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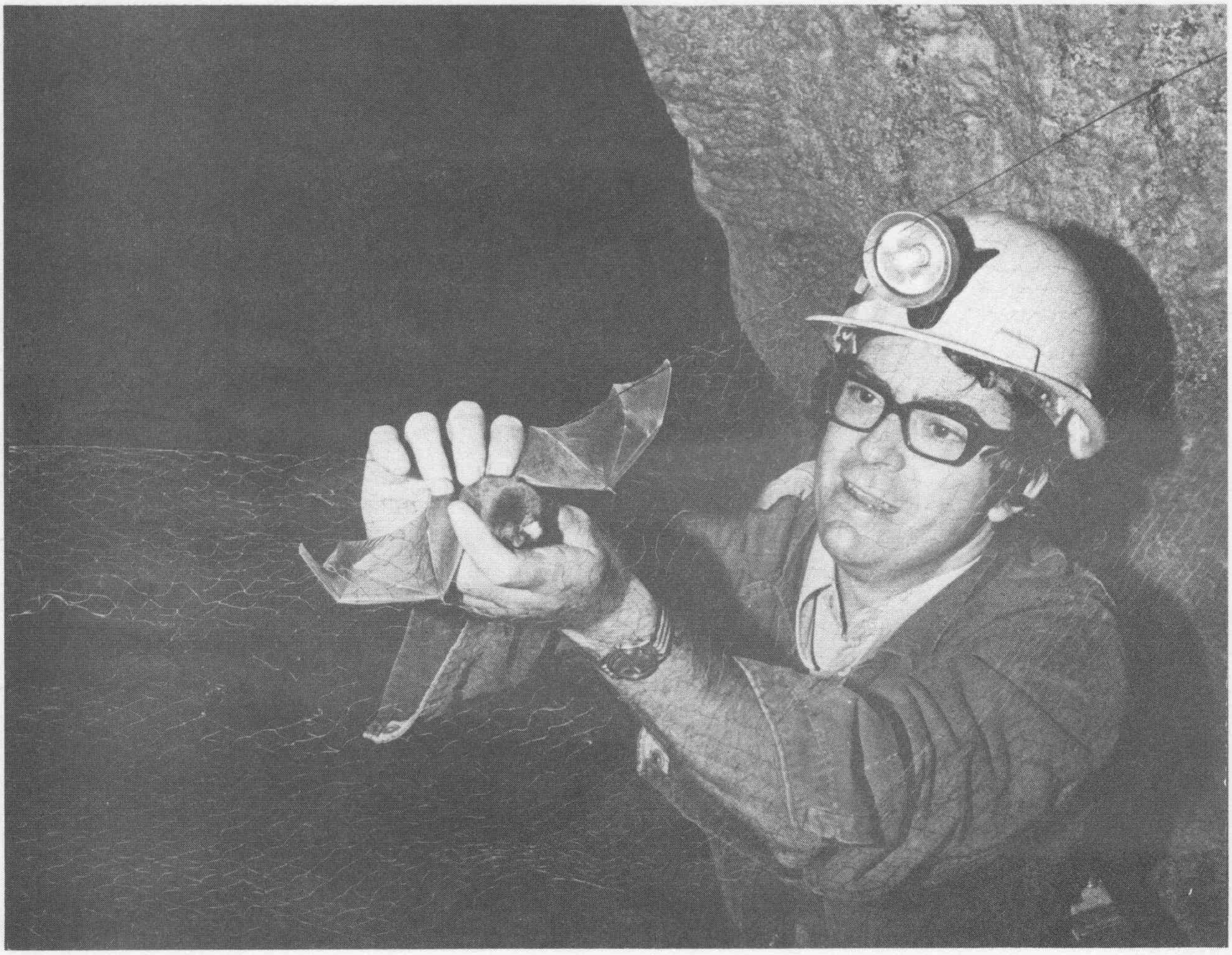

Removing a bat, Miniopterus schreibersii, from a mist net in the Drum Cave entrance, Bungonia, NSW. The cave contains a bat maternity colony.

Photo: Andrew Pavey

"HELICTITE"

Journal of Australasian Cave Research

Editors

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

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OBSERVATIONS OF KARST HYDROLOGY IN THE WAGA VALLEY, SOUTHERN HIGHLANDS DISTRICT, PAPUA NEW GUINEA

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Summary

In the neighbourhood of a possible dam site in the Waga Valley, Southern Highlands District, Papua New Guinea, there is little surface drainage apart from the Waga River itself. However, many nearby features - streamsinks, springs, estavelles, dry valleys, dolines and caves - are indicative of the marked development of karst drainage. Loss of river water by entry underground is not balanced by the known local outflows, and larger resurgences must be sought farther afield to complete an understanding of the karst hydrology relevant for the engineering proposal.

Introduction

The Waga River is one of the main tributaries of the Kikori River which drains the Southern Highlands of Papua New Guinea. This area contains about 15,000 km^2 of karst and is the largest karst area in Papua New Guinea.

Preliminary investigations of karst hydrology in the Waga Valley have been undertaken with reference to possible development of hydro-electric power. This development will depend on whether problems of water leakage from storages constructed in karst terrain can be overcome. In June 1973, the authors formed part of an investigation team organised by the Australian Department of Housing and Construction on behalf of the Papua New Guinea Electricity Commission. The team was based at the Poroma patrol post and flew in daily by helicopter to the study area. Preliminary results relating to one of the proposed hydro-electric schemes (Figure 1) are discussed here.

Geology and Geomorphology

In the Waga Valley, the Darai Limestone of early Miocene age is thrust over Cretaceous mudstone, and is overlain in places by Pliocene mudstone. The area is in the "Imbricate Zone" (Australasian Petroleum Company, 1961) in which sub-parallel fault slices repeat the same formation many times.

The imbrication has given rise to sub-parallel ridge and valley topography in this area (Figure 1). Northwest-trending limestone ridges rise to 1,800 m and alternate with valleys which have been eroded in mudstone and contain some alluvium. Karst has developed on the ridges and on dip slopes, with the formation of numerous dolines up to 75 m deep. Incipient karst is evident in some of the valleys where the overlying mudstone has been eroded or remains as a thin cover on the limestone.

East of the Waga Valley is a large area of polygonal karst (Figure 1) with no surface drainage, and with dolines up to 100 m deep (Plate 1).

Within the hydro-electric scheme area (Figure 2), the Darai Limestone strikes about 300° and consistently dips 55° - 60° NE; a set of steeply dipping master joints strikes 030°. The limestone is cream or light grey in colour, microcrystalline, and thickly bedded.

Colluvium has accumulated at the foot of most of the steep limestone slopes in the area. It consists of large blocks of limestone in a clayey matrix; in places it is thick and masks the bedrock karst features. Springs occur in the colluvium, and caves are developed in some of the larger limestone blocks.

Surface Hydrology

The nearest rainfall station is at Poroma, 15 km to the northeast. The records (of only five complete years) indicate a mean annual rainfall of about 2,600 mm with a slightly drier period from April to August.

During the investigation, gaugings of the Waga River indicated flows ranging from 50 to 100 m^3/s in the hydro-electric scheme area. The study of the groundwater hydrology (see below) indicated loss of river water underground, but insufficient gauging of the river has been done to confirm this. Apart from the Waga River itself there is very little surface drainage in the area, with only a few small tributaries fed by springs.

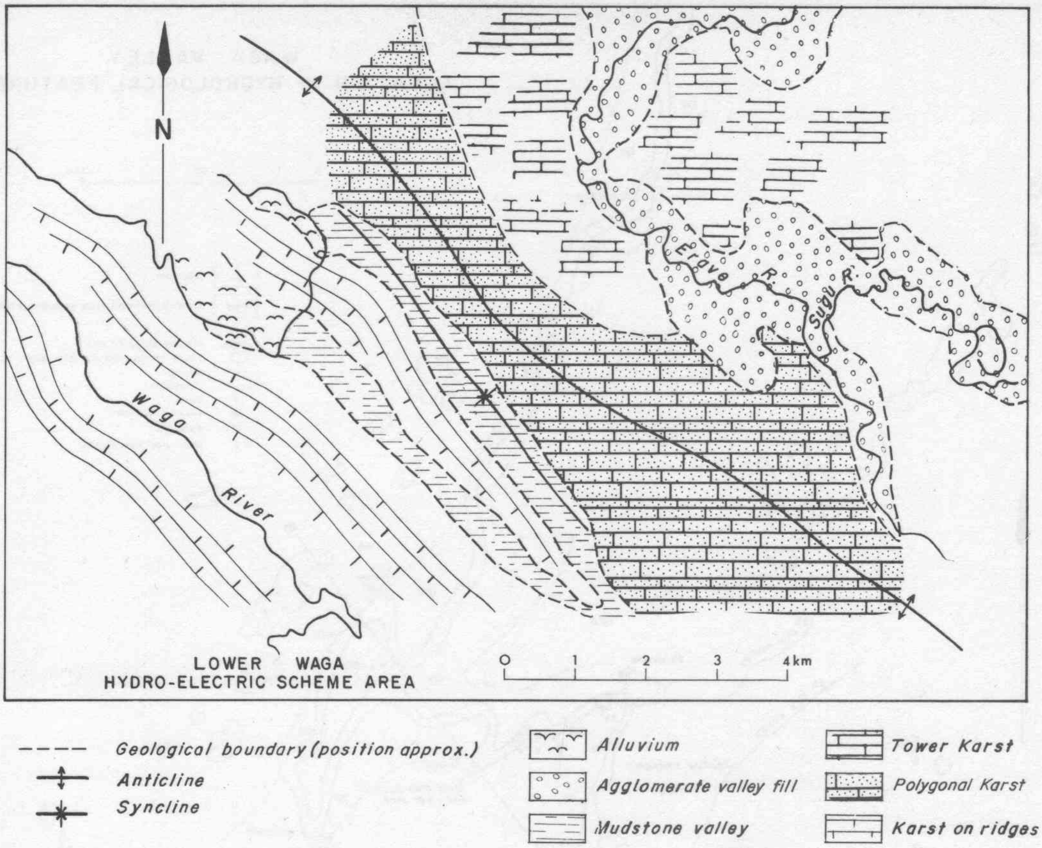
Groundwater Hydrology

There is ample evidence for substantial underground drainage in the limestone of the Waga Valley (Figure 1).

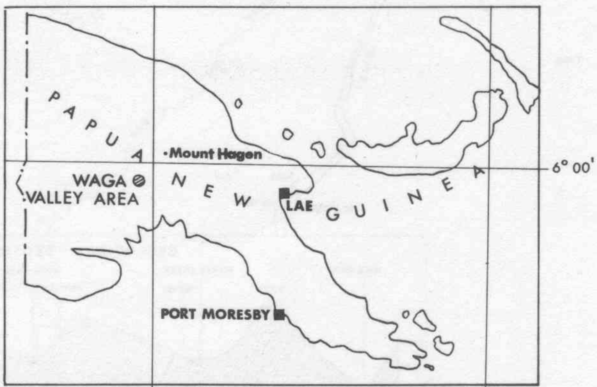
Streamsinks

Seven streamsinks were found in the left bank of the Waga River, some inactive at the time of the study (Figure 2). Their details are set out in Table 1. The total loss measured in the period 10-13 June 1973 was about 10 m^3/s.

