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Part 1

1.—Description of a New Freshwater Fish of the Family Theraponidae  
from Western Australia

By G. F. Mees\*

Manuscript received—20th November, 1962

A new species of freshwater *Therapon* from Millstream Station, West Pilbara, Western Australia, is described, and notes are given on some other freshwater fishes occurring in the same region, the fish fauna of which was hitherto very imperfectly known. Moreover *Mesopristes jenkinsi* from the Ord River is shown to be synonymous with *Therapon alligatoris*, and the range of the latter is extended to include the Kimberley Division of Western Australia.

When Whitley (1947) published his survey of the fresh-water fauna of Australia, he could list only three species of fishes from the mid-west and north-west of Western Australia (his Greyian Fluvifaunula), and correctly stated that ichthyologically the area could: "... be considered unexplored ...". The three species listed by Whitley were *Therapon unicolor*, *Hypseleotris compressus*, and the eyeless Eleotrid *Milyeringa veritas* which is restricted to subterranean waters near the tip of the North West Cape Peninsula and therefore cannot be regarded as characteristic of the area as a whole.† Shipway (1950, 1953) has since recorded *Eleotris aurea* from the Murchison River and a Melanotaeniid which he identified as *Melanotaenia nigrans*, from the Bullawarrina River, West Pilbara, but the situation has remained essentially unaltered.

When therefore, in July and August 1958, staff members of the Western Australian Museum visited West Pilbara for collecting purposes special attention was devoted to the fish fauna of the region. A popular account of the visit was given by Ride (1959), and there is a map of the area in Mees (1961). Fishes were collected by Miss K. C. A. Vollprecht (now Mrs. Thies) and the author. Eight species were obtained and I am convinced that, with the exception of an eel, presumably *Anguilla bicolor*, which was reported by locals but not seen by us, they give a fairly complete picture of the fish fauna of the Fortescue River and its tributaries in the area where we worked (about 70 miles inland). The fishes obtained belong to the following families: Ariidae (one species), Plotosidae (one species), Melanotaeniidae (one species), Dorosomidae (one species), Gobiidae (one species), and Theraponidae (three species).

A complete report on this collection had been planned, but the systematics of several groups of Australian freshwater fishes are in such disorder that they can only be solved by major revisions. Fortunately two families, the Melanotaeniidae and the Dorosomidae are now under review by Mr. I. S. R. Munro (C.S.I.R.O. Fisheries and Oceanography, Cronulla), who has received all our material of these groups on loan. Until he has completed his work it is of little use to comment on members of these groups. While the main purpose of this paper is the description of a new *Therapon*, it seems nevertheless useful to give some information on the other species collected.

Though catfishes have been known to occur in the Fortescue River since its discovery, have been eaten by explorers (F. T. Gregory in Gregory and Gregory 1884, p. 62-63), and have been mentioned by later authors like Ride (1959), and Ride and Serventy (1961), their specific identity had never been ascertained. I found these fishes to be *Arius australis*, a species that in Western Australia had previously been recorded from Noonkanbah, Kimberley Division (Rendahl 1921), though Munro (1957) did not include Western Australia in its range. This is apparently the common catfish of the State: the Western Australian Museum has recent material from Langey Crossing, Fitzroy River, west Kimberley Division, collected on 24.VI.1960 by F. W. Monck, P 5090, and from the King Edward River, Kalumburu, north Kimberley Division, collected on 27.VI.1960 by A. M. Douglas and G. F. Mees, P 5091. The goby is *Glossogobius giurus*. The Plotosid and the Dorosomid are as yet unidentified. Of the Theraponidae one is the widely distributed *Therapon unicolor* which occurs over the whole northern part of Australia, in Western Australia at least as far south as the Murchison River. Watson (1958), followed by Ride and Serventy (1961), recorded *Therapon unicolor* from the Greenough River south of Geraldton, but at the suggestion of Messrs. J. O. Knight and B. J. Parkes, who could find only *T. caudavittatus* in the Greenough River, I examined

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† *Craterocephalus cuneiceps* from the Murchison River, though not mentioned by Whitley, may also be included: it occurs not only in the upper branches of the river, but was found in its lower course by Shipway (1950); see also Whitley (1955).

Watson's specimens, which were donated to the Western Australian Museum, and found them referable to the latter species.

The second *Therapon* is *T. percoides* and the Melanotaeniid is doubtless identical with the one that in literature has been called *Melanotaenia nigrans* (Whitley 1948, Shipway 1953, Ride and Serventy 1961) or *M. australis* (Whitley 1960). It may be recalled that de Castelnau (1875) described *Neoatherina australis* and *Therapon fasciatus* from Swan River. While the record of *Neoatherina* (= *Melanotaenia*) has generally been accepted as erroneous, the Swan River, meaning south-western Australia, is at present still included in the range of *Therapon percoides* (of which *T. fasciatus* has been considered a synonym) on the basis of de Castelnau's specimen (Ogilby and McCulloch 1916, Rendahl 1922, Whitley 1948, Nichols 1949, Whitley 1960). I even believe that de Castelnau's record is the sole basis for the inclusion of the species in the fauna of Western Australia. While it is true that the name Swan River, or Swan River Colony, used to be applied to an ill-defined but large area of which Perth was the centre, it would hardly have included any part of the ranges of *Melanotaenia* and *Therapon percoides*, as I do not believe that either of these species occurs far south of the Tropic of Capricorn. In the introduction to his paper, de Castelnau states that the collector of his material from Western Australia, the Reverend G. J. Bostock, who lived at Fremantle, also provided specimens from the Dampier Archipelago, and it is likely that the types of *Neoatherina australis* and *Therapon fasciatus* were actually obtained somewhere on the mainland opposite the Dampier Archipelago. The Kimberley Division, as was only to be expected, can be included in the range of *T. percoides*, as in June 1960, I found it in several tributaries of the King Edward River near Kalumburu.

The third *Therapon* apparently represents an undescribed species that may be characterized as follows:

#### *Therapon aheneus* species nova (Fig. 1)

Description. D (XI)-XII-(XIII). ( $8\frac{1}{2}$ )- $9\frac{1}{2}$ , A III.8 $\frac{1}{2}$ , P 13-14 (ii.10.i or ii.10.ii), V I.5, C 19-20 (ignoring some very short undivided rays on each side; usually ii.15.ii), gillrakers on outer branchial arch 6-8+1+11-12, branchiostegals 6, scales in lateral line 40-44, scales under lateral line 38-44 in a longitudinal series. Differs from all other species of the genus by the combination of fin formula, gillrakers, and scale numbers.

A very normal representative of the genus; body moderately deep. Head 2.7 to 3.0 in standard length, about equal to depth of body or slightly less; profile of snout and forehead slightly concave, becoming convex behind eye; eye large, 3.8 to 4.0 in head; snout of about same length as eye diameter or a little longer, maxillary reaching to below anterior border of eye;\* nostrils well separated, anterior one just above upper lip, with an elevated rim that might pass for a very short tube; posterior one in front of middle of eye, in the anterior part of a narrow longitudinal groove with an elevated rim; mouth moderate; each jaw has an outer series of fairly small teeth, followed by a narrow band of very fine teeth; no teeth on palatine or tongue; no canines; posterior border of preoperculum free, finely serrated; operculum with a flat spine that does not normally protrude beyond the border of the soft operculum; branchiostegals six; suprascapular bone exposed.

Lateral line slightly arched, following the profile of the back, becoming straight on the caudal peduncle, and continued to the basis of the tail.

Body scaled, with the exception of the upper surface of snout and head, and chin; scales largest on the sides on the middle of the body.

Dorsal fin normally with twelve strong spines, increasing in length from the 1st to the 5th; the 2nd twice the length of the 1st; the 5th

\* In specimens fixed with open mouth, these proportions are distorted.

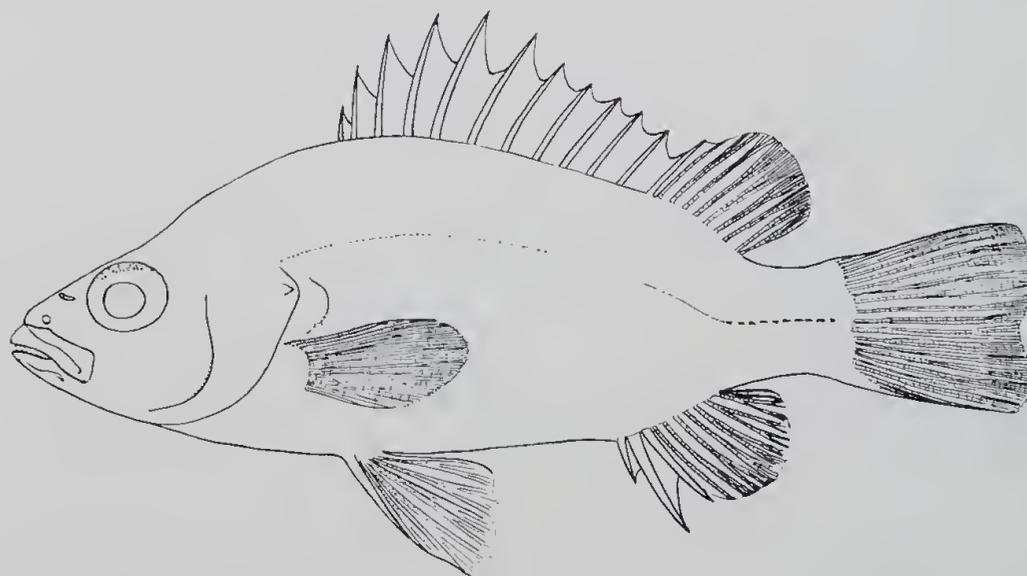


Fig. 1.—Outline drawing of *Therapon aheneus*, type, nat. size.

longest. 1.6 to 2.0 times eye diameter; from there onwards each following spine slightly shorter than the preceding one, until the 11th which is of the same length as, or slightly shorter than the 2nd, and slightly shorter than the 12th; spiny dorsal much higher than soft dorsal. Of 22 specimens, 18 have D XII.  $9\frac{1}{2}$ , two D XIII.  $9\frac{1}{2}$ , one D XIII.  $8\frac{1}{2}$ , one D XI.  $10\frac{1}{2}$ .

