Walker 1959). The structurally complex Palaeozoic rocks are overlain by nearly flat-lying Tertiary rocks consisting mainly of olivine and andesine basalts derived from nearby Mt Canobolas. Preliminary K/Ar dates on some of the basalts to the northeast of Mt Canobolas indicate a Late Miocene age (P. Wellman, pers. comm. 1969). In addition to the basalts, Walker (1959) reports pre-basaltic river gravels in the area. Tuffs and agglomerates are also present as well as scattered residual deposits of ironstone gravel.

The limestone

The limestone crops out along Boree Creek in an irregular pattern for about 5 km. Its maximum width is about 2 km. It has been designated the Borenore Limestone member of the Silurian Panuara Formation by Walker (1959) who estimates its thickness as about 450 m. Bedding in the limestone is rare but where it is discernible it dips at 20^{o} to 30^{o} to the southwest.

The basal part of the member, in which the caves are formed, is highly brecciated and contains a red clay matrix, banded in some places, that fills the interstices between the limestone blocks. In some places, especially near the upstream end of the outcrop, the limestone has been partly metamorphosed and several small abandoned marble quarries are spread throughout the area.

Carne and Jones (1919) list 13 partial chemical analyses of the limestone in which $CaCO_3$ ranges from 63.87 to 99.64 per cent, $MgCO_3$ from 0.20 to 7.26 per cent, $MnCO_3$ from 0.00 to 0.04 per cent, and Fe_2O_3 and Al_2O_3 from 0.01 to 8.10 per cent. X-ray diffraction of the $<2\mu m$ fraction of insoluble residues from the limestones showed illite to be the dominant clay with a lesser amount of chlorite. The limestone also contains quartz and biotite with the latter making up as much as 15 per cent of the rock. The quartz is rounded to well-rounded and the grains are cracked such that the enclosed polygons are about $80\mu m$ in diameter (see Plate 4 in Part II).

Physiography

The area (Fig. 1) is on the western slopes of Mt Canobolas which rises to 1400 m and dominates the landscape. The flat-lying to gently sloping basalts from the volcano have been dissected by small nearly perennial streams to reveal the highly folded and faulted limestones and other Palaeozoic rocks beneath. In places, inliers of limestone stick up above the Tertiary volcanics as isolated spires. Local relief in the area is 30 to 50 m.

The larger streams head on Mt Canobolas and so are partly fed by snow melt water in the winter months. The drainage has a radial pattern which has been modified where the streams have cut down onto the complex structure of the Palaeozoic rocks.

Boree Creek is the major stream in the vicinity of the caves and is almost perennial except for its course across the limestone where it sinks a good deal of the time during the dry summer months. The stream meanders and is incised into its own alluvium for most of its course though its channel is cut in bedrock in a few places. A prominent alluvial terrace occurs about 3 m above the stream bed, and bedrock terraces are also present in a few places. Along its course on the limestone, Boree Creek has only one major tributary, an intermittent, north-flowing stream which joins it about half way through the limestone.

THE ARCH CAVE AND ASSOCIATED FEATURES

The Arch Cave (Figs. 2, 3) spans Boree Creek near the upstream end of the limestone outcrop. It is composed of three form elements - a stream meander niche, an arch, and an irregularly shaped cave. The former two merge into one another. Together, these three elements form a rough crescent shape in plan with the concave part of the crescent on the downstream side. The subaerial area within the concave part of the crescent contains large blocks of breakdown, the consequence of the collapse of the roof of a former cave. Entrances to the underground parts are indicated with a double line on Fig. 2.

The stream meander niche, as represented in Fig. 2, is within the area delimited by 0000, 0500, 0502, 0002*. Boree Creek flows through it from east to west entering at 055025, and leaving at 010020. However, access can be gained not only at these two points but also all along the drip lines. Bed-load gravel covers the stream bed along its entire length through the meander niche. The bedrock wall and ceiling of the meander niche are generally smooth with some scallops, averaging

* Abscissa is first in all co-ordinate references.