Fig.1-Geomorphology of part of the Waga and Erave valleys



Locality map



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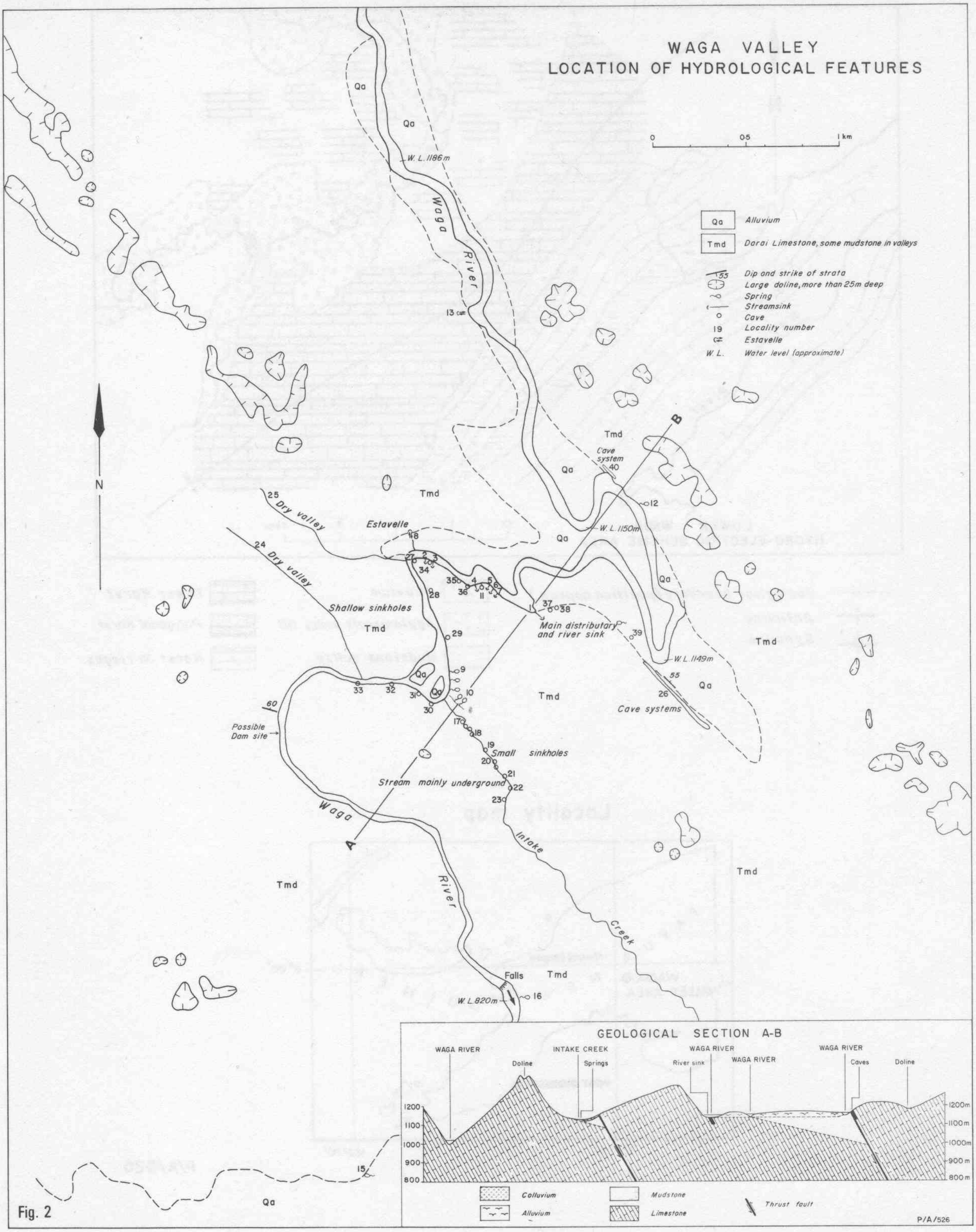

WAGA VALLEY
LOCATION OF HYDROLOGICAL FEATURES
0
0.5
1 km
Qa
Alluvium
Tmd
Darai Limestone, some mudstone in valleys
Dip and strike of strata
Large doline, more than 25m deep
Spring
Streamsink
Cave
Locality number
Estavelle
W. L.
Water level (approximate)
N
A
B
Waga River
W. L. 1186m
W. L. 1150m
W. L. 1149m
W. L. 820m
Cave system
Estavelle
Dry valley
Shallow sinkholes
Main distributary and river sink
Cave systems
Possible Dam site
Small sinkholes
Stream mainly underground
Intake Creek
Falls
GEOLOGICAL SECTION A-B
WAGA RIVER
INTAKE CREEK
Doline
Springs
River sink
Caves
1200m
1100m
1000m
900m
800m
Colluvium
Alluvium
Mudstone
Limestone
Thrust fault
P/A/526
Fig. 2

Dolines

The larger dolines in the project area discernible on photo-grammetric 25 m contour plans are shown on Figure 2. They are aligned along the strike and many are also elongated along it. There are also innumerable smaller dolines in the area. All these dolines feed runoff underground.

Dry Valleys

Dry valleys are found in the area; these represent the erosive work of former surface streams which have subsequently gone underground, as the details of their geomorphology demonstrate (Table 2).

Caves

A large number of caves were investigated in the project area; most proved to be small. The bedrock caves are commonly developed by solution along bedding planes or joint planes. Several caves were observed in colluvium or in limestone blocks within colluvium. Details of caves in the area are tabulated below (Table 3).

Springs

Nine springs were found on the left bank of the Waga River in the project area. Gaugings and estimates of flow between 3 and 12 June gave a total outflow of about 1 m^3/s. The details of the springs are given in Table 4.

Estavelles

Two estavelles were found in the area, both on the right bank of the Waga River. The estavelles are points which act as springs and as streamsinks at different hydrological stages.

A sketch map of the estavelle at locality 8 is given in Figure 4. Because of the narrowness of the entrances, it proved impossible to explore the system, and the use of explosives would be necessary to force an entrance. From 2 to 11 June the main channel was a distributary of the Waga River taking about 0.1m^3/s into entrance No. 2, while the other entrances were dry. After local heavy rain on the morning of 12 June, the flow of the distributary was reversed and all the entrances became springs with a total discharge of about 3 m^3/s. Details of the discharges are given in Table 5 together with some observations of the subsequent behaviour of the estavelle.

Further upstream at locality 13 a spring was observed to flow into the Waga River. Logs around the entrance indicate that this is an estavelle taking river water when the river level is higher. A sinkhole 30 m northwest of it contains flowing water, and the spring may be the outlet of a stream flowing underground along the foot of the ridge to the northwest.

Discussion

In the absence of detailed water tracing, the relationships of the various streamsinks, springs and estavelles remain unknown. However, for present purposes, it is sufficient to sum all the inflows and all the outflows and compare them. The result is clearly that there is a much greater water loss than gain from the Waga River in the project area.

Some springs about 7 km northwest of the project area were visited by helicopter (locality 14, Figure 6). The springs occur along the fault contact of limestone with the underlying Cretaceous mudstone. The altitude of the springs was measured by barometer and found to be about 1,180 m, which is too high for them to be an outlet for underground drainage from the project area.

Two other major springs are known in the region (Figure 6). One is about 9 km west of the project area and feeds a tributary of the Mubi River (locality 41). Another spring 13 km to the southeast (locality 42) is the most likely resurgence for the water lost in the project area.

Major springs have also been observed on a helicopter reconnaissance of the Mubi River to the south. However, these are 20-40 km away. Investigating the underground hydrology of this region would require an extensive and detailed search of the Waga, Mubi and Erave valleys for resurgences, followed by tracing experiments. Dense forest cover and difficult access would make this a long and costly investigation.

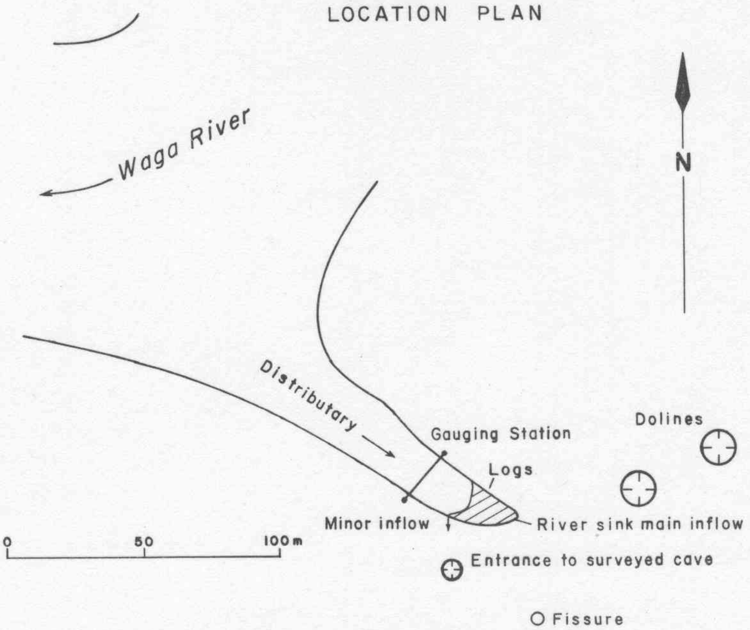
Acknowledgments

Considerable assistance was afforded by B. de G. Neale and P. Giltinan of the Department of Housing and Construction, who arranged the camp and access, and carried out the stream gauging. This paper is published with the permission of the Acting Director, Bureau of Mineral Resources, Canberra, and the Director of the Office of Minerals and Energy, Papua New Guinea.

Reference

AUSTRALASIAN PETROLEUM COMPANY, 1961 : Geological Results of Petroleum Exploration in Western Papua, 1937-61. Jour. Geol. Soc. Aust., 8 : 1-133.

Fig. 3 - Main distributary and river sink, left bank of Waga River



Flow of distributary gauged as $9 m^3/sec.$ on 13 June 1973

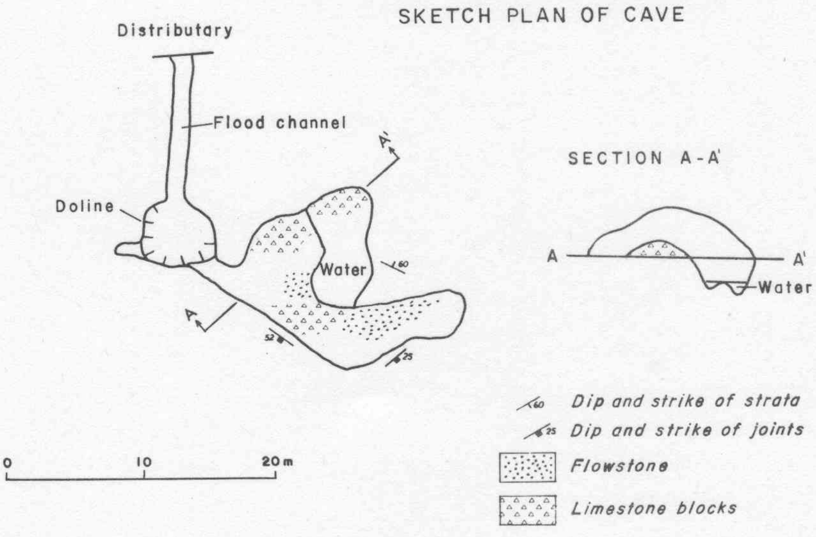


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Fig.4-Sketch map of estavelle, right bank of Waga River 12 June, 1973 (locality 8 on Figure 2)