Anal fin with three strong spines and eight rays (all but the first divided), the last of which is double. Soft part rounded. Of the spines, the second is the strongest, more than twice the length of the first; it is not or only a little longer than the third, but much stronger.

Pectorals rounded, fairly short, about 1.6 in head, with thirteen developed rays, of which nine or ten are divided.

Ventral fins with one strong spine and five divided rays; their origin almost exactly opposite origin of D.

Caudal fin slightly emarginate, not quite symmetrical, the upper lobe slightly larger than the lower lobe, with 19 or 20 rays, of which 15 are divided.

Size. As the largest specimen obtained measured only 101 mm in standard length, and as no larger individuals were seen, the conclusion seems justified that *T. aheneus* is a small species.

Colours. In life, colour bronzy blackish-brown to dark brown, sides slightly tinged pinkish, small specimens indistinctly banded vertically. P slightly yellowish.

Type. A specimen of 90 mm standard length, collected on 18. VII. 1958 by K. C. A. Vollprecht and G. F. Mees at Millstream Pool, W.A.M. regd. no. P 5350.

Further material. Eleven specimens, varying from 51 to 101 mm standard length, same data as type, P 5351 (two specimens of this lot have been donated to the Leiden Museum); five specimens, standard length 68-95 mm, 25. VII. 1958, same locality, P 5373; three specimens, standard length 59-70 mm, 18. VII. 1958, Millstream bath house, P 5358; two specimens, standard length  $47\frac{1}{2}$  and 51 mm, 20. VII. 1958, Fortescue River at Millstream, P 5423; one specimen, standard length 50 mm, 21. VII. 1958, Fortescue River at Millstream, P 5424.

Distribution. *Therapon aheneus* was plentiful in Millstream Pool, near Millstream Station homestead, in the small creek connecting the pool with the Fortescue River, and in the Fortescue River at Millstream, which at the time of our visit consisted of a chain of large, deep, pools. We, and several other collectors who have recently visited the district and donated freshwater fishes to the Western Australian Museum, failed to find the species anywhere else, so that it is likely that it has a very limited distribution.

Related species. Working from keys and descriptions it appeared that *T. aheneus* is closest to *T. argenteus*, a species that has not yet been recorded from Western Australia and of which the Western Australian Museum had no material. Thanks to the courtesy of the Chief Inspector of Fisheries of Queensland, two large specimens were received for comparison, one of which we were allowed to retain for our collec-

tion. These specimens differ by a slightly different fin formula, D XII.  $10\frac{1}{2}$ , A III.  $8\frac{1}{2}$ , smaller scales (about 52 below lateral line), number of gillrakers,  $x + 1 + 15$ , relatively deeper body; different position of nostrils. *T. argenteus* grows also to a much larger size than any specimen of *T. aheneus* I have seen: Ogilby & McCulloch (1916) examined specimens of up to 262 mm in length, and Weber & de Beaufort (1931) mention a length of 275 mm; it is also different in colour.

The affinity to *T. argenteus* places *T. aheneus* in the group of species separated by Whitley (1943) under the generic name *Mesopristes*. While I agree with Whitley that a subdivision of the large genus *Therapon* might be useful, I prefer for the moment to keep all species under the one name. Whitley (1960) placed in the genus *Mesopristes* two other nominal species which therefore, as fairly close relatives of *T. aheneus*, require discussion.

These two species are *Therapon alligatoris* Rendahl (1922), described from the South Alligator River and the McKinley River, Northern Territory, and *Mesopristes jenkinsi* Whitley (1945) from Ivanhoe Station, Ord River, Western Australia. In the original description of *M. jenkinsi*, no reference was made to *T. alligatoris*. The type localities of these two nominal species are in the same general geographic region, and only about 250 miles apart, and comparison between the description of *T. alligatoris* and the unique type of *M. jenkinsi* (which is in the Western Australian Museum, regd. no. P 2763), shows but very few differences.

The type of *M. jenkinsi* has a standard length of 113 mm. D XIII.11, A III.8, gillrakers  $9 + 1 + 19$  (of which the last two or three rudimentary). *T. alligatoris* differs only in having D XII.12-13, gillrakers  $9 + 17$ . Whitley (1945) described the colour of *M. jenkinsi* as fairly uniform dark slate grey; this was when the specimen was still fresh (the register shows that it was received on 30 October 1944); at present it is light brown in colour, and agrees with Rendahl's colour description of *T. alligatoris*: "Colour in alcohol light brownish, paler on the ventral parts. Back with a slight tinge of purplish. Pectorals yellowish, the other fins with dark membranes, on the posterior border of the soft dorsal and anal a black basal blotch". The only differences are that the darkening of the fin membranes has only just set in; there is already a darkish blotch at the end of the dorsal fin, but the anal fin is as yet without one.

Hitherto both the species *T. alligatoris* and *M. jenkinsi* seem to have been known from their respective types only: three specimens of *T. alligatoris*, and one of *M. jenkinsi*. Besides the type of *M. jenkinsi*, the Western Australian Museum has six specimens, all collected by A. M. Douglas and G. F. Mees. Two specimens, standard length 182, 187 mm, 26.VI.1960, Kalumburu, P 5384; two specimens, standard length 151, 159 mm, June 1960, Kalumburu, P. 5385; two specimens, standard length 249, 268 mm, July 1960, Beverley Springs, P 4386. The fin formulae of these specimens, in the sequence in which they are listed above, are: D XII.12 $\frac{1}{2}$ , A III.9 $\frac{1}{2}$ ; D XIII.12 $\frac{1}{2}$ , A III.9 $\frac{1}{2}$ ; D XII.12 $\frac{1}{2}$ , A III.8 $\frac{1}{2}$ ;

D XII.11½, A III.7½; D XII.11½, A III.8½; D XI.12½, A III.8½. At the moment of writing (October, 1962), over two years after their capture, these specimens are still blackish in colour.

The large variation in fin-ray counts of the additional material, D XI-XIII.11½-12½, A III.7½-9½, shows that the slight differences in fin-formula between *T. alligatoris* and *M. jenkinsi* are well within the limits of individual variation. Therefore I have no hesitation in concluding that *Mesopristes jenkinsi* Whitley is a synonym of *Therapon alligatoris* Rendahl.

*T. aheneus* differs from *T. alligatoris* in having fewer dorsal rays, larger scales, fewer gill-rakers, and in its different colour.

I have, besides the paper by Ogilby & McCulloch (1916), used Fowler's (1931) revision, but none of the additional species listed by him seems to be close to *T. aheneus*.

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## 2.—Copper Poisoning in Sheep in Western Australia

By A. B. Beck\* and H. W. Bennetts†

*Manuscript received—16th October, 1962*

Investigations were made to ascertain the cause of high-copper status of sheep in the Wiluna area of Western Australia. It was concluded that this was due mainly to the ingestion of plants naturally high in copper.

An occurrence of copper poisoning in sheep in the Toodyay area was also investigated. Here the copper content of pastures generally was not high. Although the factors responsible for the high copper status of sheep were not determined, histological evidence suggested that this was associated with a hepatotoxic principle of plant or fungal origin.

### Introduction

During investigations relating to the deficiency of copper in stock in Western Australia and in the course of routine laboratory diagnosis, we have encountered numerous cases of copper poisoning in sheep. In some instances the cause has been due to an over-generous use of copper-containing licks or fertilizers, often to both. In other cases the poisoning has been associated with lupinosis when the damaged liver accumulates excessive amounts of copper, particularly if copper supplements have been fed. Investigations into this disease and the significance of the storage of heavy metals in the liver are being continued by the Department of Agriculture at the present time.

In eastern Australia, copper poisoning is commonly associated with plants containing pyrrolizidine alkaloids, particularly heliotrope (*Heliotropium europaeum*) and "Pattersons Curse" (*Echium plantagineum*) (Bull 1961; St. George-Grambauer and Rac 1962). The first plant is rare in southern Western Australia and no cases of copper poisoning due to either plant have been reported.

The purpose of the present paper is to record the results of detailed investigations of the cause of the high copper status of sheep at Wiluna in the North Eastern Goldfields pastoral region, and at Toodyay.

### The High Copper Status of Sheep in the Wiluna Area

In 1951 one of us (H.W.B.) visited the Eastern Goldfields area of Western Australia to enquire into possible causes of sheep losses in the 1950-51 drought. Some pastoralists had considered that the losses were unduly severe and could not be attributed solely to the effects of drought. On some stations it was reported that sheep had

lost their appetite for top feed which should have been adequate for their requirements. As a result of these observations it was decided to investigate the remote possibility that cobalt deficiency was responsible for this reported anorexia. During the analysis for cobalt content it was noted that the livers contained large amounts of copper. Shortly afterwards chronic copper poisoning was diagnosed at "Albion Downs" Station. The present investigation was then carried out to ascertain the reasons for the high copper status of sheep at Wiluna and the area of country affected.

Because of the remoteness of the region and of the large areas of the properties concerned, the scope of the investigation was restricted to the determination of copper in the livers of sheep from nine station properties, to the analysis of herbage from three properties where sheep showed high copper status and to the determination of copper in well waters on one property. Histological examination was made on many of the liver samples to check for the possible effects of hepatotoxic plants.

### Materials and Methods

At "Albion Downs" Station, every species likely to be eaten by sheep was collected in the 1953 sampling. The sampling was much less comprehensive at later dates and on other stations.

Soil contamination was avoided in the collection of samples but in some short and semi-prostrate species it was not possible to avoid this entirely. In these cases an iron determination was done to obtain some indication of soil contamination.

As levels of molybdenum, manganese and inorganic sulphate are known to influence copper metabolism in sheep, determinations of these constituents were made on many of the herbage samples. Copper, molybdenum and inorganic sulphate were determined as described previously (Beck 1962), manganese by the periodate method (Willard and Greathouse 1917) and iron by the thioglycolic acid method (Mayer and Bradshaw 1951).