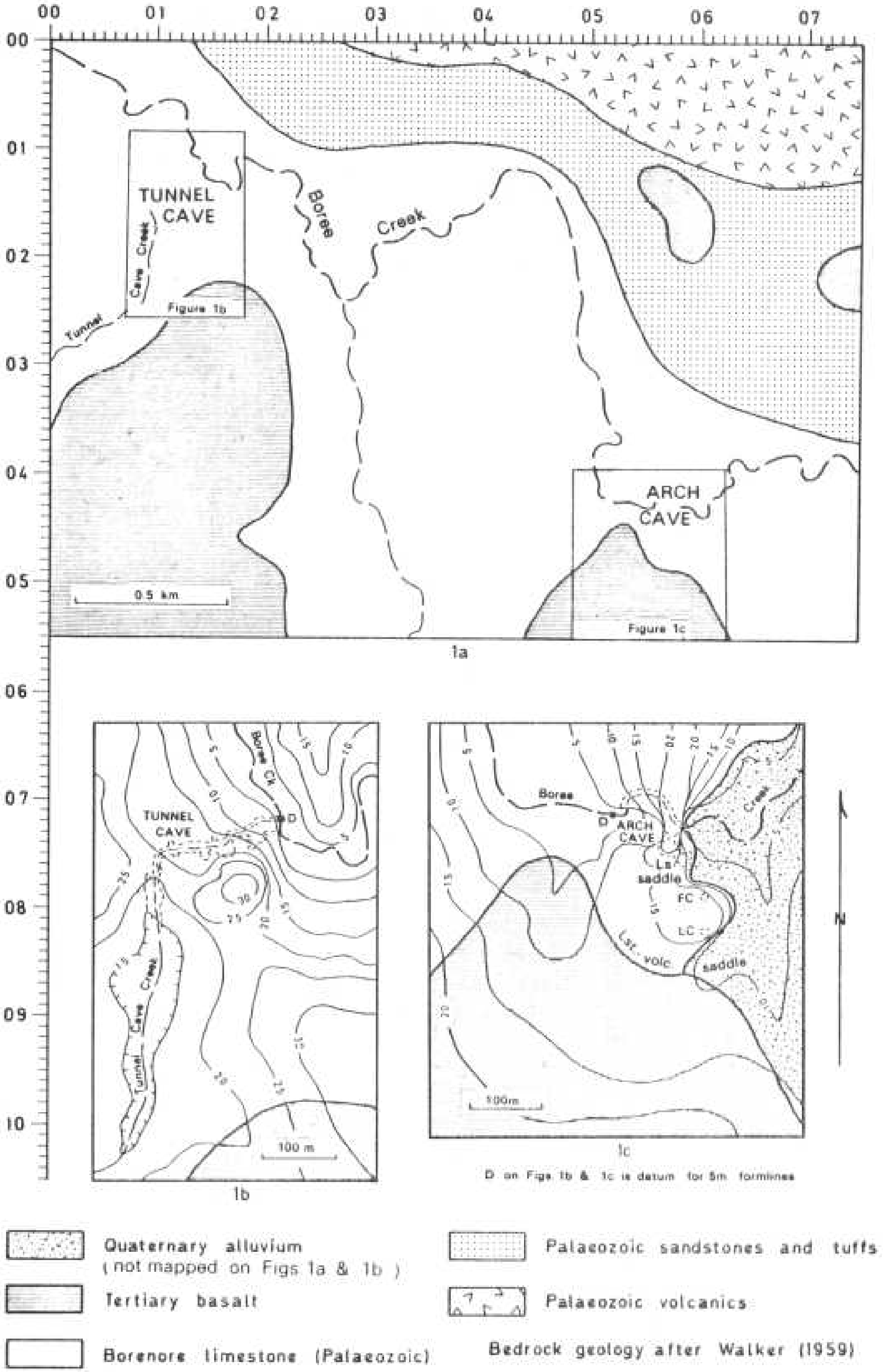
about 15 cm in diameter. Small, mostly horizontal cavities occur in the wall and ceiling (for example, at 051018 and 037016, Fig. 2) and most of these contain alluvial deposits.

The arch part of the cave, as represented in Fig. 2, is within the area delimited by 0402, 0602, 0604, 0404. Boree Creek flows through the northern part of it from east to west. The floor of the southern part is covered with breakdown on the west side, and alluvium and soil on the east. Access to the arch can be gained from three directions - along the drip line on the eastern side, along the drip line or from the meander niche on the western side, and from the irregularly shaped cave on the southern side. The ceiling of the arch is ogival in a north-south cross-section with a maximum ceiling height of about 14 m above the stream bed.

The irregularly shaped cave to the south of the arch, as represented on Fig. 2, is within the area delimited by 030035, 060035, 060065, 030065. Access to it can be gained either from the arch at 049037 or through another horizontal entrance on the west side of the cave at 033050. The general floor level of the cave is some 12 m above the stream bed of Boree Creek. The cave contains two large residual pillars of limestone (042052 and 047056, Fig. 2) and several speleothemic columns which divide it into several smaller sections. At the extreme southeast end of the cave (058064, Fig. 2) there is an old filled entrance containing limestone breakdown and non-limestone stream gravel. The bedrock walls and ceiling of the cave are smoothly concavo-convex with no sharp angles except a few internal ones where ogives are formed along joints or bedding planes.

On the surface, just south of the Arch Cave, there is a steep-sided saddle running through the limestone hill (Fig. 1c). It is rectangular in cross-section with bedrock cropping out in its relatively flat floor. On its north side the limestone wall rises to a maximum of 3 m and is nearly vertical in most places. The south wall is up to 2 m high, but is only a steep slope in most places. At the eastern end of the saddle a doline, 1.5 m deep and 7 m in diameter and filled with talus, lies directly above the filled entrance at the extreme southeast end of the irregularly shaped cave.

About 120 m farther south, is another saddle at the contact of the limestone and the Tertiary olivine basalt.



BORENORE CAVES AREA **FIG.1**

Three small, horizontally developed caves occur in the north and east sides of the limestone hill at the base of the cliff face between the two saddles. The most northerly one is merely an enlarged joint extending into the hill for about 6 m. The next one south, FC Cave (061079), Fig. 1c, is a small room about 3 m wide, 1.5 m high, and extends about 4.5 m into the hill. The third, LC Cave (061082, Fig. 1c), is a single, dome-shaped room 5.5 m in diameter and a little over 1 m high at the centre. Additional enlarged vertical joints up to 3 m deep occur on the west side of the hill near the limestone-volcanic contact.

Cave sediments

Alluvial and entrance-facies deposits occur in the Arch Cave and vicinity. Samples were taken from two excavated pits within the cave (Fig. 3); from the small extension off the arch at the north end of profile A-P5 (051018, Fig. 2); from the outcrop of exposed cave alluvium at 012050, Fig. 2; and from the small LC Cave. Other alluvial sediments occur in the numerous small holes in the walls and ceiling of the arch and main meander niche, in small pockets along the west-facing cliff west of the main cave, and mixed with breakdown at the extreme southeast end of the irregularly shaped cave. Breakdown is widespread and is shown in Fig. 2. There is also some breakdown mixed with the sediments in the irregularly shaped cave. Soil-derived sediments occur throughout the Arch Cave as well as in a few small bedding-plane and joint cavities in the cliff face to the south and west of the cave.

Only the salient features of each deposit sampled will be described below; details are tabulated in Frank (1972)*. Most sedimentological terminology is that of Folk (1961). Terms used for the various types of cutans are from Brewer (1964).