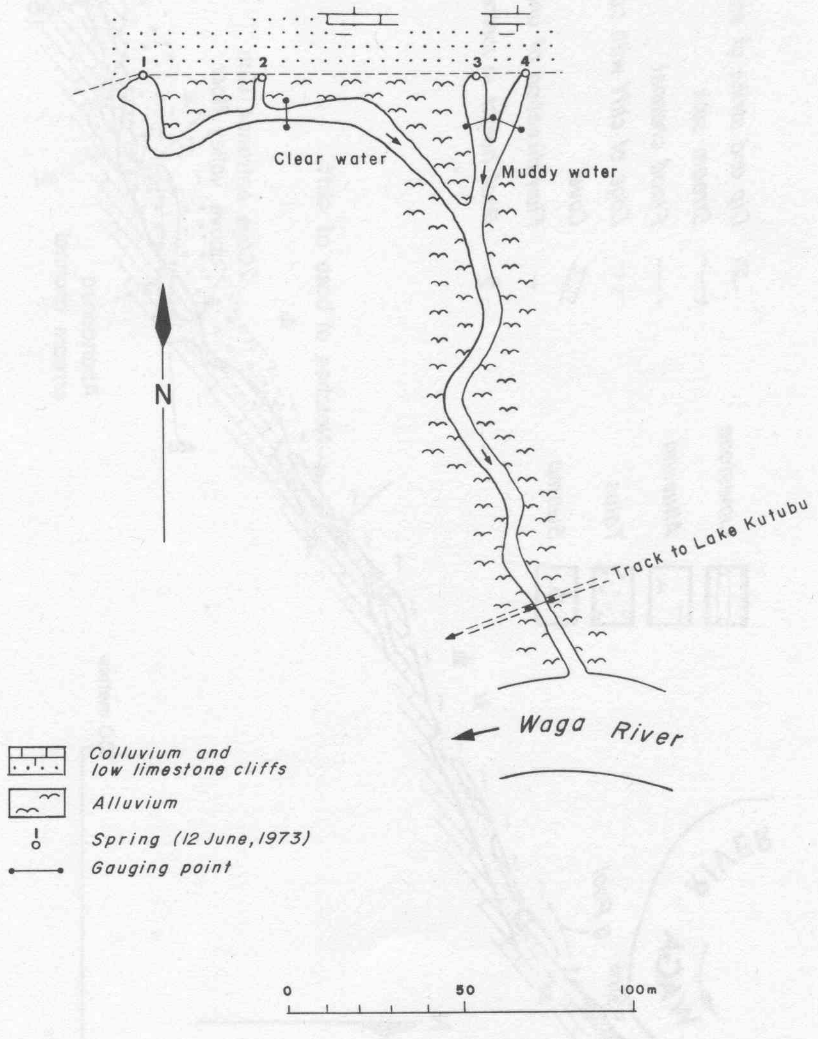

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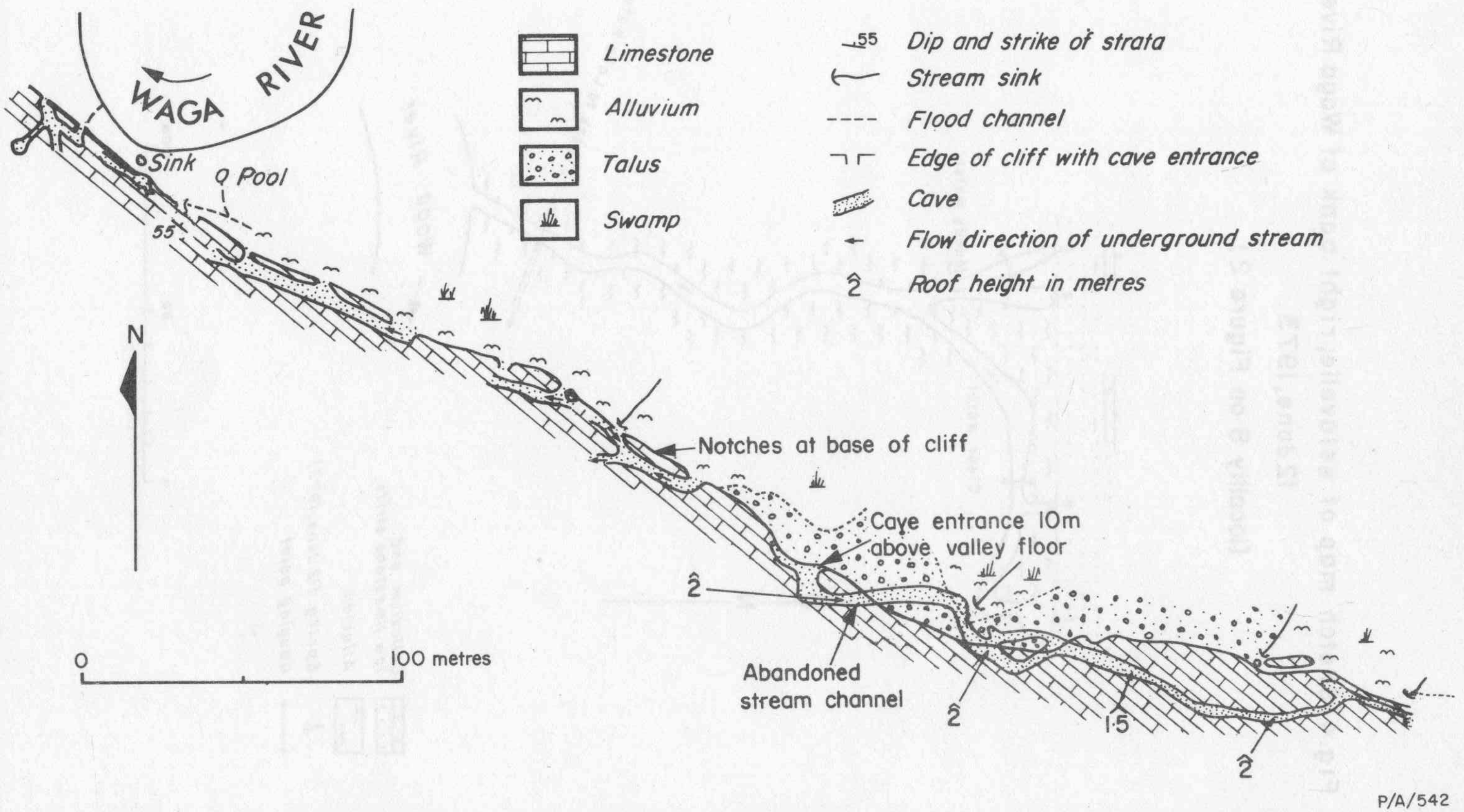
Fig. 5 – Cave systems in dry valley near Waga River (locality 26 on Fig. 2)



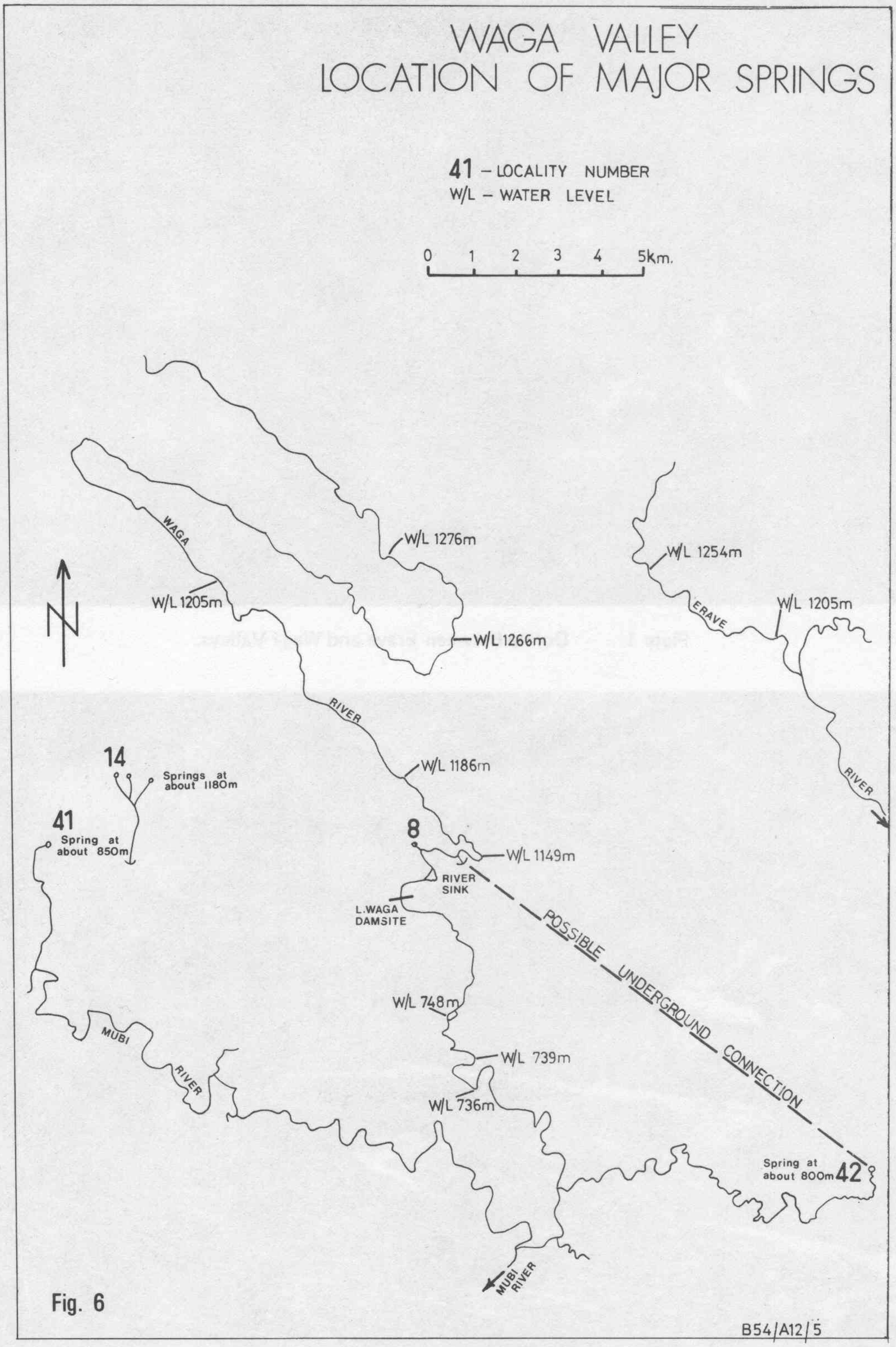

WAGA VALLEY
LOCATION OF MAJOR SPRINGS
41 – LOCALITY NUMBER
W/L – WATER LEVEL
0 1 2 3 4 5km.
N
WAGA
W/L 1205m
W/L 1276m
W/L 1266m
RIVER
W/L 1186m
W/L 1254m
ERAVE
W/L 1205m
RIVER
14
Springs at about 1180m
41
Spring at about 850m
8
W/L 1149m
RIVER SINK
L.WAGA DAMSITE
POSSIBLE UNDERGROUND CONNECTION
W/L 748m
W/L 739m
W/L 736m
MUBI
RIVER
Spring at about 800m
42
MUBI RIVER
B54/A12/5

Fig. 6

Plate 1 Doline between Erave and Waga Valleys.