Except for one sheep which died from copper-poisoning, all liver samples were from healthy sheep killed for rations. The livers were preserved in copper-free alcohol or alcohol-formalin mixture.

The analysis of all samples is reported on the dry-matter basis. No correction was made for the fat content of livers, but no obvious fat was noted in any of the samples.

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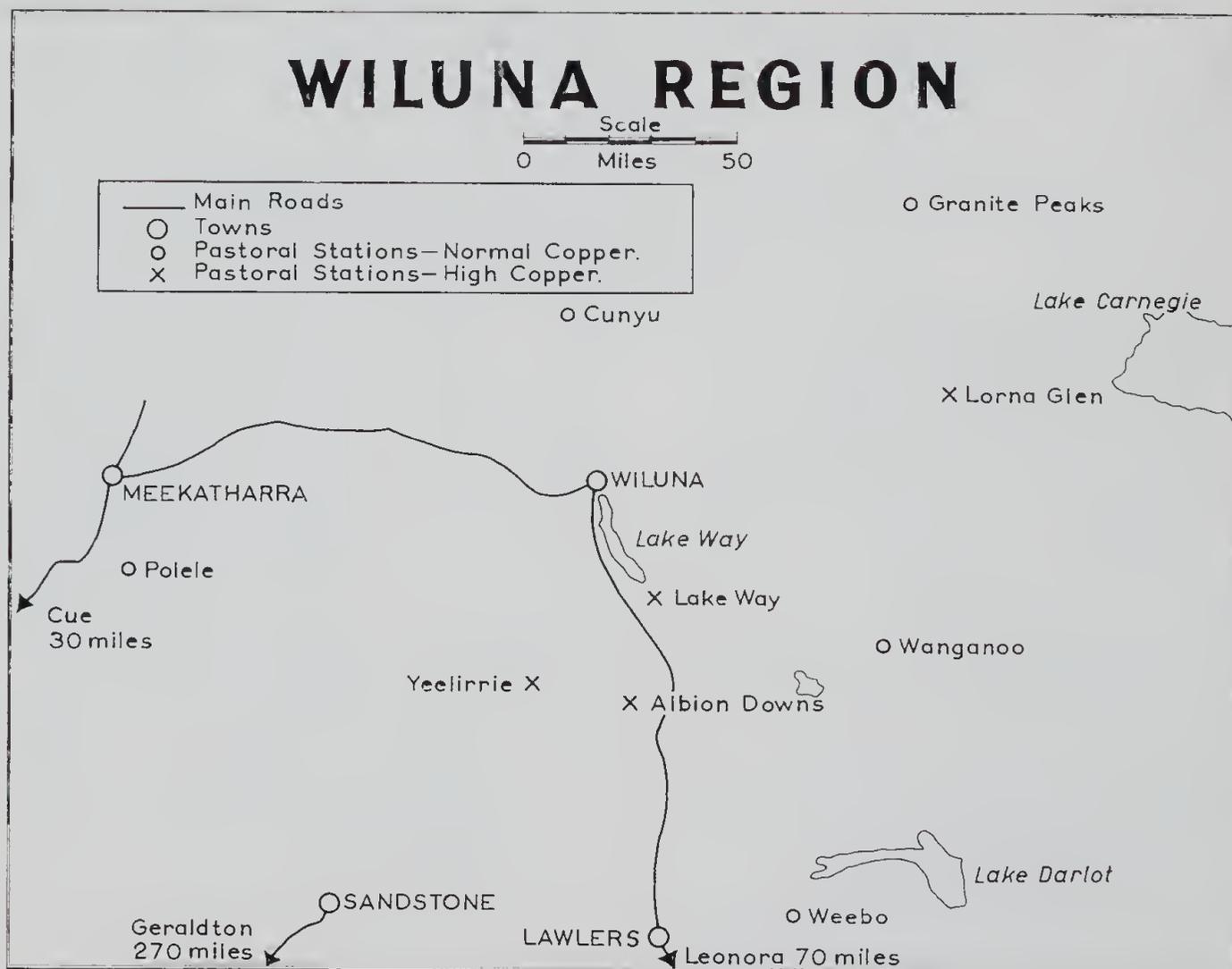


Fig. 1.

### Results

An examination of well waters was made on "Albion Downs" Station in 1953 but the copper levels were less than 0.04 mg per litre and would not be responsible for the high levels of copper in liver.

The analytical data for liver samples and for herbage material are set out in Tables I and II respectively. The livers of normal Western Australian sheep contain 50 to 400 p.p.m. copper and as sheep with levels over 1000 p.p.m. are liable to develop copper poisoning under conditions of stress, the percentage of such samples is indicated in Table I. The geographical distribution of properties is shown in the accompanying map.

With *Goodenia Mueckeana* and *Eremophila leucophylla* there was little difference in copper content at the different times of sampling, but in all other species the levels in the 1953 samples were appreciably higher. There was no obvious difference in other constituents of species at different sampling times or on the different properties.

A number of livers from ration sheep have been examined histologically for evidence of ingestion of hepatotoxic plants. Some of

the high-copper samples showed small areas of megalocytosis but there was no significant liver damage in any of the specimens.

Prior to the outbreak of copper poisoning in 1952 it had been noted that the affected sheep had been grazing heavily on *Goodenia eremophila*. This species did not reappear in appreciable amounts until 1959 when a sample was forwarded to the C.S.I.R.O. Chemical Research Laboratories, Melbourne, for alkaloid determination. The analysis showed a very low alkaloid content (0.015 per cent. tertiary base, on assumed molecular weight of 300; N oxides were absent) which would be unlikely to cause any liver damage.

### Discussion

From the data obtained it would seem that the occurrence of high copper status in merino sheep is restricted to an area within 100 miles of Wiluna.

It seems probable that the development of the high liver copper levels was primarily due to the ingestion of herbage of high copper content. Data from the agricultural areas of Western Australia (Beck 1941, 1962) indicate that in those regions, levels of copper in pastures

**TABLE I**  
**Copper Content of Wiluna Sheep Livers**  
 Values as p.p.m. Cu on dry liver

Property	Date	No. of Samples	Liver Cu		Details
			Mean and Range	Percentage of values above 1000 p.p.m.	
" Albion Downs "	Sept.-Nov., 1952	7	1010	43	One sheep died Cu poisoning
	Jan.-April, 1953	6	300-1760	83	Aged wethers
	July, 1953	2	1410	0	
	Sept., 1953	3	350-1990	0	
	Sept., 1953	7	780-940	100	Aged ewes
	Aug.-Sept., 1954	8	1600	37	
	Sept., 1955	12	1190-2100	33	Mixed age ewes and wethers
	Sept.-Oct., 1956	6	440-600	83	Aged wethers
	May-Oct., 1959	6	810	17	Aged ewes and wethers
	Jan., 1954	6	220-1440	67	Wethers mixed ages
" Veeterie "	Feb.-Aug., 1955	8	1820	25	Wethers 3-6 years
	March-April, 1954	5	790-2730	60	Aged sheep
" Lorna Glen "	Nov., 1951	3	1220	33	
" Lake Way "	Feb., 1952	6	520-1850	17	
	Oct.-Nov., 1952	6	870	33	
	Jan.-March, 1953	6	310-1750	33	Wethers 3-4 years
" Wanganoo "	July-Aug., 1956	6	450-2000	0	Wethers 3-7 years
	Aug.-Nov., 1952	6	450	0	Wethers 3-5 years
" Cunyu "	Aug.-Sept., 1956	6	180-740	0	Wethers 3-5 years
	Oct.-Nov., 1952	3	380	0	Wethers 3-5 years
" Polele "	Aug.-Sept., 1954	6	150-820	0	Wethers 4 years
	Aug.-Sept., 1954	6	300	0	
" Weebo "	Aug.-Sept., 1954	6	140-520	0	
			290	0	
			210-440	0	
			290	0	
			100-830		

rarely exceed 10-12 p.p.m. (dry basis). Dick (1954) has shown that cross-bred sheep will store dangerous amounts of copper when receiving more than about 10 p.p.m. copper in the diet, although merinos can, apparently, tolerate somewhat higher levels. The copper content of *Goodenia Mueckeana* was consistently high (14-22 p.p.m) and other species, at least in certain seasons, supplied amounts of copper well above normal. Seasonal variations in liver copper levels could be explained by the preferential grazing of species of lower copper content in some years.

The storage of copper in sheep is also controlled by factors other than the copper intake. Molybdenum above about 5 p.p.m. in the diet causes depression of copper storage provided adequate sulphate is present (Dick 1954). Very low molybdenum levels have been found in some of the species and this may have favoured copper storage. Sulphate levels were generally similar to those found elsewhere in Western Australia (Beck 1962). High levels have been observed in *Hibiscus pinonianus*, *Bassia* spp. and in three salt bushes, but the area of salt lake country was quite restricted on the properties where the investigations have been carried out. Similar high levels of sulphate have been found in halophytes elsewhere (Spais 1956; Barker 1961).

There is some evidence that manganese interferes with the limitation of copper storage imposed by molybdenum and sulphate (Anon. 1957-58) and it has been shown that very high levels of manganese cause an increase of copper storage in liver of the rat (Gubler *et al.* 1953). However, it is not known what effect the moderately high manganese levels of the Wiluna herbage would have on the copper storage of the grazing sheep.

Although the histological studies have given no definite evidence, it is still possible that hepatotoxic alkaloids may have contributed to the development of high copper levels in some instances.

The occurrence of liver copper levels up to 2700 p.p.m. in clinically healthy sheep indicates the very high concentrations which can be tolerated by sheep in the absence of stress. As it is well known that starvation will readily precipitate a fatal haemolytic crisis in such sheep, it is highly probable that some unexplained losses, reported during mustering and shearing, may have been due to copper poisoning.

#### Copper Poisoning in Sheep in the Toodyay Area.

In August, 1955, reports of heavy sheep losses were received from a 1,100 acres property some 10 miles north of Toodyay. A clinical diagnosis

of copper poisoning was confirmed by pathological examination and chemical analysis.