The sediment exposed in pit 1 (Fig. 4) is an entrance-facies deposit consisting mainly of soil-derived material and limestone breakdown. Excavation was stopped at a depth of 2.2 m by solid limestone but whether this was bedrock or just a large block of breakdown was not determinable. No bedding is discernible in the lower 130 cm. In the upper 90 cm horizontal bedding is poorly developed by subparallel orientation of small-animal long bones, flat gravel and plant fragments as well as the remains of two fireplaces. The sequence grades from a loose, red, slightly granular fine sandy mud near the bottom to a loose, brown, silty medium

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* Copies of the tables may be obtained from the Department of Biogeography and Geomorphology, Australian National University.

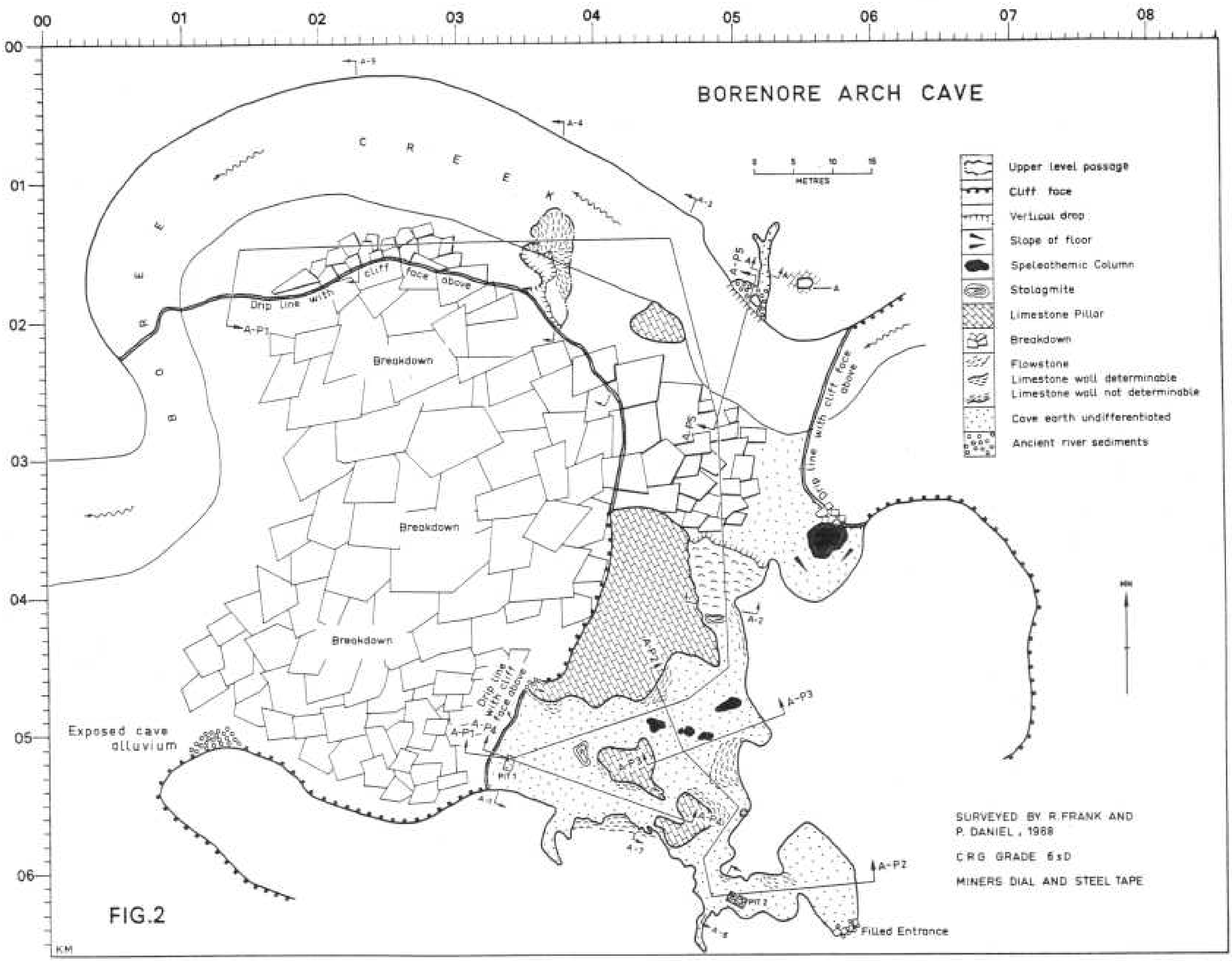
BORENORE ARCH CAVE
METRES
Upper level passage
Cliff face
Vertical drop
Slope of floor
Speleothemic Column
Stalagmite
Limestone Pillar
Breakdown
Flowstone
Limestone wall determinable
Limestone wall not determinable
Cave earth undifferentiated
Ancient river sediments
B O R E E C R E E K
Drip line with cliff face above
Breakdown
Breakdown
Breakdown
Exposed cave alluvium
Filled Entrance
SURVEYED BY R. FRANK AND P. DANIEL, 1968
CRG GRADE 6 s D
MINERS DIAL AND STEEL TAPE
KM

FIG.2

sandy pebble gravel near the top. This textural gradation is interrupted between 90 and 96 cm from the top by a distinct bed of loose, brown to grey, pebble gravel consisting of 85 per cent angular limestone rock fragments, moderately to poorly sorted. Except for this thin bed, the sorting is very poor to extremely poor. Samples tend to be either bimodal or trimodal. Scattered throughout the sequence - but slightly concentrated in the lower half - are angular detrital fragments of alluvial cave sediments, themselves partly composed of cave-sediment fragments. The second-order fragments are up to 20 cm in diameter. They are cemented with calcite and their textural class is a pebbly fine sandstone.

The two fireplaces exposed by pit 1 in the Arch Cave occur at the surface and at 40 cm; they were considered to be of historical age. Of the remaining organic material in pit 1 there was not a sufficient amount in any single horizon for dating.