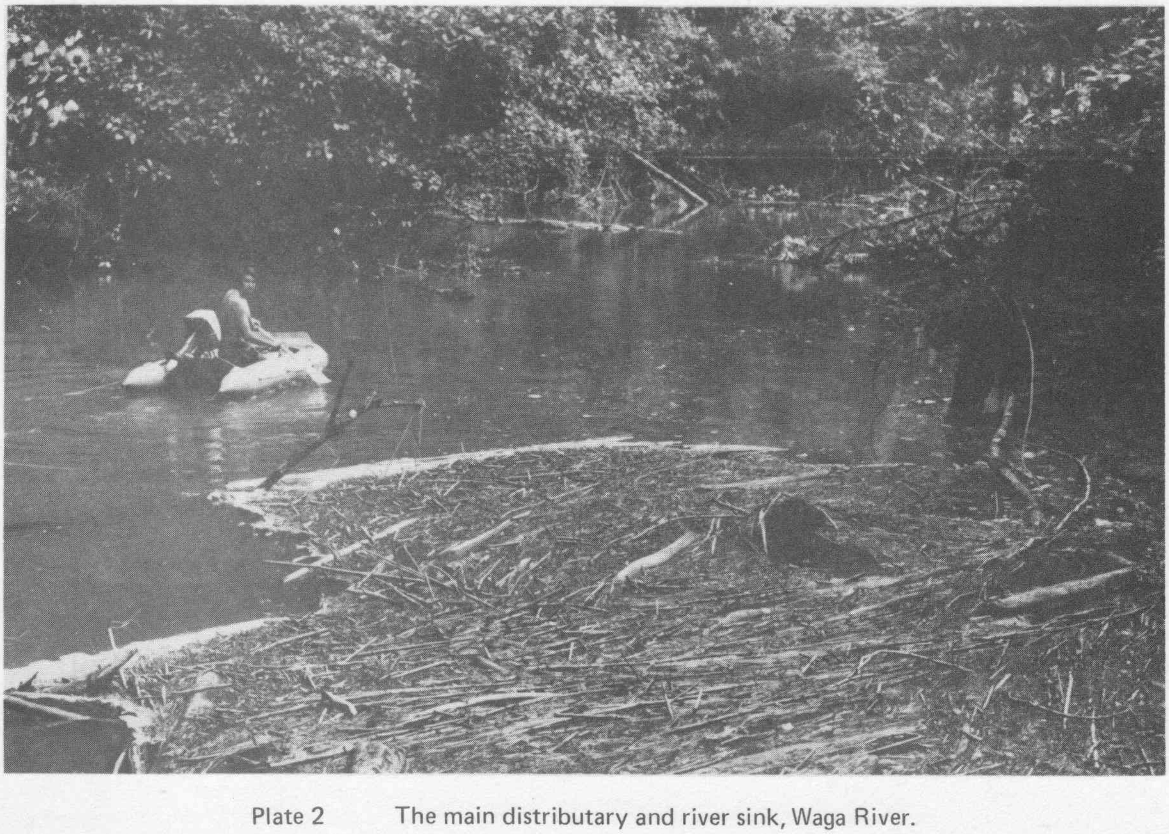


Plate 2 The main distributary and river sink, Waga River.

TABLE 1

LIST OF STREAMSINKS

Locality No.	Intake	Details
1	9 m^3/s (13 June)	A distributary 25 m wide and 100 m long (Plate 2). No access at streamsink but a cave 15 m to the south with 0.3 m^3/s was surveyed (Figure 3). Water was heard in a fissure 40 m SE of sink, 3.5 m long, 0.5 m deep, along joint with 050° strike and 70° dip to SE. Two dolines 7 m diam., 14 m deep, E of sink.
2	0.1 m^3/s (10 June)	A distributary 20 m long, 2 m wide, into base of limestone cliff.
3	Est. 0.1 m^3/s	A distributary 10 m long sinks in a hole blocked by logs.
4	Dry (12 June)	A hole with flood debris in entrance; must receive Waga River water in flood.
5	Dry (12 June)	Small dry distributary channel in alluvial terrace.
6	less than 0.1 m^3/s (12 June)	Distributary crosses narrow terrace into small hole.
7	not known	River water flows into silt and boulders of riverbank 2 m high over length of 2.5 m.

TABLE 2

LIST OF DRY VALLEYS

Locality No.	Details
17-23 ("Intake Creek")	A chain of sinkholes and breached cave systems. The stream flows underground for most of its length and is only visible in a few windows. Locality 17: A series of small caves in creek bed; one is developed on join dipping 40°S and contains water more than 6 m below dry creek bed. Locality 18: Creek flows beneath breached cave with solution funnels developed on join dipping 30°S. Locality 19: Breached cavern above stream developed on vertical fissure trending 030°. Cavern is 20 m long, 1-4 m wide and 6-10 m high. Locality 20: Doline with two fissures on east - dipping joints and a shaft 10 m deep. Locality 21: Valley is indistinct chain of small sinkholes; stream exposed beneath fissure trending 140°, and flows on the surface for a short distance. Locality 22: Shaft 5 m deep in small circular doline. Joint fissure dipping 60°at base of shaft. Locality 23: Doline with vertical fissure trending 025°at its base. Fissure 15 m long, 2 m wide, 1-2 m deep and contains rounded stream gravel.
24	Chain of sinkholes, some with openings several metres deep; all that were investigated proved to be choked with debris. Sinkholes mostly 5-10 m diameter and 3-5 m deep.
25	Dry stream bed with one window exposing flowing water. Lower part of valley is incised 20 m into gently sloping terrain. Further up, valley is poorly defined, consisting of series of gullies with limestone blocks and numerous sinkholes up to 8 m diameter and generally 3-5 m deep.
26	Cave system in dry valley (Figure 5). Underground stream beneath foot of limestone cliffs visible in several windows. Several small tributary streams drain broad swampy valley to north and enter sinkholes near foot of cliffs. Some of the caves are dry, including an abandoned stream channel 300 m long which is several metres above the present stream.

TABLE 3

LIST OF CAVES

Locality No.	Dimensions	Details
27	15 m long	In colluvium; takes flood flows of Waga River.
28	5 m long, 3 m high	Beneath large limestone block which has slipped on steep south-dipping joint planes.
29	15 m long, 5 m high	Behind large semi-detached block.
30	10 m long, 2 m high	In colluvium (limestone boulders).
31	7 m long, 4 m deep	Fissure with two shafts in floor.
32	6 m deep, 1-2 m diameter	Shaft on joint plane trending 050°.
33	7 m deep	Shaft with collapsed walls developed on intersecting bedding and joint planes.
34	5 m long, 2 m deep	Contains small stream which appears to flow towards river.
35	Several metres deep	Small doline with shaft beneath which is dry stream bed.
36	Several metres deep	Small doline containing flowing water, about 8 m from river bank.
37	Several metres long	Fissure developed on vertical joint striking 350°.
38	10 m long	L-shaped cave developed on intersecting bedding and joint plane fissures.
39	10 m deep	Collapsed sinkhole.
40	Extensive - not explored	A series of caves at the foot of limestone slope, probably developed along thrust faulted contact of limestone with underlying mudstone (Figure 2). Extends below level of Waga River.

TABLE 4

LIST OF SPRINGS

Locality No.	Flow	Details
9	$0.1\ m^3/s$ (3 June)	3 springs: North. From colluvium 5 m above river.
	less than $0.1\ m^3/s$ (3 June)	Middle. A smaller spring.
	$0.1\ m^3/s$ (3 June)	South. From colluvium, flows 20 m to river.
10	$0.1\ m^3/s$ (6 June)	2 springs at foot of limestone slope feed small tributary of Waga River.
11	less than $0.1\ m^3/s$ (12 June)	Small creek from foot of limestone slope.
12	$0.5\ m^3/s$ (June)	Drains shallow doline to NE.
		Flows from fissure striking 300° and dipping 65°NE along channel 30 m long and 6 m wide to river.
15	less than $0.1\ m^3/s$ (4 June)	From colluvium at foot of spur.
16	not known	From colluvium.
		Resurgence of river water sinking into colluvium near base of nearby waterfalls.

TABLE 5

OBSERVATIONS OF FLOW AT ESTAVELLE (LOCALITY 8)

FLOW (m^3/s)

JUNE 1973	Entrance 1	Entrance 2	Entrance 3	Entrance 4	Total
2-11	dry	0.1 in	dry	dry	0.1 in
12	1 and 2 together (1.8 out)		0.4 out	1.0 out	2.7 out
13	dry	dry	out	out	out
14	not visited				in
15	dry	substantial flow in	dry	small flow out	0.3 in
16	not visited				in
17	trickle in	0.4 in	less than 0.1 out	0.1 out	in

CHIROPTERITE DEPOSITS IN MOORBA CAVE, JURIEN BAY, WESTERN AUSTRALIA

P.J. BRIDGE, L.C. HODGE, N.L. MARSH, A.G. THOMAS

Government Chemical Laboratories, Perth, Western Australia

Summary

An old guano pile deposited by *Macroderma gigas* has been examined chemically and mineralogically. Sixteen sectional analyses of a profile are presented and discussed. The main soluble components are P_2O_5, CaO and SO_3 (present as brushite, ardealite, gypsum and collophane) with insoluble quartz. Taranakite occurs as a minor constituent.

Moorba Cave

Cave phosphate deposits have been known from Jurien Bay since 1908 when Goeczel (1909) examined the deposits for their potential as a fertiliser. Moorba Cave (J3) (Figure 1), containing the major deposit, is 8 km NNE of Jurien townsite (30° 15' S., 115° 01' E.) and 200 km NNW of Perth.

The cave is developed in a north-south trending ridge of "Coastal Limestone" - consolidated Pleistocene sand dunes. The surface expression of the cave is a collapse doline with the entrance down a steeply sloping boulder pile leading into the main chamber. Solution features on the roof and walls appear to indicate a phreatic origin for the cave. Temperature and humidity readings recorded in the main chamber over three days in May 1966 were 16.7°C + or - 0.5° and 90 per cent.

The main chamber of the cave has been mined to a depth of two metres. Remnants of the guano pile lie at the end of the chamber and other piles exist in smaller chambers deeper in the cave. Guano production in records of the Department of Mines, Western Australia, from 1957 to 1965 is 1,074 tonnes, thought to be much less than the total production. Mining has now ceased and following representations from the authors the cave was reserved and is now part of a National Park.

Macroderma gigas

Macroderma gigas (Dobson), the Ghost Bat, is responsible for the chiropterite deposits in caves between Yanchep and Dongara (P.J. Bridge, to be published elsewhere). The Ghost Bat is carnivorous with a diet of small mammals, birds, lizards, and insects (Douglas, 1967). Numerous animal remains were found in the main chiropterite deposit, but the only recognisable skeletal fragments were a few tooth fragments of *Macroderma* and murids. Hair-like material collected from the surface of the pile may be fur from the last species of bats to occupy the cave. The present southern limit of *Macroderma gigas* is Gahnda Rockhole (26° 36' S., 125° 52' E.) (Western Australian Museum, M4637). A. Baynes (pers. comm.) has found *Macroderma* in nearby Hastings Cave (J4) throughout the full 3.1 m depth of a deposit excavated. Twigs and woody fruit from 1 - 2 cm below the surface gave a radiocarbon date (GaK-2645) age of 400 + or - 70 years BP. The disappearance of *Macroderma* is not an isolated case, the majority of mammal species whose remains are present in the top layers are now locally extinct.

Small colonies of another bat, *Chalinolobus morio* (Gray) are known to live in caves in the area, but only one of these colonies appears to have produced appreciable quantities of guano. Other bat species may occur there.

Description of the Guano Pile

The main guano pile in Moorba Cave was a flattened cone shape beneath a ceiling "bell hole" where the bats once roosted. Mining operations have left a vertical section through the deposit and a face of approximately 4.5 m height was sampled in 30 cm sections. The guano is colour banded, the layers vary from dark brown to black and are white flecked, friable and stratified and show slumping and lensing over a limestone boulder near the base of the section (Plates 1 and 2). This may have been caused by gradual consolidation and shrinking of the pile or by its collapse into underlying crevices nearer the watertable.

The chiropterite is composed of finely comminuted bone fragments (consisting of collophane, mainly carbonate apatite, calcium phosphate with F, OH and CO_2), brushite ($CaHPO_4.2H_2O$), gypsum ($CaSO_4.2H_2O$), ardealite ($Ca_2HPO_4SO_4.4H_2O$) and ubiquitous quartz grains (Plate 3). There is very little chitinous material, indicating the lack of insects in the bats' diet, and no individual faecal pellets are present. The pile has obviously undergone thorough disintegration by coprophagous insects as it was deposited.