Copper fertilizers and supplements were not used and the sheep were bred on the property. The soils and pastures resembled those of a large belt of agricultural country where no cases of poisoning had been reported. At first it was thought that the poisoning might be similar to that encountered in sheep grazing on subterranean clover in certain seasons in Western Victoria (Anon. 1956). Analysis of the Toodyay pastures showed moderately high copper levels but the liver histopathology was quite distinct and suggested that a hepatotoxic plant was implicated (Bull, personal communication).

#### Geology and Soil Types

No geological survey of the area has been made but the rocks appear to be mainly biotitic gneisses and quartzite with dolerite intrusions.

The soils are red brown clay loams and sandy clay loams with non-calcareous subsoils.

#### History

The history was not very satisfactory. Losses from what was apparently copper poisoning were reported to have occurred on this property for many years. Young sheep were not affected. Losses were seasonal and occurred usually in August and September. In 1955, losses began earlier and the mortality was reported to be 50 in a flock of 1,700 Corriedale sheep. In 1956 there were no losses, in 1957 one or two cases and none in subsequent years. Occasional deaths from what appeared to be a similar condition have been reported from elsewhere in the district, but investigations have been confined to the one property.

TABLE II

#### Inorganic Constituents of Wiluna Herbage

Values expressed as mean and range on dry matter basis

Figures in brackets indicate number of samples analysed when less than the total number

Species	Date	Stations* Sampled	No. of Samples	Cu p.p.m.	Mo p.p.m.	Mn p.p.m.	Fe p.p.m.	SO <sub>4</sub> %
<i>Goodenia Mueckeanii</i>	July, 1953	a c	4	19.9	<0.1	900	...	0.15 (2)
	Feb.-Aug., 1955	a b	4	17.1-20.9	...	790-1100	...	0.14-0.16
<i>G. ecenophila</i>	Oct., 1952	a	1	19.1	<0.1	760	190 (2)	0.11
	July, 1953	a	3	13.8-21.7	...	570-1000	150-230	0.08-0.18
	Sept., 1954	a	1	15.7	...	...	...	...
	Aug., 1955	a b	2	11.8	<0.1	430	...	...
<i>Helichysum Ducepocitii</i> (Everlasting)	Sept., 1954	a	1	10.0-13.3	<0.1-0.16	340-500	...	0.36
	Aug., 1955	a b	2	6.8	<0.1	490	...	0.16
	Oct., 1959	a	1	8.3	<0.1	1100	...	0.08-0.25
	July, 1953	a	1	8.0-8.7	0.11	810-1400	...	0.14
<i>Helichysum Ducepocitii</i> (Everlasting)	July, 1953	a	1	7.9	0.11	370	...	0.53
	Sept., 1954	a	1	20.3	...	...	...	0.40
	Aug., 1955	a b	2	15.3	<0.1	...	160 (1)	0.36-0.43
<i>Hibiscus pinonianus</i>	July, 1953	a b	4	11.2-12.4	0.1-0.20	280-490	...	1.2 (3)
	Aug., 1955	a b	2	14.6	0.27 (3)	92 (2)	...	0.9-1.5
<i>Didiscus glaucifolius</i> <i>Trichinium obtusum</i> (Cotton bush)	July, 1953	a	1	12.3-16.5	0.15-0.47	82-103	...	0.62
	July, 1953	a	1	9.4	0.38	97	225 (1)	0.51-0.74
	Aug., 1955	a b	2	7.3-11.6	0.22-0.55	95-100	...	...
<i>T. caeruleum</i> <i>Myriocephalus Gueriniae</i> (Billy Button)	July, 1953	a	1	13.6	<0.1	...	...	...
	July, 1953	a	1	13.5	0.28	100	...	...
	Aug., 1955	a b	2	5.6	0.72	57	165 (1)	0.16
<i>Eremophila leucophylla</i> (Poverty or flannel bush)	July, 1953	a	1	5.5-5.8	0.31-1.13	50-65	...	0.15-0.17
	July, 1953	a	1	10.1	0.86	...	...	1.10
	Aug., 1955	a b	2	12.7	0.28 (1)	300 (1)	...	0.73-1.47
<i>Eremophila leucophylla</i> (Poverty or flannel bush)	July, 1953	a	4	7.5-11.4	0.08-0.30	200-690	...	0.25-0.40
	Aug., 1955	a b	3	12.3	0.15 (3)	600	...	0.21
<i>Erodium cymosum</i>	July, 1953	a c	6	9.8-13.9	0.13-0.17	400-740	...	0.15-0.27
	July, 1953	a	1	12.8	0.22	450	160 (2)	0.26
<i>Kennedya sp.</i>	July, 1953	a	1	10.3-14.5	0.13-0.29	190-870	150-170	0.22-0.30
	July, 1953	a	1	11.1	0.17 (5)	130 (1)	...	0.34 (2)
<i>Sida corrugata</i>	July, 1953	a	1	9.3-14.3	<0.1-0.37	...	...	0.24-0.44
	July, 1953	a	1	10.3	0.33	...	...	0.14
<i>Danthonia bipartita</i> (Wau- darrie grass)	July, 1953	a	1	9.8	...	...	...	0.24
	July, 1953	a	4	9.6	0.15 (3)	290 (2)	...	0.31 (2)
<i>Ruellia luxophylla</i>	July, 1953	a c	3	7.7-10.4	0.10-0.25	250-330	...	0.30-0.32
	July, 1953	a	1	9.0	...	275 (1)	...	0.12
<i>Halorrhagis sp.</i>	Aug., 1955	a	1	6.9-11.0	...	...	...	0.08-0.15
	July, 1953	a	1	8.8	<0.1	2400	207	0.37
<i>Bassia spp.</i>	July, 1953	a c	5	8.6	0.42 (2)	...	...	3.3 (4)
	July, 1953	a	2	7.3-9.8	0.27-0.58	...	...	0.8-6.0
<i>Codanocarpus cotinifolius</i> (Native poplar)	July, 1953	a	2	8.6	0.62 (1)	360 (1)	...	0.79 (1)
	July, 1953	a	2	7.9-9.3	...	...	...	...
<i>Brachysema Chambersii</i> (flowers only)	July, 1953	a	2	6.3	...	...	...	...
	July, 1953	a	1	6.0-6.7	...	...	...	0.10
Salt Bushes	July, 1953	a	1	3.3	...	...	...	...
	July, 1953	a	1	8.2	...	...	...	5.0
	July, 1953	a	1	4.9	...	...	...	1.0
<i>Lycium australe</i>	July, 1953	a	1	9.3	...	...	...	2.0

\* "a" indicates "Albion Downs," "b" "Yeelirrie" and "c" "Lorna Glen."

TABLE III

## Copper, Molybdenum and Inorganic Sulphate Levels of Toodyay Pastures

Values expressed as mean and range on dry matter basis

Date	No. of Samples	Details	Cu p.p.m.	Mo p.p.m.	SO <sub>4</sub> %
Oct., 1955	2	Capeweed	14.4	0.65	0.30
			14.2-14.6	0.60-0.70	0.28-0.32
Aug., 1956	1	Sub. clover	14.6	0.40	0.24
	1	Mixed sub. clover and capeweed	9.7	0.50	0.33
	6	Grasses	6.7	1.37	0.19
			4.3-8.6	0.62-2.26	0.13-0.34
	4	Capeweed	6.7	1.87	0.19
Sept., 1956	2	Mixed pasture	5.4-8.3	1.6-2.6	0.17-0.22
			9.7	1.10	0.17
	1	Capeweed	9.2-10.2	0.95-1.25	
Aug., 1957	1	Capeweed	14.4	0.49	0.19
	1	<i>Plantago cretica</i>	9.2	0.49	0.28
Aug., 1957	1	Mixed pasture	11.0	0.60	0.18
	4	Capeweed	11.5	0.63	0.28
			9.1-14.0	0.48-0.94	0.17-0.49
	1	Grasses	8.4	0.61	0.17
	2	Sub. clover	12.0	0.16	0.12
			10.2-13.9	0.14-0.18	0.07-0.18

## Pasture Investigations

The pastures were of the annual Mediterranean type common to the 20-25 inch rainfall belt. The main species were *Trifolium subterraneum*, capeweed (*Cryptostemma calendula*), wild geranium (*Erodium botrys*) and annual grasses (*Bromus* spp. *Vulpia myuros* and *Wimmera* rye grass, *Lolium* spp.). Surveys were carried out by the former Government Botanist (Mr. C. A. Gardner) in August, 1955, and September, 1956, but the only unusual species found was *Plantago cretica*. An examination of dry paddocks in March, 1957, showed no unusual plants and none considered likely to cause toxic effects. *Echium plantagineum* ("Pattersons curse") and lupins (*L. varius* and *L. angustifolius*), known to cause liver damage, were completely absent from the property.

Analysis of pasture samples is set out in Table III. Levels of molybdenum and inorganic sulphate were determined as these are known to affect copper metabolism. Two samples (August, 1956) were analysed for manganese content but normal levels were found (72 and 85 p.p.m. on dry matter).

As the histology described in the following section had suggested the action of a hepatotoxic alkaloid, determinations for alkaloid content were made on *P. cretica* at the C.S.I.R.O. Chemical Research Laboratories, Melbourne. As the manager of the property had stated that cases of poisoning only occurred in years of rank capeweed growth, this species was also examined, even though there was no suggestion that it caused trouble elsewhere. Both species showed very low alkaloid content (*P. cretica*, 0.018 per cent. tertiary base, quaternary and weak bases and N oxides absent; capeweed, 0.014 per cent. tertiary base and 0.004 per cent. N oxide).

## Animal Studies

**Chemical.**—The liver of the sheep dying of copper poisoning in August, 1955, showed 900 p.p.m. copper (dry basis); a similar sheep in July, 1957, showed 600 p.p.m. These values are rather lower than those usually found in cases of haemolytic jaundice due to copper poisoning.