The possibility of dating the entrance-facies sediments in the Arch Cave with artifactual material was conceived before sampling began. The protection offered by the cave and the proximity to running water seemed to provide an ideal occupational site. With this in mind the choice of the site for the excavation of pit 1 was assisted by Dr R.V.S. Wright, archaeologist at the University of Sydney. The entire 2.2 m was sieved, 15 cm at a time, by Dr Wright's assistant, Mr Peter Thompson, but only a few flakes of possible human origin were found and none of these were classifiable chronologically.

Pit 2 was excavated to a depth of 4 m in the southeast part of the cave (Fig. 2). There are three main lithologic units of water-deposited material with one interbedded flowstone unit (Fig. 4).

The exposed part of the lower unit is about 0.5 m thick. It is a brown, slightly phosphate-cemented conglomerate with no discernible bedding. The median particle-size is about 20 mm with an extreme range of from $<$2 m to about 8 cm. It is moderately sorted with a unimodal distribution. The principal constituents are well-rounded volcanic and sedimentary rock fragments, quartz, and clay. The contact with the overlying middle unit is irregular with relief up to 45 cm.

The middle unit is about 0.5 m thick and consists of a brown, uncemented, pebble gravel with no discernible bedding. The median particle-size is about 10 mm and the extreme range in particle-size is from $<$2 m to about 3 cm. The material is moderately sorted with a unimodal distribution. Subround to round, pebble-sized balls

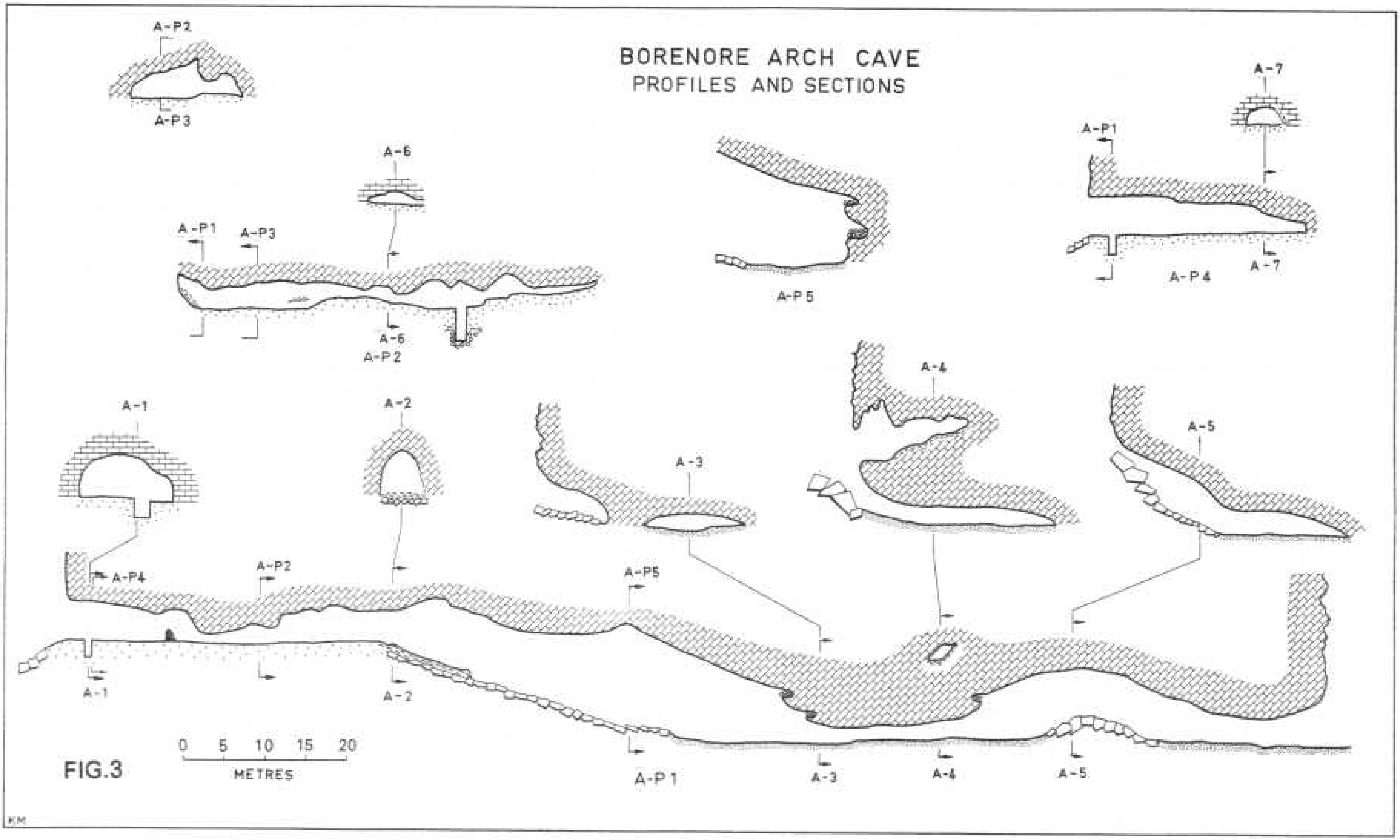
BORENORE ARCH CAVE
PROFILES AND SECTIONS
A-P2
A-P3
A-6
A-P1
A-P3
A-6
A-P2
A-P5
A-7
A-P1
A-P4
A-7
A-1
A-2
A-3
A-4
A-5
A-P4
A-P2
A-P5
A-1
A-2
A-P1
A-3
A-4
A-5
0 5 10 15 20
METRES
KM

FIG.3

of fine sandy mud make up 95 per cent of the detritals. Some of these have poorly developed concentric orientation of clay particles. A few have a thin coating of concentrically oriented clay. The principal constituents of the mud balls are quartz, clay, sanidine, and volcanic rock fragments. Plant fragments, microcrystalline chert, and calcite also occur as trace constituents. The matrix between the mud balls has essentially the same composition as the mud balls. The contact with the overlying upper unit is again irregular with relief up to about 75 cm.