The most striking aspect of the guano pile is the selective development of the large - up to 12 cm - nodules of ardealite and brushite only near the base contact with limestone (samples 11 to 12, Plage 4). The pile can be divided into 5 zones:

1. Samples Top to 1: "rapid decomposition zone" organics, gypsum and nitrogen rich surface.

2. Samples 2-8: "stable zone", brushite and gypsum zone.

3. Samples 9-10: "transition zone", brushite, gypsum ardealite zone.

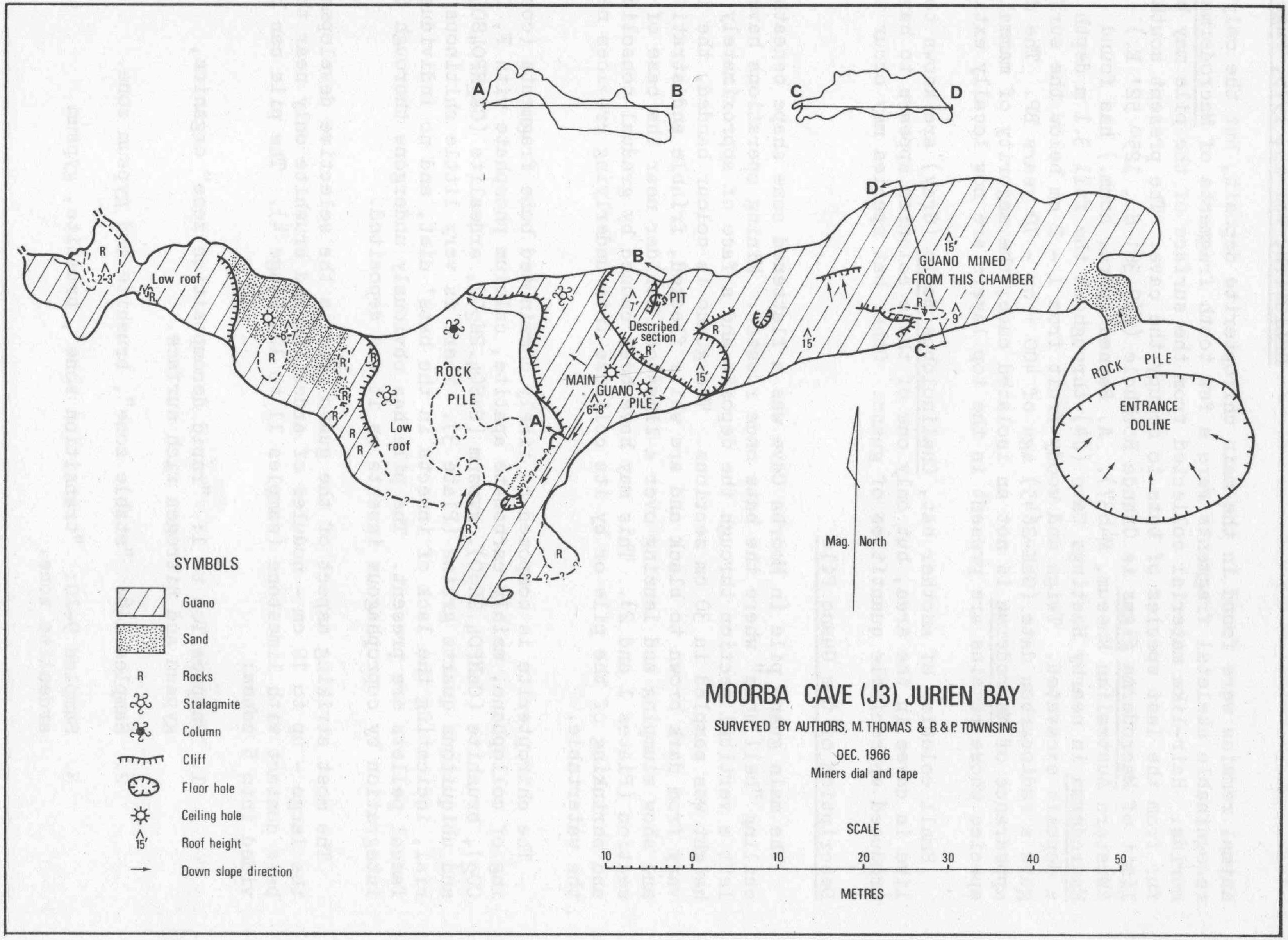

MOORBA CAVE (J3) JURIEN BAY
SURVEYED BY AUTHORS, M. THOMAS & B. & P. TOWNSING
DEC. 1966
Miners dial and tape
SCALE
10 0 10 20 30 40 50
METRES
Mag. North
SYMBOLS
Guano
Sand
R Rocks
Stalagmite
Column
Cliff
Floor hole
Ceiling hole
15' Roof height
Down slope direction
ENTRANCE DOLINE
ROCK PILE
GUANO MINED FROM THIS CHAMBER
MAIN GUANO PILE
Described section
PIT
Low roof
Low roof
A
B
C
D

Fig. 1

4. Samples 11-12: "nodule zone", ardealite and brushite zone.

5. Samples 13-15: "sandy zone", quartz sands and phosphates on limestone.

Mineralogy

Detailed description of the phosphate minerals will be published elsewhere. The grain size of the phosphates and gypsum (except collophane bone fragments) does not exceed that of the brushite crystals which are up to 0.1 mm in size, and are usually much finer. The nodular occurrence of cave guano phosphates has been recorded previously though very few occurrences have been mineralogically examined. The nodules have no apparent internal structure, range in size from 1 to 12 cm and are usually pure, with no incorporated guano or quartz grains. Ardealite is the dominant nodular mineral, but brushite is more widely distributed in the deposit.

Ardealite occurs in fine-grained, compact, yellow nodules which are larger and better formed than the brushite nodules. X-ray powder patterns indicate that three ardealite phases, tentatively termed ardealites I, II and IIIm are present in Moorba Cave. Analyses of ardealites have been reported by Marsh (1967). Ardealite I is similar to that of Halla (1931).

Brushite occurs as white, soft, finely granular nodules, aggregates, bands and streaks in the guano and as soft crusts on some limestone fragments. It also occurs as an alteration product of calcite on the surface of a stalagmite which was covered in guano. The X-ray powder pattern is almost identical with that of artificial $CaHPO_4.2H_2O$, but is slightly different from that described by Murray and Deitrich (1956).

Gypsum is common in the cave as layers in the chiropterite but some also occurs as pure masses. Where drops of water hit the floor, gypsum crusts form a peripheral ring to the damp area. Several variants of normal gypsum have been identified by X-ray diffraction.

Collophane, the major mineral constituent of bone, naturally comprises a large part of the deposit. It also occurs as dark crusts around bat-roosting ledges and coats the walls at the limestone-guano contact. Such dark crusts are almost always associated with bat roosts in limestone caves.

Taranakite ($2K_2O.3Al_2O_3.5P_2O_5.26H_2O$) is derived from the phosphatisation of the clay fraction of the aeolianite and occurs as white 3 mm pellets in the sandy base layers of the guano above the limestone boulder.

Ardealite, a rare mineral, has been recorded only twice before - by Schadler (1932) in Romania and by Sekanina (1956) in Moravia. The authors have also found it in cave phosphates from Sarawak.

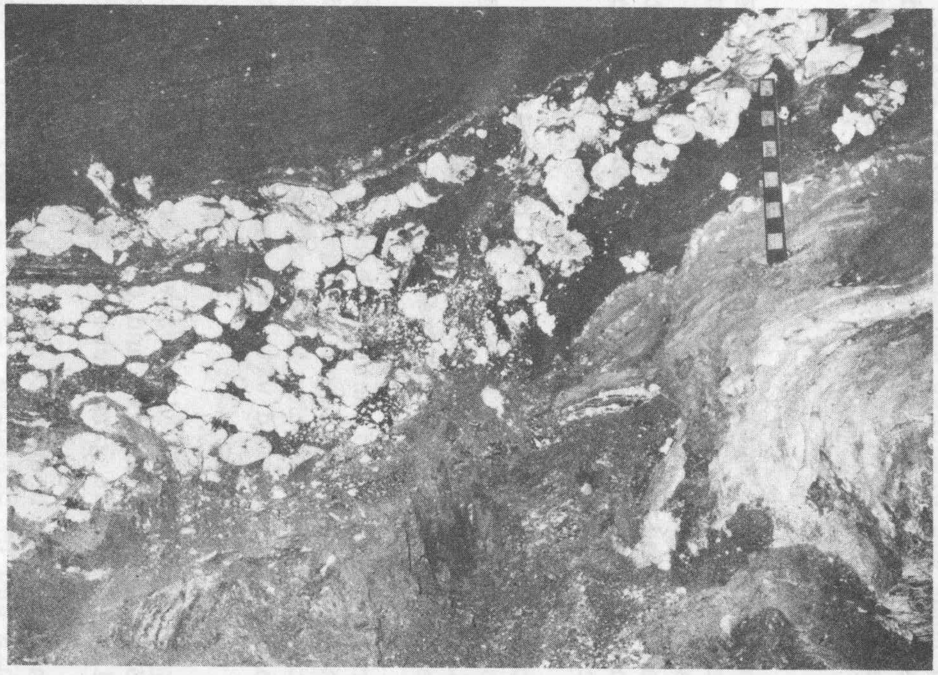


PLATE 1.

Guano with nodules showing slumping and lensing over a limestone boulder. (Scale in inches)

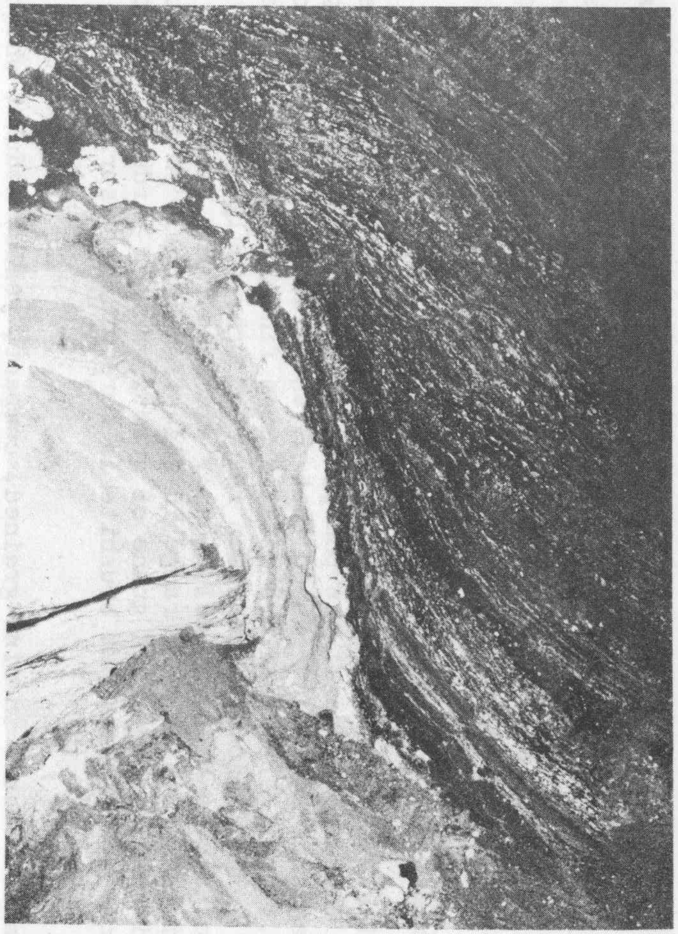


PLATE 2.