In June, 1956, liver samples for chemical and histological examination were collected at the abattoirs from 30 sheep from the property. The sheep had been without food for at least 18 hours and consequently the livers contained more fat than usual. There had been no losses from haemolytic jaundice during yarding. Some of the livers were macroscopically abnormal; two were small, five were yellowish and one rather fibrous. Chemical analysis showed the following results which are expressed as the means with range of values in parenthesis; the values for fat are on the dry material and values for iron and copper on the dry, fat-free material:—copper 1500 p.p.m. (490-3120), iron 990 p.p.m. (280-2410), fat 23 p.c. (15-40). Seventy-three per cent. of the livers contained over 1000 p.p.m. copper. Livers from normal Western Australian sheep contain 50-400 p.p.m. copper, 200-800 p.p.m. iron and less than 10 per cent. fat.

**Histology.**—Sections were available from the two moribund animals and the thirty abattoirs animals mentioned above.

In the liver from the first affected animal (August, 1955) the interstitial tissue in the portal tracts was slightly increased and abnormally cellular. A slight fine diffuse fibrosis was present. Excess bile pigment was present in the ducts and canaliculi. There was some new bile duct formation. Ceroid and protein inclusion globules were plentiful, but megalocytosis and central necrosis were absent. The kidney tubules were laden with haemoglobin casts and degradation products. The second liver (July, 1957) showed marked portal tract fibrosis infiltrated with lymphocytes and polymorphs. These reactive cells were also significantly increased in numbers, both diffusely and focally throughout the liver, presumably as a reaction to necrosis of liver cells. There was a great variation in nuclear size. The reticulo-endothelial cells were increased in numbers, swollen and packed with degenerating red blood cells and bilirubin. There was some small bile duct proliferation in the portal tracts.

The livers of many of the abattoirs sheep showed cellular reaction in the portal tracts

with fibrosis and bile duct damage. The Kupffer cells frequently showed yellow-brown granules.

#### Discussion

Copper levels of pasture were at times moderately high but it is not considered that these alone could have caused a dangerous accumulation of copper in sheep livers. Molybdenum and inorganic sulphate levels were normal.

The histological data on livers were limited but suggested that two processes were involved. The first consisted of fibrotic and bile duct changes probably leading to some degree of excretory obstruction. This had probably been acting for some time before deaths occurred, and could have been due to ingestion of a plant containing a hepatotoxic alkaloid or to recovered facial eczema due to fungal toxicity. The absence of megalocytosis indicated a different type of poisoning from that due to *Heliotropium* (Bull 1961). The second change in the livers was due to an acute haemolytic process which caused the actual deaths. Although the clinical findings indicated that this was due to copper poisoning, the histological picture gave some suggestion that it may have been due to difficulty in the excretion of bilirubin normally produced. The relatively low liver copper liver values for the two sheep which died also gave some support to the idea that copper toxicity was not the primary cause of death.

It is not possible to give a satisfactory explanation for the massive accumulation of copper in the thirty abattoirs sheep but it was probably consequent on the liver damage as in heliotrope and lupin poisoning.

#### Acknowledgments

This investigation was carried out cooperatively by the Division of Animal Health, C.S.I.R.O. and the Western Australian Department of Agriculture.

The authors wish to express their indebtedness to the station owners of the Wiluna region who co-operated in this investigation and in particular to Mr. and Mrs. R. S. Howard, of "Albion Downs" Station. Acknowledgment is also made to Dr. J. R. Price of the C.S.I.R.O.

Chemical Research Laboratories, Melbourne, for arranging the determination of alkaloids in herbage; to the Botany Branch of the Western Australian Department of Agriculture for identification of species; to Dr. L. B. Bull of the Division of Animal Health, C.S.I.R.O., and Dr. M. R. Gardiner of the Department of Agriculture of Western Australia for discussions on the histology of the Toodyay samples, and to Messrs. C. N. Macliver, A. Negrin and V. McLinden for analytical assistance.

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### 3.—Two New Western Australian Cockroaches

By K. Princis\*

Manuscript received—21st August, 1962

I received recently from Mr. Athol M. Douglas, of the Western Australian Museum, a small lot of cockroaches for identification. These cockroaches had been collected partly in caves partly in mines and although but two species were represented they proved to be new to science. For the opportunity to study them I wish to express my gratitude to Mr. A. M. Douglas.

#### *Shawella douglasi*, sp. nov.

♂ (holotype), Western Australia, Jurien Bay, Limestone Caves (30° 17'S, 115° E), IX. 1958 (associated with the droppings of small cave dwelling bats *Eptesicus pumilus*), A. M. Douglas leg. (W. Aust. Mus.); 3 larvae, the same data (W. Aust. Mus. and Lund Mus.).

♂. Light brown with rather weakly chitinized integument. Eyes somewhat reduced (they are rather narrow with acute apices instead of rounded). Maxillary palpi and antennae rather long. Pronotum flat. Tegmina slightly overlapping in the middle of dorsum and reaching with their rounded apices to the 4th tergite; subcosta provided with rami anteriores in its distal part. Wings vestigial, reaching with their apices to the 2nd tergite. The 1st tergite with a well developed glandular area. Supra-anal plate (Fig. 1) quadrangular, with rounded latero-caudal angles; its caudal margin rather heavily spined and mesally slightly emarginate, Hypandrium (Fig. 1) considerably exceeding the supra-anal plate, markedly asymmetrically developed; the right style is somewhat larger than the left one and is situated about on the median line, while the left style is strictly confined to the left side of the plate; the upper surface of

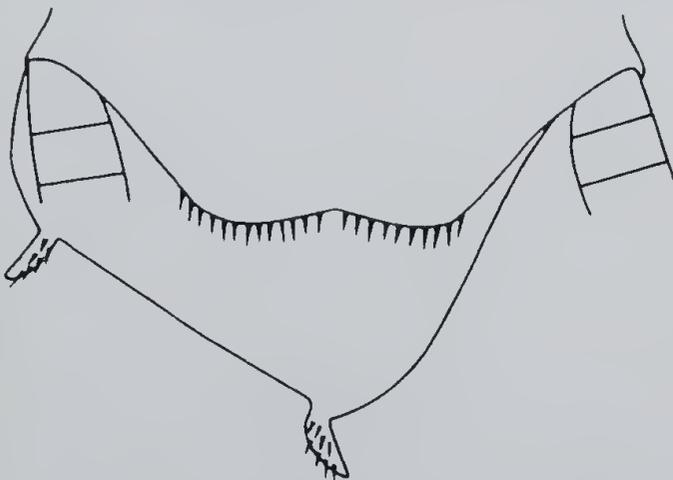


Fig. 1.—*Shawella douglasi* sp. nov., ♂ (holotype).  
Apex of abdomen from above.

\* Zoological Institute, Lund, Sweden.

both the styles is heavily spined. Legs rather long, heavily spined. Lower anterior margin of front femora armed after type A† and bearing 3 heavy distal spines. Pulvilli lacking. Tarsal claws symmetrical, unspecialized. Small arolia present. Length of body 17.5 mm; length of pronotum 4.5 mm; width of pronotum 5 mm; length of tegmina 9 mm.

The female of *S. douglasi* is still unknown. The new species differs from *S. coulouiana* (Sauss.) in the absence of pulvilli as well as in the moderately reduced eyes and the asymmetrically situated styles (in *S. coulouiana* they are symmetrically arranged). Also the male supra-anal plate in both the species is quite distinct. I suppose *S. douglasi* to be a true guanobie, although there are some characters, such as the weak pigmentation and chitinization of the integument as well as the reduced eyes, which might indicate a development leading to the troglobies.

#### *Paratemnopteryx atra*, sp. nov.

5 ♂♂ (holotype and paratypes) and 4 ♀♀ (paratypes), Western Australia, Marble Bar (21° 07' S, 119° 41' E), 10. X 1957 (collected deep in mines on piles of dung of the bat *Macroderma gigas*), A. M. Douglas leg. (W. Aust. Mus. and Lund Mus.); 1 ♀ and 1 larva, the same data (W. Aust. Mus.).

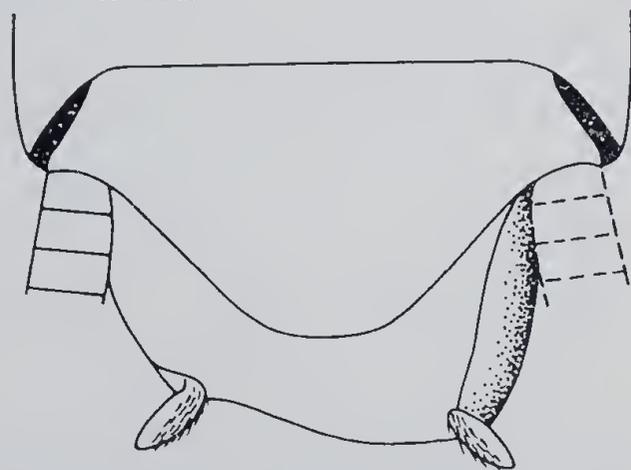


Fig. 2.—*Paratemnopteryx atra* sp. nov., ♂ (holotype).  
Apex of abdomen from above.

♂. Piceous. Eyes well developed. Maxillary palpi rather long. Pronotum flat. Tegmina not quite reaching to the apex of abdomen, although otherwise normally developed, i.e. not truncate; subcosta with rami anteriores in its apical part. Wings reduced to narrow pads, reaching with their apices to the 3rd tergite. Dorsum of

† Editorial note: for explanation of type A see Bruijning, C.F.A. (1948).—“Studies on Malayan Blattidae.” p. 33 (Brill: Leiden.)

abdomen unspecialized. Supra-anal plate as figured (Fig. 2), with rounded apex. Hypan-drium ample, provided with two nearly sym-metrically situated styles (Fig. 2) and with the right margin usually rolled upwards; the upper surface of both the styles rather densely spined. Legs heavily spined. Lower anterior margin of front femora armed after type A and provided with 3 heavy distal spines. Tarsal claws sym-metrical, unspecialized; pulvilli and arolia none. Length of body 19-25.5 mm; length of pronotum 7-7.5 mm; width of pronotum 9.5-10 mm; length of tegmina 16-18 mm.

♀. More robust than the male. Supra-anal plate generally as in the male but the apex more or less emarginate. Subgenital plate ample, scoop-like, with the hind margin slightly con-vex. Otherwise as the male. Length of body 23.5-26.5 mm; length of pronotum 7.5-9 mm; width of pronotum 10-12 mm; length of tegmina 17-17.5 mm.