The upper unit is about 3 m thick and consists of a brown, uncemented, muddy coarse sandy granule gravel near the bottom that grades into an uncemented, granular coarse sandy mud near the top. Poorly graded beds from a few centimetres to 30 cm thick become less distinct with depth. There are several cavities 30 to 45 cm in diameter throughout the unit which have been interpreted as wombat burrows. In-place roots up to 5 cm in diameter also occur throughout the unit and some of these are of living surface trees. The top 30 cm is compacted and moderately cohesive but does not contain any precipitated cement. The dominant constituents are granule-sized mud balls of the same general type as those in the middle unit, except that they contain a larger proportion of clay minerals than those in the middle unit and the concentric orientation of this clay is better developed. Both the proportion of clay and the degree of orientation decreases with depth. Clay, quartz, and sanidine are also present in moderate amounts. Scattered throughout the upper unit are occasional, rounded pebbles and cobbles of limestone rock fragments with phosphate coatings. X-ray analysis of the coatings showed calcite, hydroxylapatite/fluorapatite, and quartz. Other minor constituents of the upper unit include silt- to fine sand-sized limestone rock fragments (in the interval from 30 to 55 cm from the top) and small-animal bone fragments.

Within the upper unit, between 230 and 260 cm from the top of the pit, there is a flowstone unit the detrital texture of which is a slightly granular silty medium to coarse sandstone. Bedding consists of less and more pure calcite, 2 to 20 mm thick. The contact of the flowstone with the enclosing upper unit is abrupt at the top and gradational at the bottom. The detrital constituents are similar in kind and proportions to those of the surrounding unit with the addition of a small amount of organic matter which gives the appearance of having been melted into the flowstone. This organic matter is probably derived from bat guano but no original structure or insect chitin could be found in a thin section. About 60 kg of the flowstone containing the material was submitted to the A.N.U. Radiocarbon Dating Laboratory but, unfortunately, no date was

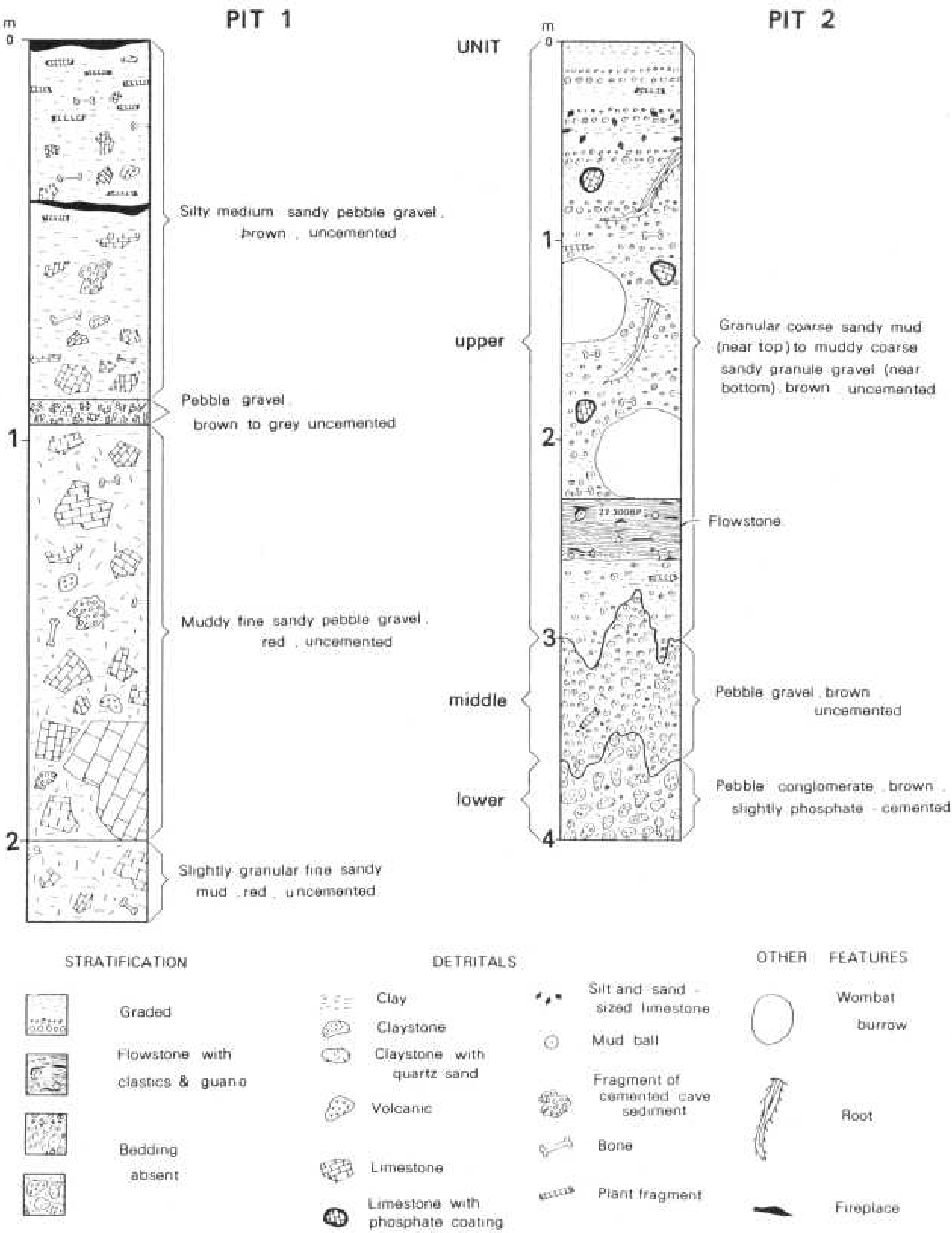
PIT 1
m
0
1
2
Silty medium sandy pebble gravel, brown, uncemented
Pebble gravel, brown to grey uncemented
Muddy fine sandy pebble gravel, red, uncemented
Slightly granular fine sandy mud, red, uncemented
PIT 2
UNIT
m
0
1
2
3
4
upper
middle
lower
Granular coarse sandy mud (near top) to muddy coarse sandy granule gravel (near bottom), brown, uncemented
Flowstone
Pebble gravel, brown uncemented
Pebble conglomerate, brown, slightly phosphate - cemented
STRATIFICATION
Graded
Flowstone with clastics & guano
Bedding absent
DETRITALS
Clay
Claystone
Claystone with quartz sand
Volcanic
Limestone
Limestone with phosphate coating
Silt and sand - sized limestone
Mud ball
Fragment of cemented cave sediment
Bone
Plant fragment
OTHER FEATURES
Wombat burrow
Root
Fireplace