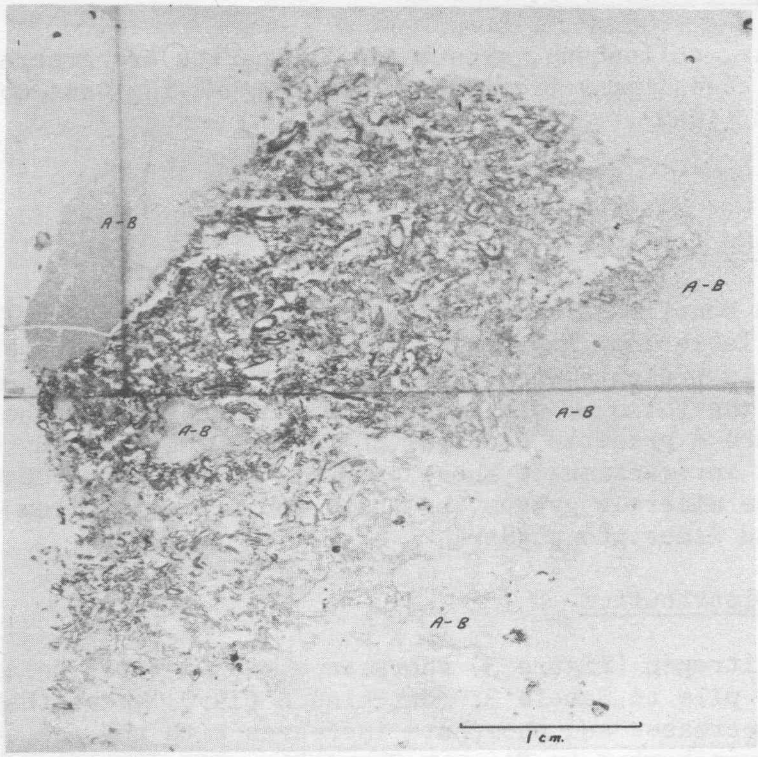


PLATE 3. Thin section of guano showing nodules (A-B) and bone fragments.

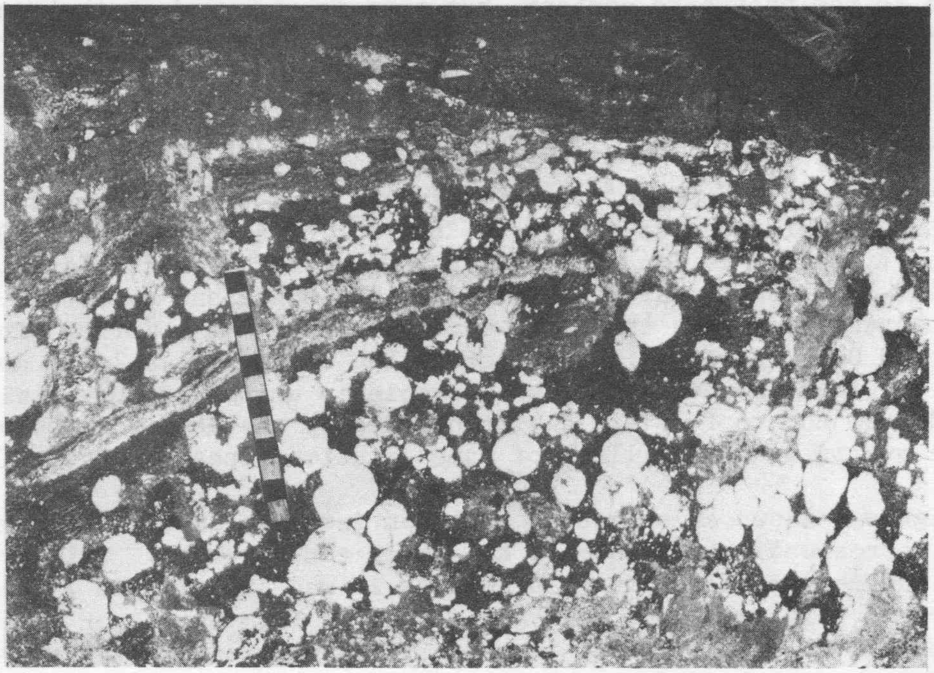


PLATE 4. Ardealite nodules near base of the deposit. (Scale in inches)

Brushite, collophane, gypsum and taranakite are generally much more common in caves, many previous occurrences having been documented Hutchinson (1950).

ANALYSES

Introduction

Sixteen contiguous samples from the top to the base of the pile were analyses (Table 1). A graph of the distribution of the five major constituents is presented in Figure 2. In Figure 3 distribution is presented of the forms of nitrogen normalised to exclude the acid insolubles. Figure 4 presents CaO,P_2O_5,SO_3 and H_2O normalised to 100% to show the mutual interaction of these products of the guano decomposition in forming the minerals gypsum, brushite and ardealite from collophane, bat excreta and limestone powder.

Nitrogen Distribution

Total nitrogen (Figure 3) shows an expected rapid descrease from the top of the pile to Sample 3. Hutchinson (1950) shows that the amount of nitrogen decreases and phosphate increases with the age of the guano and this is demonstrated in Figures 3 and 4.

Thereafter, with the profile, the nitrogen content is generally inverse to the phosphate content, but this is reversed in the sandy layers. It is unlikely that for samples 3 and below that this inverse relationship can be correlated with age.

Acid Insolubles

The average content of acid insolubles from the pile top to sample 12 is 21.5%. This is most likely due to roof breakdown. The $CaCO_3$ content of the limestone ceiling averages 89%, indicating that a large amount of calcium other than that available from bat bones and excreta. The low CO_2 content indicates that this excess calcium has combined with the P_2O_5 and SO_3. However, the effect of the additional calcium derived from the roof is modified by an appreciable amount of quartz also derived from the roof. This has been added by the bats scratching out the loose quartz sand in-filling of some solution pipes in the ceiling.

Figure 2 shows at sample 13 a sudden increase in acid insolubles, with corresponding decrease in all other constituents. This trend with a slight decrease continues in samples 14 and 15. Sample 15 near the floor may well represent removal of calcium from the floor limestone by phosphatic solution, but it is more likely that sample 14, above 15, represents normal roof breakdown prior to occupation by bats, with some sand enrichment from the solution pipes.

It is suggested that sample 13, highest in acid insolubles, represents a limited period of accelerated roof breakdown caused by the bats, at their first massive occupation, scratching out the looser "surface" sand and limestone from the ceiling.

Increases in K_2O and Al_2O_3 in these sandy layers are associated with taranakite formed by phosphatisation of the clay fraction. Fine-grained collophane is also present here and is presumed to have precipitated from downward percolating solutions.

Lime, Phosphate, Sulphate, Water

Figure 4 illustrates the division of the whole pile into several zones using the percentage of lime, phosphate, sulphate and water adjusted to 100%. The "rapid de-composition" zone, indicates surface evaporation of sulphate-bearing solutions forming a gypsum efflorescence.

The "stable zone" is reasonably constant in all major components including acid insolubles.

The "transition zone" shows changes in the SO_3:P_2O_5 ratio.

The "nodule zone" is characterised by the striking presence of the large nodules of ardealite and brushite. The calcium content and also the total of P_2O_5 plus SO_3 remains fairly constant throughout the zone, but the P_2O_5 and SO_3 contents show an inverse variation.

The "sandy zone" has a large amount of brushite.

The trends illustrated by Figure 4 are:

1. A relatively uniform calcium increase, 29-36%.
2. The total phosphate plus sulphate shows a similar but smaller increase, 42-44%, a remarkably uniform one considering the variation of the phosphate/sulphate.
3. The phosphate trends are almost a mirror image of the sulphate trend. These two trends are noteworthy for their inverse symmetrical variation, especially in the lower zones showing nodule development.
4. The total water decreases relatively uniformly from 28-20%. The interpretation of the significance of the above trends is difficult due to the high proportion of collophane of the samples (noted in microscopic examination) and the contribution of phosphate by surface reactions of the bone fragments which cannot even be estimated.

Some other points of interest arising from the analyses are (1) that low totals (samples HT, 1,4,7,8,10,11) correlate with relatively high "other" nitrogen, and may indicate, at least on the surface, the presence of organic nitrogen compounds; (2) the distribution of acid insolubles closely matches the corrected value of phosphate distribution.

Copper contents of up to 0.4% have been recorded from bat guanos Hutchinson (1950), but the amounts reported here are negligible.

Origin of the Phosphates

Kaspar (1934) described the sequence of minerals deposited from leaching solutions in guano and has shown that phosphate migrates farther than sulphate, which is precipitated as gypsum close to the guano.

The authors consider that the leaching solutions contain a higher concentration of ammonium phosphates and sulphates, rather than ammonium carbonate solutions as proposed by some earlier authors. This solution is enriched in phosphate during its downward percolation, continuously precipitating brushite as it moves and also depositing ardealite and brushite in large amounts near the base of the deposit. Crystallisation of brushite in the bone fragments probably assists their disintegration by crystal exsudation.

The Moorba Cave chiropterite shows high phosphate levels throughout due to lack of solution mobility and phosphate leaching in the cave, which is generally dry. However, the conditions which must have prevailed during deposition were different from those prevailing at present, as is indicated by the authors' observation of corrosion effects of phosphates on limestone similar to those described by Kettner (1948).

Macroderma gigas probably disappeared from this cave since the arrival of European man in Australia and thus the "rapid decomposition" zone may still be shrinking. When the bats were still present and actively adding to the guano pile, the zone probably extended to a greater depth with an upwards shift as the pile accumulated. A suggested simplified sequence of chemical change combining data obtained from other investigations is given in Figure 5.

Acknowledgments

The authors which to thank Mr J. Just of Australian Selection (Pty) Ltd and Dr M. Rieder of Charles University, Prague, for their help in translating the Czechoslovakian texts; Professor Halla for his personal co-operation in a preliminary investigation of ardealite; members of the Western Australian Speleological Group for help in surveying; Departmental colleagues for their co-operation and advice; Dr D. Merrilees and Mr A. Baynes for critical comments; and the Mapping Division of Surveys and Drafting Branch, Western Australian Department of Mines, for the map and diagrams.