*P. atra* differs from the 3 previously known species of *Paratemnopteryx*, i.e. *P. australis* Sauss., *P. blattoides* Tepp. and *P. rufa* (Tepp.), in its normally developed, non-truncate tegmina. It is obviously a true guanobie.

## 4.—Bronzite Peridotite and Associated Metamorphic Rocks at Nunyle, Western Australia

By C. R. Elkington\*

Manuscript received—21st December, 1962

The field occurrence and petrology of an ultrabasic body is described in detail, and observations on the associated metamorphic country rocks and later intrusives are recorded.

The ultrabasic body consists almost entirely of massive bronzite peridotite which has, however, been completely serpentized in places. Secondary hornblende occurs throughout the body and is particularly abundant near the margins.

The bronzite peridotite has intruded the gneiss, quartzite and basic granulites of the Jimperding "Series". Although definite transgressive contacts occur in the southern part of the area mapped, the ultrabasic mass is generally conformable with the surrounding country rocks.

The intrusion occurred after the main period of regional folding, and at a metamorphic grade probably equivalent to lower amphibolite facies. It resulted in the distortion of the adjacent quartzite, together with flowage and recrystallization of some of the gneisses and basic granulites. The ultrabasic mass was apparently serpentized by autometasomatism soon after emplacement; all of the serpentine which had formed at this stage has recrystallized to antigorite. Pegmatite dykes cutting the ultrabasic body have produced talc, anthophyllite and clinocllore by silicification of the bronzite peridotite. The secondary hornblende probably also formed during pegmatization.

Transgressive dolerite has caused minor hydrothermal alteration of the ultrabasic mass and a suite of rodingites has resulted from the metasomatism of bronzite peridotite and serpentine by lime and alumina from the dolerite.

### Introduction

The bronzite peridotite mass is about four miles north-east of Toodyay at Nunyle (longitude 116°31' E, latitude 31°31' S). Toodyay is 53 miles by road and 65 miles by rail north-east of Perth. The main road from Toodyay to Goomalling passes a quarter of a mile to the south of the area studied (see Figure 1).

The aim of this investigation was to examine the relationship of the bronzite peridotite mass to the surrounding metamorphic rocks, and to study the petrology of the ultrabasic rocks.

An area 3,400 feet from north to south and 2,000 feet from east to west was mapped in detail. All locations cited in the text are referred to the south-west corner of the area. Using a six figure group, in which the first three figures are "tens of feet" east, and the last three figures are "tens of feet" north, any point within the area mapped can be specified to within ten feet. One hundred and thirteen specimens were collected and examined. A detailed account of the petrography of these rocks is available in manuscript form at the Department of Geology of the University of Western

Australia. Specimen numbers cited in the text are those of specimens held in the collection of that department.

### Previous Geological Investigations

Before the present study, almost all of the geological work in the Toodyay district had been confined to the south-west of the Avon River. The name "Jimperding Series" was proposed by Clarke (1930, p. 167) and a detailed petrological examination of the Jimperding "Series" in the Toodyay district was made by Prider (1944). According to Prider (1944, p. 84): "This series comprises pelitic and psammitic metasediments with intercalated basic and acid igneous bands. A study of the pelitic members shows that over the whole area mapped the rocks lie within the sillimanite zone." Farther south, sections of the "series" have been examined in detail at Lawnswood (McWhae 1948) and Hamersley Siding (Johnstone 1952).

Prider (1941) recognized a conformable sequence of Precambrian metamorphic rocks. These represent a variety of sediments with

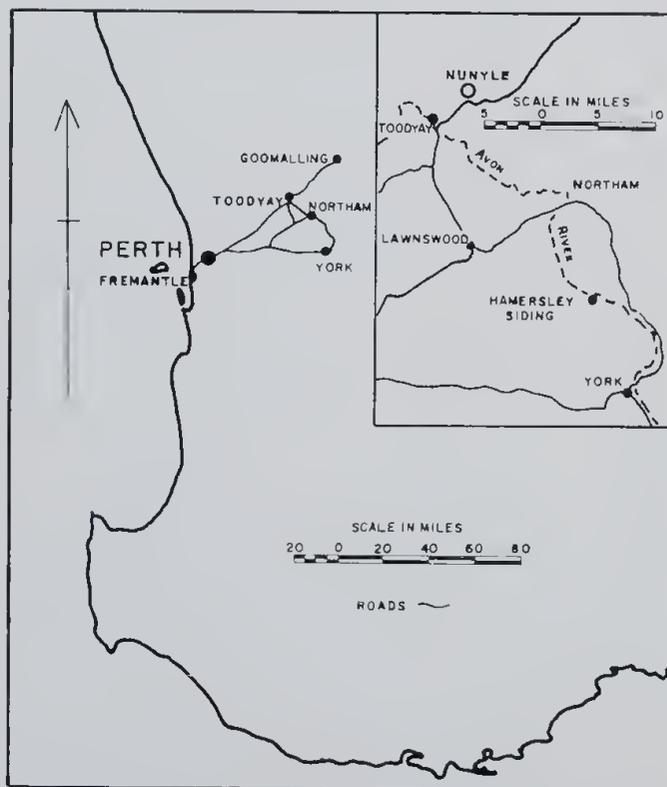


Fig. 1.—Locality map showing south-western Western Australia, Nunyle and the Avon River Valley between Toodyay and York.

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interbedded basic igneous rocks, which may have been sills or flows of tholeiitic character. Two periods of granite emplacement were postulated, with the intrusion of rare ultrabasic dykes both before and after these. Later the rocks were intruded by quartz dolerite.

The rocks at Nunyle, into which the bronzite peridotite was intruded, are a part of the Jimperding "Series". The basic granulites and the quartzite show similarities both in texture and mineralogy to rocks from parts of the "series" which lie to the south-west.

#### Physiography and General Geology

The Jimperding "Series" which has been briefly described in the introduction, strikes generally north-south at Nunyle, and the rocks have a moderate to steep easterly dip. The country rocks consist of gneiss and quartzite with interbanded basic granulites. The locus of intrusion of the bronzite peridotite is the lower contact of the quartzite and the gneiss and the bronzite peridotite crops out on the immediate west of the quartzite. The contact of the bronzite peridotite and the quartzite is characterised by *Hakea preissii*, which usually grows as rounded bushes about fifteen feet high.

Laterite which is characteristic of much of the surrounding country, does not occur in the area mapped; however, iron stains and quartzite fragments cemented with limonite are common on the higher features and the gneiss and dolerite in the uplands are kaolinized and leached. It appears that these rocks were in the zone of leaching directly below the laterite, which once covered the whole district at about 950 feet above sea level.

Only skeletal soils are developed and these are commonly colluvial containing fragments of quartzite and other rock types, which have come down the hill slopes. Alluvium is common in the valleys, but as solid bronzite peridotite crops out in the creek bed at 020011 (approximately the local base level), it is thought that the alluvium seldom exceeds 10 feet in thickness.

The area lies in the 21" rainfall belt and most of the rain falls between May and August. The Toodyay district is an undulating plateau at about 1,000 feet above sea level, which has been dissected to a maximum depth of about 600 feet by the Avon River drainage system. The area mapped has an elevation of between 680 feet and 970 feet above sea level. Here the streams are young, cascades are common and solid outcrops occur frequently in the creek beds.

The ground water is unusual in that on the hillsides it is saline whereas the springs in the valleys provide excellent drinking water. Many of the creeks in the district are located along fault or shear zones, as evidenced by epidote-filled shears and epidote impregnations in the rocks in the creek beds. These creeks are typically straight and have numerous springs and seepages along their courses. The creeks from 200095 to 180048 and 130012 to 000010 are of this type. The creek from 086279 to 000230 has none of the characteristics outlined above and its course is probably controlled by the quartzite. The river gum (*Eucalyptus rudis*) grows alongside the larger watercourses.

Quartzite crops out strongly forming the most prominent physiographic features in the area. In the creeks on the other hand, exposures of quartzite are rare, indicating that the watercourses tend to pass through any natural gaps in the quartzite rather than to cut down through it. The holly-leaved dryandra, *Dryandra floribunda*, and white gum, *Eucalyptus redunca*, are the typical vegetation on the quartzite hills.

A shear, which has caused local shattering and distortion of the quartzite, has weathered at 100120 to form a remarkable topographic break. Projection along the line of this shear to the south-west shows that it is parallel to the platy flow of the bronzite peridotite outcrops on the immediate north. To the north-east there is no apparent dislocation of the gneiss and the break does not conform with the regional structure. It is related in time and space to the intrusion of the ultrabasic body into a semi-rigid quartzite, and represents distortion of the quartzite during the intrusion of the bronzite peridotite.

Outcrops of gneiss generally occur on the lower hill slopes and in the valleys. Aerial photographs indicate that the gneisses overlying and underlying the ultrabasic body have straight parallel trends, whereas the quartzite (which immediately overlies the ultrabasic body) has a highly variable strike and dip. Examination on the ground shows that there is far more distortion of the rocks in contact with the ultrabasic body than in those a few hundred feet stratigraphically above or below it. The gneiss appears to have flowed into the quartzite and filled openings which occurred during the intrusion of the bronzite peridotite. Shallow valleys at 120300 and 120160 are considered to have resulted from differential weathering of such intrusive gneiss.

York gum, *Eucalyptus loxophleba* and jam, *Acacia acuminata*, are characteristic of the richer soils in the area and generally grow over basic granulites or bronzite peridotite. Where these species grow on quartzite talus, the talus probably overlies basic or ultrabasic rocks.

The bronzite peridotite usually crops out on the hill slopes below the escarpment of the quartzite, in the form of numerous boulders up to about three feet in diameter. In some places, however, the outcrop is in the form of large blocks, which are *in situ*, and are as much as twenty feet in diameter (see Figure 2). Such an outcrop occurs at 048125. The tunnels and crevices under the blocks have been used by small animals, such as foxes, and where these animals have rubbed against the rocks, the surfaces are smooth and polished.