FIG. 4

produced because of technical difficulties during processing. However, a ^{14}C date was obtained from this flowstone unit by Dr C.H. Hendy. It was calculated according to the procedures set out by Rafter (1965) and then further corrections were applied for dating speleothem material (Hendy 1969: Hendy and Wilson 1968). The result was 27,300 years B.P.

In the small extension off the arch at the north end of profile A-P5 (051018, Fig. 2) there is a section of alluvium, 2 m thick, which consists of a brown, calcite-cemented, slightly pebbly coarse sandy mudstone. This deposit is typical of the cemented alluvial material occurring in other holes in the walls and ceiling of the arch and the main meander niche. Graded beds, interrupted by cut and fill structures, occur throughout the exposure. Detrital material makes up about 40 per cent of the rock and about half of this is clay. Quartz and felspar constitute most of the remainder of the detritals.

The outcrop of exposed cave alluvium at 012050, Fig. 2, is about 2 m thick. It is a red, calcite-cemented, medium sandy pebble conglomerate except for the top few centimetres which are of a red, fissile material composed mostly of calcite precipitate with small amounts of clay and silt. There is no discernible bedding in the conglomerate. The laminations in the fissile calcite are from 0.05 to 3 mm thick. The conglomerate sits on a highly irregular limestone bedrock surface with relief up to 30 cm. At the top, the contact of the fissile calcite with the limestone bedrock is flat and sharp. The detrital material in the conglomerate is chiefly volcanic rock fragments, magnetite, ilmenite, haematite, quartz, felspar, limestone rock fragments, and mud balls.

The small LC Cave contains scattered cobbles of well-rounded limestone and volcanic rock fragments as well as an orange, calcite-cemented, muddy medium to coarse sandstone adhering to the walls. The detrital composition of the sandstone is chiefly soil particles composed of clay and quartz silt.

Development of the cave

The development of the Arch Cave is closely related to Boree Creek and an elucidation of the vertical and horizontal positions of Boree Creek through time, using evidence from the sediments and bedrock forms of the cave and stream-produced surface features, indicates various stages in the cave's development.

The earliest indication of the position of the ancestral Boree Creek is the saddle at the limestone-volcanic contact directly south of the Arch Cave (Fig. 1c). Three lines of evidence show that there is a high probability that it did flow through this saddle as a surface stream sometime in the past. Firstly, the general meander-like form of the saddle and the adjoining ephemeral stream valleys on either side of the limestone outcrop suggest that the saddle, together with these ephermeral stream valleys, once formed a meander loop of the ancestral Boree Creek. Secondly, recent gullying in the ephemeral stream valley on the upstream side has exposed a soil containing river gravel extending from Boree Creek to about half the distance to the saddle. Finally, the alluvial cobbles contained in the sediment in LC Cave strongly suggest that the ancestral Boree Creek flowed nearby at some time in the past.

The next position occupied by Boree Creek was through the steep-sided limestone saddle just south of the Arch Cave at 057077, Fig. 1c. Its rectangular cross-section and bedrock floor are ample evidence that it was formed by the stream. The highest point of this saddle is nearly 6 m above the highest part of the saddle at the limestone-volcanic contact, and this implies that it has been some considerable time since the creek flowed through the limestone-volcanic saddle. That is, the height of the limestone-volcanic saddle must have been at least 6 m higher than its present level when the creek was diverted into the area of the limestone saddle. It may, of course, have been higher still because the creek must have eroded its bed while it was flowing through the limestone saddle. The much less resistant volcanics, larger catchment, and the fact that the older saddle is a lithologic contact would make the rate of denudation there much greater than in the limestone saddle after both were abandoned.

Whether the ancestral Boree Creek flowed through the area of the limestone saddle as a surface stream or as an underground stream is a moot point. It is certainly tempting to speculate on a previous arch cave in this area. The limestone outcrop is narrower from east to west at the limestone saddle than either north or south of it. Moreover, the limestone saddle is shorter than the limestone-volcanic saddle. This introduces the possibility that Boree Creek was captured from the limestone-volcanic saddle by the process of a meander cutoff. A surficial meander cutoff would be expected to leave a saddle which was shorter still, or at least wider at both its upstream and downstream ends than the existing one. On the other hand, the lack of talus that would have resulted from collapse of a former arch cave seems to exclude the possibility that there ever was such a cave.