TABLE 1. GUANO ANALYSES, MOORBA CAVE

SAMPLE:	Heap Top	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P_2O_5	7.80	24.1	28.0	27.7	25.9	26.4	26.8	25.4	24.5	21.3	22.7	20.6	18.1	4.81	7.33	8.71
CaO	22.0	25.2	26.3	25.5	23.8	24.9	25.2	24.2	23.4	22.3	23.0	26.3	22.4	4.5	11.1	11.8
SO_3	24.1	6.84	6.93	6.03	5.75	6.50	6.67	6.17	5.00	6.67	6.33	12.4	10.3	0.75	5.25	5.58
Al_2O_3	0.15	0.13	0.15	0.13	0.17	0.15	0.17	0.21	0.25	0.30	0.26	0.21	0.28	0.66	0.49	0.42
Fe_2O_3	0.37	0.30	0.30	0.27	0.30	0.27	0.30	0.27	0.34	0.34	0.30	0.27	0.29	0.43	0.24	0.27
K_2O	0.24	0.12	0.10	0.08	0.10	0.07	0.08	0.10	0.10	0.16	0.16	0.12	0.12	0.29	0.24	0.31
Na_2O	0.09	0.08	0.05	0.07	0.07	0.05	0.07	0.07	0.08	0.15	0.11	0.16	0.11	0.09	0.11	0.11
MgO	0.03	0.05	0.05	0.03	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.07	0.03	0.02	0.02	0.02
CO_2	0.19	0.19	0.13	0.13	0.13	0.14	0.11	0.11	0.16	0.20	0.18	0.19	0.18	0.08	0.12	*
N Ammonia	0.32	0.21	0.20	0.14	0.21	0.14	0.13	0.11	0.09	0.19	0.19	0.19	0.12	0.03	*	*
N Nitrate	0.21	0.20	0.17	0.13	0.12	0.11	0.12	0.07	0.06	0.24	0.17	0.29	0.10	0.03	0.06	0.13
N Other	0.83	0.49	0.32	0.28	0.37	0.26	0.21	0.23	0.26	0.19	0.25	0.20	0.24	0.08	0.06	0.01
Total N ≠	1.36	0.90	0.69	0.55	0.70	0.51	0.46	0.41	0.46	0.62	0.61	0.68	0.46	0.14	0.12	0.14
Total H_2O	21.2	22.6	22.7	21.8	21.1	21.0	20.8	18.0	17.3	16.9	18.0	18.3	15.3	2.47	5.76	6.69
Cu, p.p.m.	110	70	70	70	80	80	80	90	90	100	80	80	20	10	10	5
Acid insoluble	20.1	15.3	14.7	16.4	18.5	20.0	18.9	21.5	25.9	31.4	25.2	19.6	32.4	85.4	69.1	65.1
TOTAL	97.6	95.8	100.1	98.7	96.6	100.0	99.6	96.5	97.5	100.4	96.9	98.9	100.0	99.64	99.89	99.17

Notes: All analyses except those for total water and acid insolubles were carried out on the acid soluble portion of the samples.

All analyses on as received basis.

* less than 0.01 ≠ not included in total summation

Analyst. A.G. Thomas

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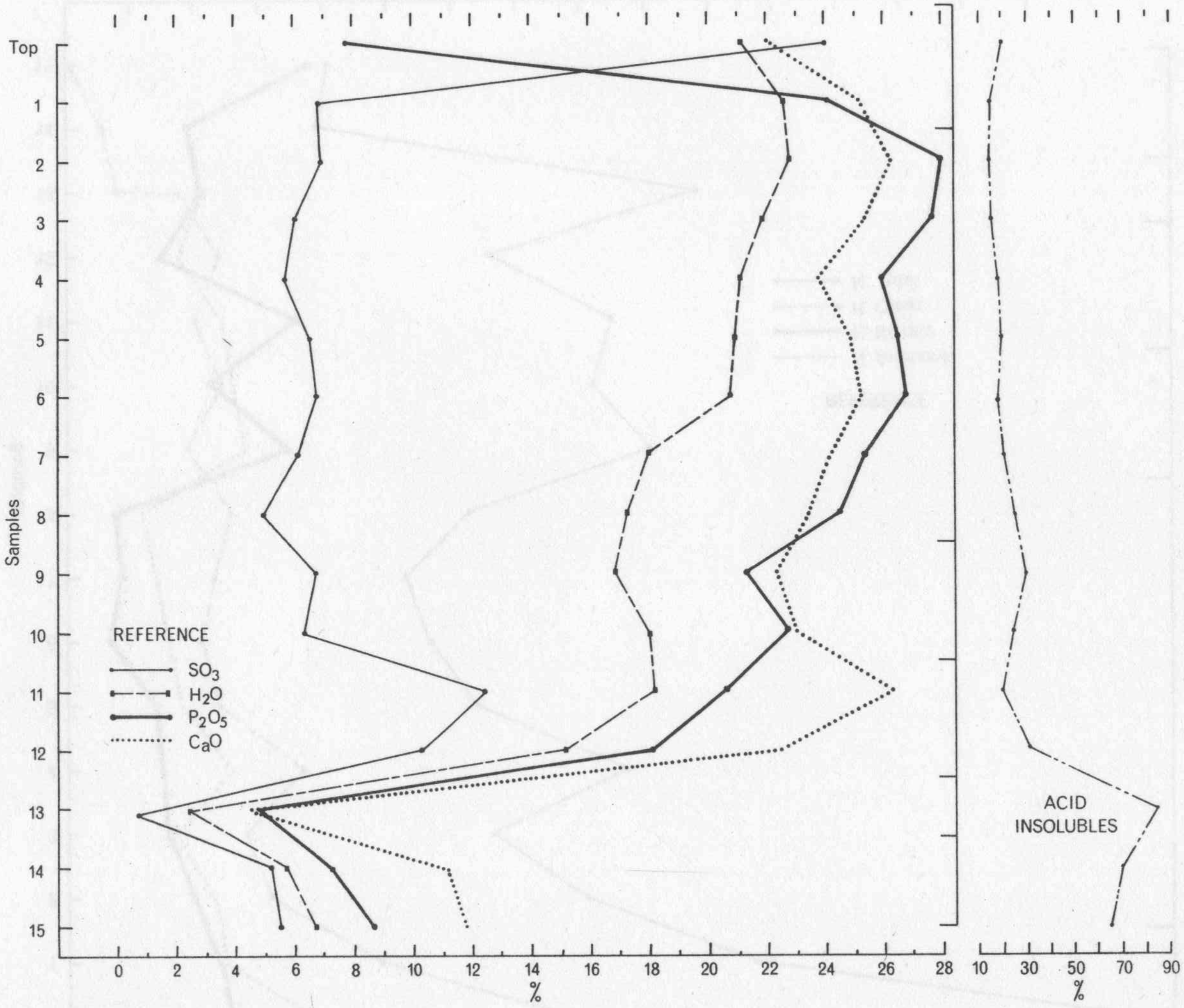

Fig. 2 Distribution of major components.

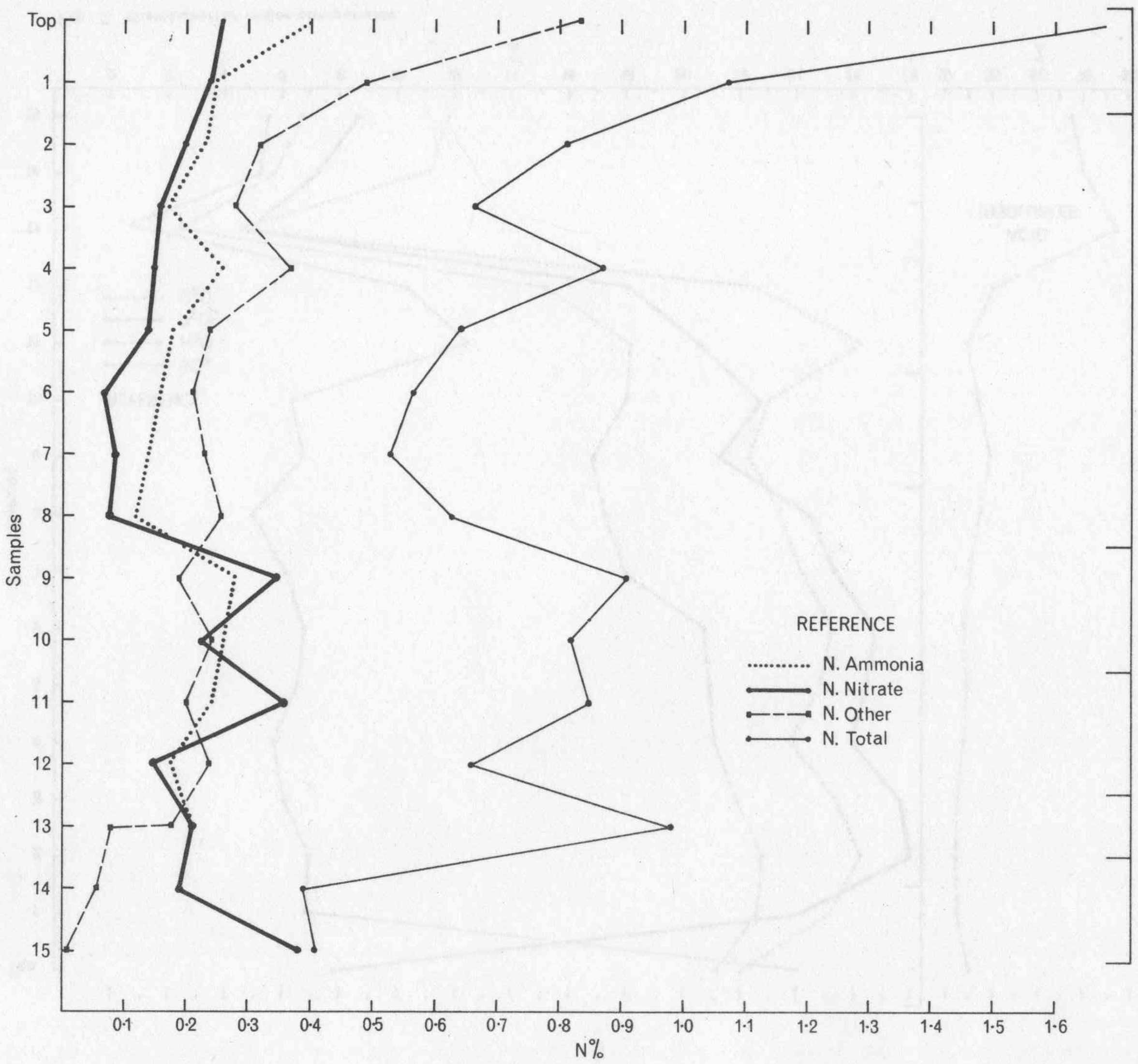

Fig. 3 Nitrogen distribution, normalized to exclude acid insolubles.