#### The Ultrabasic Body

##### Introductory Statement

The ultrabasic body is made up dominantly of bronzite peridotite, with variations from relatively pure serpentinite to pyroxenites which may have little olivine or antigorite.

It is overlain apparently conformably, by quartzite to the east and north, and is underlain by gneisses to the south and west. Definite transgressive contacts have been established between it and the gneisses to the south. Out-



Fig. 2.—The south-western aspect of "Black Rocks", a large outcrop of bronzite peridotite at 048125.

crop in the central and eastern portion of the area is good, but much of the south-western corner is covered by colluvial soils derived from dolerite, quartzite, ultrabasic material and sometimes gneiss. In 1950 a new road was constructed from 000140 to 050230 and the ditch on its south-east side exposes gneisses and quartzite which apparently occur in the centre of the ultrabasic body. The ultrabasic material, in turn, cuts through the gneiss and quartzite in narrow dykes of the order of a few feet wide. Thus the general form of the body appears to be two distinct lenses lying parallel to the strike of the country rocks, connected by a series of narrow dykes.

Planar structures are developed throughout the body; these are considered to be platy flow-structures and mapping has shown that they tend to be parallel to the contacts of the body.

The only mineralogical trend observable in the field is the enrichment in amphibole towards the margin of the body.

No lineations have been recognized in the ultrabasic rocks. The pyroxene may be oriented, but in view of the coarse grain size, it has been impractical to test this. Certain rock slices give pyroxene cross sections with similar orientations, but as most slices only show three, four or at the most twelve cross sections of pyroxene, study by the normal statistical methods is precluded.

#### *Petrography*

A bronzite peridotite and a hornblende bronzite have been chosen for description as they portray the typical occurrence and interrelations of minerals throughout about 80 per cent. of the intrusive mass. Two serpentinites indicate the character of the remainder of the mass. It has not been possible in mapping to separate bron-

zite peridotites and serpentinites. Also described are veins having their origin within the ultrabasic body, altered rocks associated with the pegmatite dykes, alteration associated with the quartz dolerite dyke and a small group of rocks thought to be xenoliths.

*Bronzite peridotite.*—Specimen 39725 was collected from 007032 about two hundred feet from the southern contact of the ultrabasic body with the gneisses. The outcrop consists of numerous boulders mostly *in situ*. In hand-specimen it has a general dark green colour, with pale grey patches (about 10 mm in diameter) making up about 40 per cent. of the rock. It is massive and porphyritic, with hard porphyroblasts in a softer, serpentinous, fine-grained groundmass. Small flakes of chlorite are disseminated throughout the rock.

In thin section the texture is pseudoporphyritic. Large pyroxene porphyroblasts\* have inclusions of olivine, some of which are euhedral. No crystal faces are developed on the pyroxene. The following minerals are present: Antigorite (approx. 45%), very fine-grained fibrous or laminated mineral, occurring as pseudomorphs after olivine giving a characteristic mesh texture of "grains" 0.2 mm in diameter. There is a strong tendency for it to be oriented with X and Z lying in the same directions throughout the whole slide. Fine inclusions of magnetite dust occur everywhere within it and particularly along the contacts of "grains" pseudomorphous after olivine. Alteration is to clinocllore by reaction with spinel. *Bronzite* (approx. 33%), rather irregular grains, from 1 to 5 mm in diameter, with abundant inclusions of anhedral, sieve-textured olivine averaging 0.5 mm in

\* The term porphyroblast is used here to describe prominent crystals which have grown in a solid or crystalline medium.

diameter, and also of rounded grains of spinel and magnetite 0.1 mm in diameter. *Olivine* (approx. 16%), occurs mainly as sieve-textured inclusions in bronzite 0.5 mm in diameter, and as relics 0.1 mm in diameter in mesh-textured antigorite marginal to bronzite. Some of the grains included in the bronzite show development of the 010, 001 and 021 faces, but such euhedral grains, though significant, are exceptional. Alteration is to antigorite and magnetite dust, or to hornblende. *Hornblende* (approx. 3%), rare prisms up to 0.5 mm long or pseudomorphs after olivine. *Spinel* (approx. 2%), dark yellowish green 5 GY 5/4† rounded grains (0.1 mm in diameter), included in bronzite. Alteration is to magnetite and isotropic, fine-grained chlorite, by reaction with antigorite. No spinel remains except where it is armoured with another mineral against antigorite; reaction rims are not well developed in this specimen. *Clinochlore* (trace), books up to 0.05 mm by 0.3 mm associated with magnetite. These associated laminae cut across the mesh texture and exert their form strongly.

The relationship of the olivine and bronzite in this specimen is most significant. The textures that may be produced from bronzite with abundant poikilitically included olivine will be discussed later.

*Hornblendic bronzite*.—Specimen 39739 was collected from 084268 where the outcrop consists of scattered boulders. The rock appears to consist of normal bronzite peridotite (with the typical rough weathered surface) in which are ellipsoidal blebs of material about 9 in. by 4 in. by 6 in. which weather to a smooth surface. These blebs are outlined by a weathered groove, about  $\frac{1}{2}$  in. deep and in hand specimen they are uniform grey and of even hardness. Numerous grains of amphibole averaging about 1 mm long compose about 50% of the blebs.

In thin section the texture is poikilitic. Large masses of bronzite enclose numerous hornblende prisms, which in quantity exceed the host crystal. *Bronzite* (approx. 40%), forms oikocrysts up to 5 mm in diameter, which are cut by small veins of antigorite and chrysotile. Alteration is to chrysotile. *Olivine* (trace), occurs only as rare relics in mesh-textured antigorite intergranular with respect to bronzite. *Hornblende* (approx. 52%), occurs as euhedral, subhedral or anhedral prisms included in bronzite and is commonly traversed by chrysotile veins.

This specimen is notable in several respects:—

(a) The absence of spinel and clinochlore both of which are found almost universally throughout the ultrabasic body. Possibly both of these minerals were in the rock, but they have now been altered and their components used to form hornblende. (b) The absence of olivine included in the bronzite. Conditions appear to have been particularly favourable for the formation of hornblende, and included olivine would have been converted to hornblende. (c) The predominance of hornblende inclusions and the general texture. There is a textural

similarity in thin-section between this rock and specimen 39725, in which the bronzite porphyroblasts have abundant inclusions of sieve-textured and euhedral olivine.

*Serpentinite*.—Specimen 39751 was collected from 040120, which is 50 feet south-east of Black Rocks. The outcrop consists of scattered boulders, with smooth weathered surfaces. In hand specimen the rock is greyish green, uniformly soft and has an uneven fracture.

In thin section the specimen has a fine-grained feathery texture with some recognizable mesh-texture. Areas up to 3 mm across contain reticulate, or knitted-textured masses of antigorite. *Antigorite* (approx. 90%), occurs as feathery groundmass, in reticulate areas, and as anhedral "grains" up to 0.8 mm in diameter. Much is recrystallized and oriented so that when the nicols are crossed and the gypsum plate inserted, if the stage is rotated the field appears alternately dominantly orange and blue. *Magnetite* (approx. 3%), is present as fine inclusions up to 0.2 mm in antigorite, and as ragged grains up to 1 mm in diameter associated with chlorite. *Chlorite* occurs as laminae frequently associated with magnetite grains or laminae. The characteristic occurrence is in books 0.3 mm by 0.1 mm. Two varieties were recognized, *clinochlore* (approx. 3%) and *pennine* (approx. 4%). The variation between these two varieties is probably continuous. Clinochlore formed by the reaction of antigorite with aluminous spinel, and positive and negative pennine resulted from a reaction between relatively aluminous clinochlore and antigorite.

This rock is a highly serpentinized bronzite peridotite in which the original pseudoporphyratic texture is preserved. The reticulate masses of antigorite, 3 mm in diameter, represent earlier porphyroblasts of bronzite.

*Serpentinite*.—Specimen 39734 was collected at 048129, that is, on the immediate north of Black Rocks from an outcrop of scattered boulders. The hand specimen is a uniform, fine-grained dark green rock with numerous minute silvery chlorite flakes. Under the microscope the rock appears to consist dominantly of antigorite with the characteristic mesh texture, in which are several partly serpentinized hornblende prisms and also a bronzite porphyroblast altered to structureless serpentine. The chlorite flakes are always associated with magnetite laminae. This rock bears a striking resemblance to specimen 15425 (collected from a dyke just south of Toodyay) described by Prider (1944, p. 128) which was shown from analysis to be a normal serpentinite.

*Veins having their origin within the ultrabasic body*.—A variety of veins have their origin within the ultrabasic rocks themselves. They are easily distinguished in hand specimen as they are normally subject to differential weathering with respect to the enclosing rocks. In thin section however, they have less distinct boundaries, being composed of altered or recrystallized minerals on a planar or distorted planar surface. The chrysotile veins are of particular interest for it is veins of this character which

† Colours of minerals given are from the colour standards of the Rock-Colour Chart prepared by the National Research Council, Washington, D.C.



Fig. 3.—Polished specimen (x 4) showing bronzite crystals (pale grey) in a serpentinous groundmass (dark grey). The left half of the specimen consists of normal bronzite peridotite, in the centre-right is the pyroxene-rich vein, to the right of this is the zone of intense serpentinization, and on the extreme right there is normal bronzite peridotite. A magnetite-clinocllore vein passes from the upper left of the specimen to the lower right of the pyroxene-rich vein, but does not stand out strongly in the photograph.

form the commercial deposits of chrysotile asbestos elsewhere. Further, chrysotile veins alone have produced noticeable dilation.

*Pyroxene vein.*—The only outcrop of this type of vein may be seen on the northern vertical surface of the outcrop referred to as Black Rocks. The vein has a relief of about 1", is about 2" wide and crops out for a length of some 30 feet. Specimen 39727 is 13" by 9" by 6", and one face of it has been polished to reveal the relationship of the vein to the enclosing bronzite peridotite (see Figure 3). The rock and the pyroxene vein are both traversed by magnetite-clinocllore veins.