In any case, some time prior to 27,000 B.P. a sufficiently large cave had developed in the place where the irregularly shaped part of the Arch Cave is now, such that the old route of the creek through the limestone saddle was abandoned and the stream was entirely diverted underground through the doline at the upstream end of the saddle. Evidence for this is seen in the non-limestone stream boulders which, together with angular limestone breakdown, still clog the connection between the surface doline and the extreme southeast end of the cave. During this time the alluvium making up the phosphate-cemented pebble conglomerate exposed at the bottom of pit 2 was also deposited. The direction the stream took from the area of pit 2 is not certain. The outcrop of exposed cave alluvium about 35 m west of pit 1 (012050, Fig. 2) is at approximately the same level as the phosphate-cemented conglomerate of pit 2. Also, the mineralogy of the two is not drastically different except for the high proportion of opaque heavy minerals in the former which could simply be the result of concentration by deposition in a side passage. The difficulty about a route for the ancient stream directly from pit 2 to the alluvial outcrop is that the sediment of pit 1 lies directly in this path and contains no primary alluvial deposits even though the exposed section lies at the same level as the outcropping conglomerate. There are a number of possible explanations none of which have any good supporting evidence. Considering the scattered vertical and areal disposition of all the alluvial sediments in the vicinity of the Arch Cave, the most likely is that the stream did not in fact flow directly from pit 2 to the outcropping conglomerate locality but took some other, more devious and indeterminable route. A second possible explanation which is almost as likely is that the outcropping conglomerate was deposited prior to the pit 2 conglomerate while the stream was still flowing through the limestone saddle. The outcropping conglomerate is not far to the side from the downstream end of the limestone saddle and it could have been deposited in a former side passage leading from the limestone saddle.

The texture and composition of the sediment in the middle unit in pit 2 implies that by this time the ancestral Boree Creek had ceased to flow through this area as a permanent stream and was only entering the cave through the surface doline during occasional floods. The reason for this is that cavities in the area now occupied by the arch had opened sufficiently to take most of the flow. At first, the ancestral Boree Creek probably flowed through the approximate centre of the area now occupied by the large breakdown mass and slowly worked its way downward and northward. During the deposition of the upper unit in pit 2 essentially the same conditions prevailed, that is, normal-stage stream flow was going through the newly formed arch but discharge was too high during flood times and the overflow spilled

DEVELOPMENT OF THE BORENORE ARCH CAVE AREA

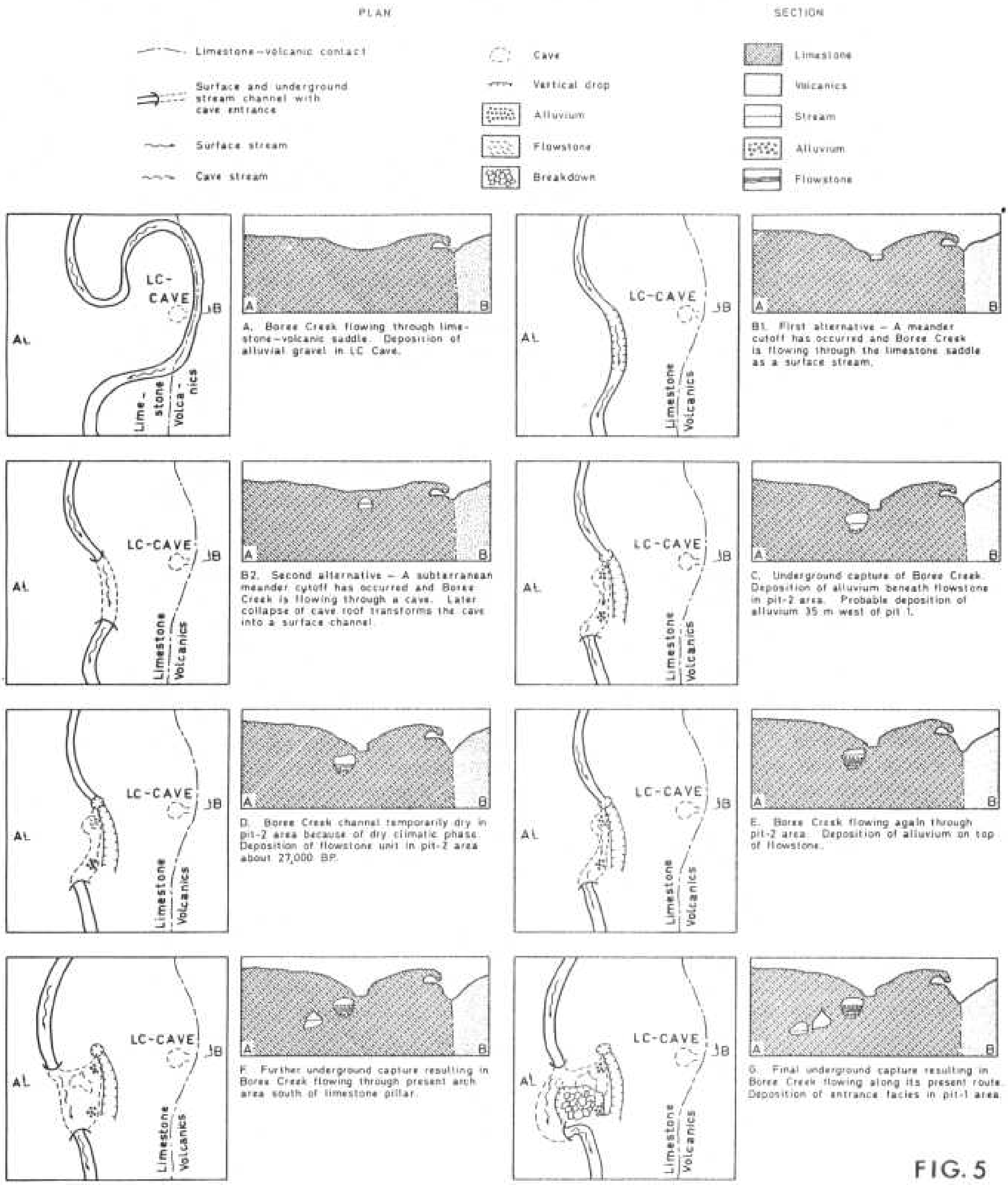

FIG. 5

into the pit 2 area through the doline bringing with it the reworked alluvial muds and clays from the flood-plain outside and perhaps also some material from the small southeast room.