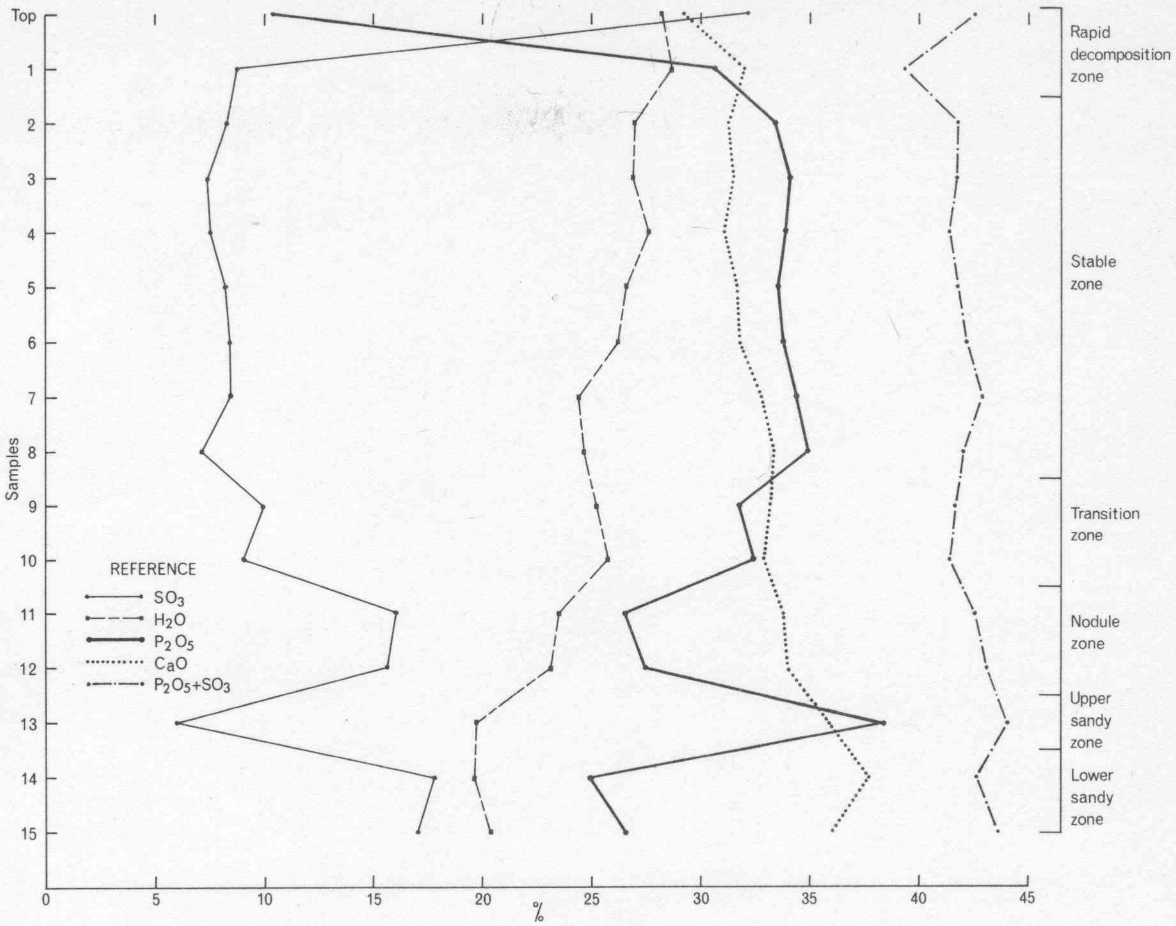

Fig. 4 Major components, normalized to 100%

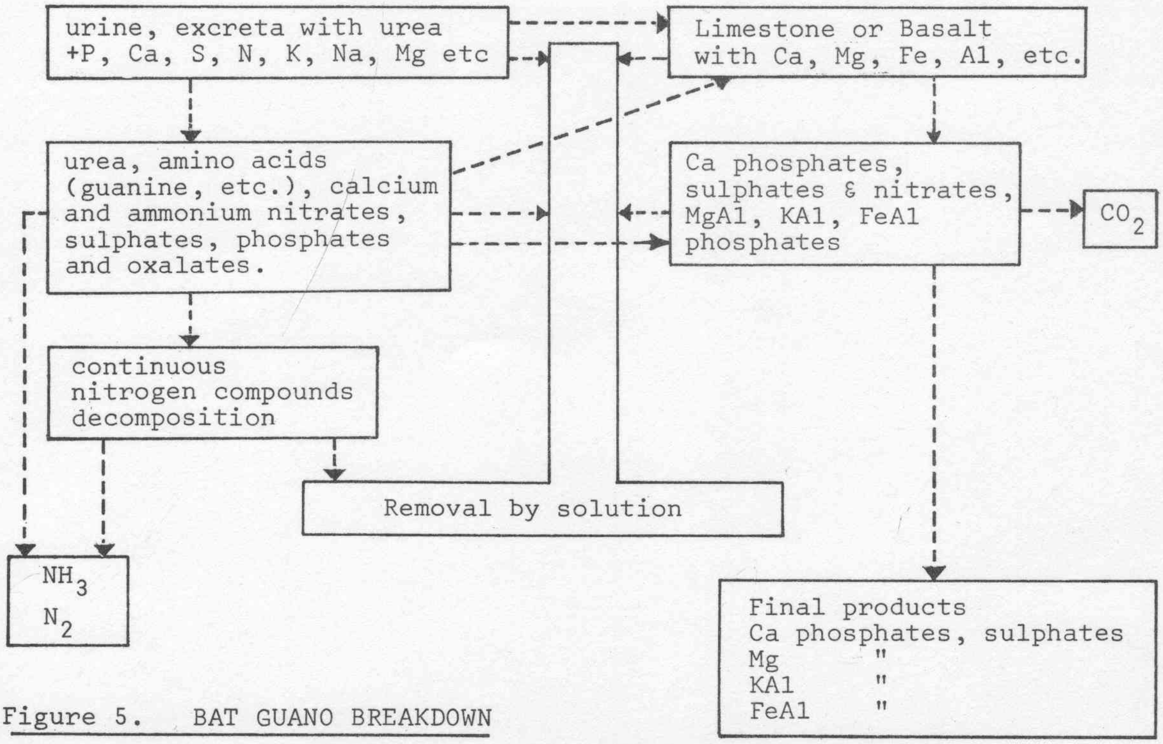

Figure 5. BAT GUANO BREAKDOWN

PALEO-DISTRIBUTION OF MACRODERMA GIGAS IN THE SOUTHWEST OF WESTERN AUSTRALIA

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The Ghost Bat, *Macroderma gigas* (Dobson 1880), has been shown to have occurred over a greater range in the past than its present distribution by Douglas (1967), who lists skeletal material in the Western Australian Museum collections and discusses the decrease in range.

A study of the distribution of *Macroderma* remains in the caves of the southwest of Western Australia has shown greater past bat concentrations than previously recorded.

The most southerly fossil occurrence is in Devils Lair, a cave near Witchcliffe (34° 1'S., 115° 6'E) approximately 600 km SSW of Mt Kenneth (28° 57'S., 118° 20'E), the site of the most southerly recorded sighting of live Ghost Bats by R. Austin in 1854 (Douglas, 1967). *Macroderma* remains occur in the Devils Lair deposit in a layer containing charcoal dated by radiocarbon as about 12,000 years old (A. Baynes, D. Merrilees and J.K. Porter, pers. comm. 1974). The nearest presentday occurrence of live *Macroderma* is the Vanaurum Mine, 176 km east of Wiluna (Douglas, 1967), but this is well outside the area under discussion.

The other southwest occurrences are from the area between Perth and Dongara, west of the Geraldton road (Figure 1). An examination of many of the caves in this area has revealed about 30 caves containing evidence of *Macroderma* habitation. These can be divided into two groups on the basis of whether they contain skeletal material alone or skeletal material plus guano piles. This is also a geographic division with the southern caves containing the skeletal remains and the northern caves containing guano piles plus skeletal material.

The caves of the Wanneroo-Yanchep region contained only sporadic skeletal material, while those of the Ledge Point-Dongara and Coorow-Watheroo areas contained many large guano piles and abundant skeletal material which were undisturbed until recently. The size of the guano deposits increases towards Dongara, culminating in huge deposits in Weelawadji Cave.

Few radiocarbon dates are available from caves in the Ledge Point-Dongara area. Wedges Cave on Mimegarra Station, excavated by E.L. Lundellius, contains *Macroderma* from the surface to a depth of six feet. A radiocarbon date of 3750 + or - 240 years BP was obtained from a unit between 1'3" to 3'6" below the surface by Lundelius (1960).

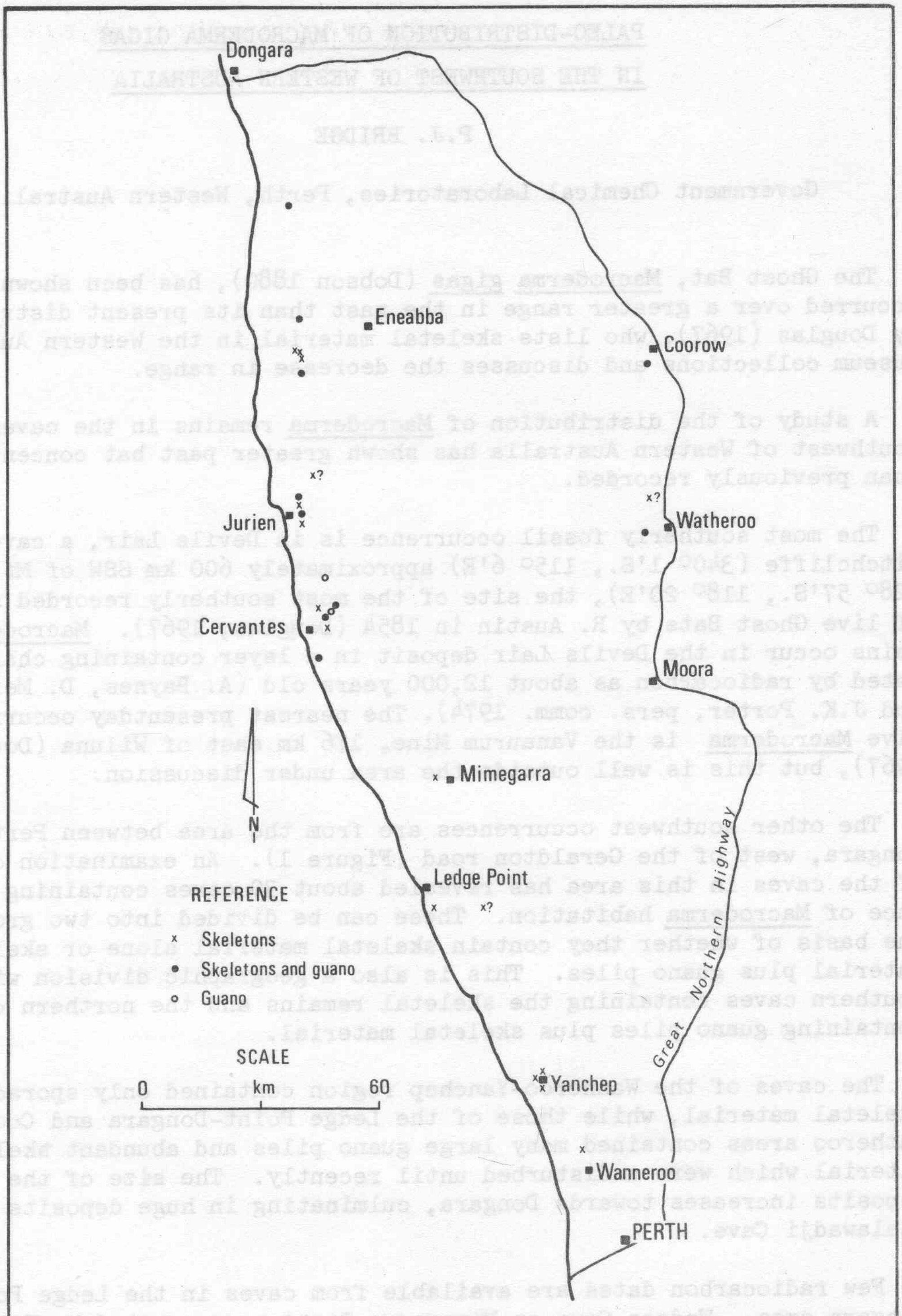

Fig. 1 Distribution of the caves in the Perth-Dongara region containing Macroderma remains.

Hastings Cave, Jurien Bay, contains a deposit radiocarbon dated from about 400 years old at the surface to about 11,000 years old at a depth of 3 metres, with Macroderma remains present throughout (A. Baynes, pers. comm., 1974).

The radiocarbon date of the surface material and the condition of the guano piles indicate that Macroderma was present until historical times in the Ledge Point-Dongara area.

The author suggests that the distribution of skeletal material and guano piles indicates a series of expansions and contractions of the Macroderma range during the Holocene. The Ledge Point-Dongara area represented the edge of the species range. It is believed that this area was marginally suitable for Macroderma habitation up to the time of arrival of European man, since when the bats have disappeared.

The Wanneroo-Yanchep surface-remains may represent a relatively recent southward expansion. The small guano deposits that may have been present in the southern caves could have been destroyed by solution.

The lack of material from between Perth and the extreme southwest and from the area east of the Geraldton road is probably attributable to the lack of suitable caves.

No Macroderma remains have been found among the large amount of surface material collected from caves in the Witchcliffe area and the single occurrence of Macroderma remains in Devils Lair may be related to the lack of excavations of suitable Pleistocene sites.

The interpretation of this data is limited by a lack of radiocarbon dates and further work on guano and bone deposits is needed.

Acknowledgments

The author wishes to thank Alex Baynes of the Western Australian Museum, Perth, for his constructive suggestions.

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