The flowstone unit within the upper sequence in pit 2 represents a cessation in sedimentation, or at least a drastic reduction in sedimentation rate, of the clastics. After the flowstone unit had accumulated, fluvial sedimentation was again resumed. Local causes such as sealing up and reopening of the streams entry point could account for such a sedimentologic anomaly but as will be discussed later there is a climatic cause for this particular one.

The bat guano within the flowstone unit and the small-animal bone fragments imply that the entire unit at pit 2 was deposited in an air-filled cave. The phosphate cement of the lower unit and the phosphate crusts on the limestone cobbles indicate sufficient circulation of water for deposition of the phosphate.

The sediment in pit 1 shows that it accumulated under a completely different environment of deposition from that in the pit 2 area. It represents the simultaneous deposition of soil and breakdown without the aid of any significant amount of water. The immediate source for almost all the material was the cliff face and lip of the cliff directly above the site of deposition. This assemblage of breakdown and soil indicate that the cliff face was approximately in its present position during deposition and consequently the deposits are probably not very old. The reworked alluvial sandstone from pit 1 bears a strong textural and mineralogical resemblance to the lower unit in pit 2 and to the outcropping cave alluvium 35 m west of pit 1. However, its angularity implies that it was not transported as a rock fragment by water and so its presence within pit 1 is due to the same agent as that which deposited the soil and breakdown. In other words, its source was small pockets of alluvium in the overhead cliff and its deposition was a consequence of the recession of the cliff.

In the arch area, further morphological development continued as the stream cut northward and downward into the bedrock to produce a large ancestral arch cave in the area now occupied by the huge mass of breakdown (0303, Fig. 2). Normal surface denudation coupled with this underground bedrock erosion eventually resulted in the thinning of the roof of this large arch cave and its structural instability. The huge mass of breakdown is the consequence of its eventual collapse.

One final, small capture occurred to leave the residual limestone pillar at 044020, Fig. 2, before the stream reached its present position in the cave. Like the previous underground ones, this capture resulted from diversion of the stream into a prior phreatically developed cavity. The remnants of vadose-altered phreatic cavities still remaining in the walls of the large meander niche attest to this.

In this history of the Arch Cave, the creek has moved laterally and downward from its initial position as a left-swinging surface meander loop through the limestone-volcanic saddle to its present position as a right-swinging underground meander loop. This has been accomplished by successive captures the first of which may have been a surface meander cutoff. The remaining captures were all underground and each succeeding one followed a route which had been partly prepared previously by solutional formation of cavities in the saturated zone. The sequence of major events in the history of the Arch Cave is diagrammatically illustrated in Fig. 5.

(Part II of this paper will be published shortly in this journal)

ABSTRACTS AND REVIEWS

BUNGONIA CAVES. Ed. Ross Ellis *et al.* 1972, 230 pp, 24 plates, maps, foldout map in pocket, hard cover. Published by The Sydney Speleological Society, Sydney. ($A 6).

This book is an excellent and timely study of a region - a product of several years work by numerous individuals in many societies. Being a comprehensive multi-discipline study of a geographical region, its scope extends far beyond hard-core speleology. Although early speleological work in the Bungonia area (New South Wales) was directed towards the exploration of caves, a conservation versus mining battle stimulated this broad approach. The book is an attempt to "make a significant contribution to the campaign of safeguarding for all time the Bungonia Caves Reserve and the surrounding complementary areas."

While making this contribution, it has set a standard to be followed in the serious description of any important karst region and, for that matter, any geographical region in which land use decisions must be made.

The book begins with three papers on the early history of the district and the later discovery and exploration of the caves. These are supplemented by a comprehensive bibliography and extracts from historical sources. Three papers on cave descriptions and maps follow.

Many caves in the area can be dangerous. The cave descriptions mention the "pit-falls" that await the unwary and discuss equipment needed for safe exploration. The descriptions are non-technical (technical descriptions occur in the geomorphology section) and well illustrated with photographs. Drafting of cave maps is variable in style and quality, underlining the collective effort involved. Unfortunately, many insignificant caves are mapped in lavish detail while the plan of the morphologically significant B 4-5 Cave is poorly drafted and lacks detail. However, this cave has proved notoriously difficult to explore.

What might be described as the more scientific papers range through geomorphology, zoology and botany. "The Geomorphology of Bungonia Caves and Gorge", by J.N. Jennings and others, is the most definitive and includes a discussion of the general geology and a brief but excellent review of current ideas on the geomorphic events which shaped the Eastern Highlands during the Tertiary. The geomorphology of the caves and gorge area is particularly interesting in this regard. The authors have not tried to work local geomorphology into a regional history worked out by others - they have used local details to extend knowledge of the region. Discussion of the karst is detailed and their interpretation of the hydrology makes fascinating reading. Some ideas may be modified in time. For example, the authors (p. 133) explain horizontal sections at lower levels in the system as probably relating to slackenings in the incision rate of surface streams. These sections, however, could be horizontal reaches between vertical drops formed when underground drainage adjusted to a new base level. This base level was produced when waters were able to drain from the steeply dipping Lower Limestone to the Upper Limestone by either breaching or skirting the intervening "impermeable" beds.

Among the biological papers, the checklists of cave invertebrates and the surface flora should prove most useful. However, the former suffers from lack of comparisons with the adjacent surface fauna, and the latter, while compendious, fails to indicate the dominant species in particular habitats. The checklist of birds of the area is also valuable. In the main, other papers cover little new ground, but are worthwhile reviews of previous literature.

The book covers the case for conservation with two carefully researched papers which should be prescribed reading for any group wishing to organise a conservation campaign. - G.S. HUNT.

END OF VOLUME 10