Inter-relations of the minerals in the vein are essentially the same as in the normal bronzite peridotite. Large bronzite porphyroblasts comprise about 66% of the vein; olivine included in the pyroxene and adjacent to the pyroxene has been partly preserved from serpentinization. On one side there is a zone of intense serpentinization. The only feature fundamentally distinguishing the vein from the enclosing rocks is the high proportion of bronzite.

*Magnetite-clinocllore veins.*—These are present in specimen 39727 and are relatively abundant throughout the rest of the ultrabasic body. As seen in thin section they consist of strings of roughly equidimensional composite grains (averaging 0.2 mm in diameter), which are composed of alternating lamellae of clinocllore and magnetite. They may transgress bronzite crystals in which case the bronzite immediately adjacent to the vein is altered to clinocllore.

*Magnetite-antigorite veins.*—These veins are characteristically weathered to a depth of up to 4 mm deeper than the surrounding rocks, giving

an entrenched appearance. Under the microscope they appear as numerous strings and groups of magnetite granules and occasional composite magnetite-clinocllore grains in a serpentinous material. Examination under high power magnification shows that some of the magnetite consists of dust (0.001 mm in diameter) surrounding antigorite "grains", which are approximately 0.02 mm in diameter. The antigorite is oriented with X normal to the plane of the vein. The veins themselves are traversed by gamma chrysotile veins.

*Ercnzite peridotite breccia.*—Specimen 39754 was collected at 057290. The zone of brecciation is not more than a few feet wide, and in it the bronzite peridotite is broken into angular fragments averaging 40 cm in diameter. The groundmass is composed of antigorite and magnetite with numerous fine striae parallel to the margins of the fragments. The antigorite is either in large crystals or else in parallel-oriented small crystals since areas up to 4 mm in diameter show essentially the same optical orientation. This brecciation appears to be a late-stage effect due to adjustments within the ultrabasic mass after its consolidation.

*Chrysotile veins.*—These are typical cross-fibre chrysotile veins and occur in two varieties. The oldest is characteristic of the more highly serpentinized rocks and forms swarms of intricately distorted thin lenses averaging 0.02 mm in thickness. This variety appears to be more recent than any antigorite-bearing veins or antigorite in the groundmass of the bronzite peridotite. These irregular thin veins are in turn cut by young regular chrysotile veins which are of uniform sheet-like form from 0.1 mm to 1.0 mm in thickness. These later veins exhibit only minor distortion.



Fig. 4.—Zoned chrysotile vein cutting serpentinite. Crossed nicols, x 15.

*Altered rocks associated with the pegmatite dykes.*—The ultrabasic mass has been intruded by several small pegmatite dykes and addition of material has caused considerable local alteration.

At 110010 on the south bank of the creek, some tens of feet from a pegmatite dyke, bronzite has been altered and replaced by a fine-grained felted mass of hornblende (25%), clinocllore (30%), talc (35%), anthophyllite (10%) and magnetite (trace). The original groundmass, presumably antigorite, has been mainly replaced by hornblende, which is medium-grained and comprises about 90% of the present groundmass. Thus the pseudoporphyratic texture is preserved even though the mineralogy has been almost entirely changed.

Xenoliths of ultrabasic material included in the pegmatite dykes have been very extensively altered, and all former textures destroyed. The amphiboles, however, are still those of the ultrabasic body. A typical xenolith is 8 in. in diameter and has a core composed entirely of pure coarse-grained hornblende; clinocllore, magnetite, spinel and the serpentine minerals are conspicuous by their absence. Surrounding this core is a rock in which hornblende is still dominant but chlorite, vermiculite or chlorite-vermiculite mixtures comprise about 30% of the rock. Talc or anthophyllite may be present. The outer shell of the xenolith is either chlorite or vermiculite schist one or two inches thick and is very friable. In one specimen examined alteration had proceeded to a stage at which hornblende had been corroded and replaced by oligoclase. The resulting rock is composed 60% of hornblende, 30% of oligoclase ( $An_{13}$  —  $An_{37}$ ), and 1% of quartz.

Talc bodies are found in the vicinity of the pegmatite dykes. These have a core of talc of variable thickness and are separated from the bronzite peridotite by a sheath of anthophyllite needles of the order of 4 cm long, oriented with their *c* axes normal to the contact. Anthophyllite may also occur in the core as feathery masses but is always heavily corroded by talc, which is either pseudomorphous after anthophyllite or in irregular masses. Interleaved with the anthophyllite needles are rare flakes of vermiculite and pennine (cf. specimen 39765).

One of the talc bodies had a core consisting of about 80% of talc with corroded inclusions of chlorite (diabantite) up to 1 mm in diameter, anthophyllite and hornblende being present in trace quantities.

Anthophyllite and talc are the products of progressive silicification; chlorite has resulted from alteration in an environment rich in water but deficient in silica, but subsequent addition of silica has led to steatitization of the chlorite.

*Alteration associated with the quartz dolerite dyke.*—A quartz dolerite dyke about 150 feet wide has been intruded across the south-western part of the area studied. Near this dyke bronzite has been extensively altered to talc, hornblende and anthophyllite. This alteration started along cracks and cleavages and worked outwards converting adjacent bronzite to amphibole. Antigorite is present in the normal quantities but occurs as a feathery groundmass with associated pennine and magnetite. Distinct mesh texture is not developed.

At 036014 the bronzite peridotite has been completely altered to a very fine-grained mass of intricately intergrown clinocllore and talc. No amphiboles are present at this locality.

*Xenoliths in the ultrabasic body.*—In certain areas there are patches of mixed float of bronzite peridotite and amphibole schist. These amphibole schists are thought to be xenoliths, as their general appearance is different from either the country rocks or the ultrabasic rocks. Three specimens which are essentially quartz-tremolite schists have been examined in detail. The texture varies from schistose to granoblastic with poor platy orientation and there may be a poor or a strong linear orientation. The colour is pale green but may be reddish due to oxidation. Tremolite (9%-100%) occurs as subhedral prisms with lamellar twinning parallel to 001.  $\gamma$  = 1.630 — 1.648, apatite and monazite are common inclusions, alteration is to talc. Quartz (trace — 90%) forms equant to elongate grains with inclusions of apatite, monazite and more rarely rutile.

The tremolite is similar to the amphiboles of the ultrabasic body and quite unlike the hornblendes of the basic granulites in the country rocks. As all the outcrop is in the form of float it has not been possible to correlate the lineations with any structure elsewhere. These rocks have a mineralogical affinity with the ultrabasic rocks but have different textures, the accessory minerals apatite, monazite and rutile, and occur only within the boundaries of the ultrabasic body.

#### Mineralogy

*Olivine* varies from forsterite to chrysolite. Originally this mineral probably constituted over 95% of the "magma", but now, due to silicification and serpentinization, it is uncommon to find rocks with more than 5% of olivine.  $\beta$  ranges from 1.663 to 1.674 indicating a variation in composition from Fa.7 to Fa.12 (Poldervaart 1950). Spinel is a rare inclusion. Where the inter-relations can be seen, olivine is idiomorphic towards pyroxene, though it is usually embayed until only sieve-textured relics remain. Bronzite, hornblende and chrysotile have evidently all formed from olivine under appropriate conditions, but usually chrysotile appears to have recrystallized to antigorite.

The only *pyroxene* encountered is bronzite. No 010 sections of clinopyroxene have been seen, nor have any sections perpendicular to the optic axes given figures similar to those of clinopyroxene. Nevertheless clinopyroxene present in small amounts would be difficult to detect unless the grains were favourably oriented.

*Bronzite* occurs throughout the ultrabasic body except where it has been serpentinized or metasomatized to produce hornblende or talc and anthophyllite. Even where complete serpentinization has occurred, structureless serpentine pseudomorphs, or knitted-texture antigorite pseudomorphs testify to the earlier presence of pyroxene. Similarly where the rock has been metasomatized, talc, or talc-anthophyllite pseudomorphs after pyroxene

clearly indicate its original presence. These pseudomorphs are equivalent in size to the fresh pyroxenes and are also present in the same proportions with respect to the groundmass, as the pyroxenes are in the less altered rocks. Measurement of  $2V$  and  $\gamma$  has shown that these pyroxenes are aluminous (see Table I) and do not conform with the composition—optical property diagram of Poldervaart (1950). As the percentage of ferrosilite is between 11 and 25, and the Mg:Fe ratio is between 9 and 2.33, all these pyroxenes are bronzite. This nomenclature is in accordance with Poldervaart (1950) even though some of these pyroxenes contain less than 70% of enstatite.

In thick sections the bronzite is pleochroic with X colourless, Y pale pink and Z pale green.

The bronzite porphyroblasts are distinctive not only in thin-section and hand specimen but also in their persistence in shape and size in replaced and altered parts of the ultrabasic body. Their origin and relation to other minerals is of interest. There are three important points in the inter-relations of olivine and bronzite. First, the bronzite is never euhedral and never shows any crystal faces; second, the bronzite usually includes sieve-textured or embayed olivine which was probably once euhedral (cf. specimen 39725); third, the margins of the bronzite porphyroblasts are commonly rich in olivine inclusions, in fact some may be so well coated with olivine that the serpentinous groundmass of the rock is only rarely in contact with the pyroxene. The bronzite porphyroblasts are the result of introduction of silica into an aggregate of olivine crystals. Thus, the porphyroblasts contain relic granules of olivine cemented together by bronzite formed by the silicification process; the persistence of olivine depended upon the availability of silica and the armouring effect of the already-formed bronzite.

Spinel is found in all of the less-altered bronzite peridotites. Grains of ragged magnetite associated with clinocllore in the serpentinites testify to the earlier presence of spinel. The stages—spinel, spinel with magnetite and fine-grained chlorite reaction rims, spinel with magnetite-clinocllore reaction rims, and finally magnetite grains with clinocllore—clearly illustrate the progressive “serpentinization” of these grains. The normal amphibole, a near-tremolite, is apparently undersaturated with respect

to  $Al_2O_3$ . Regional metamorphism has led to the absorption of magnetite and spinel by hornblende. Although the previous existence of spinel in these rocks cannot be proved, it was clearly present in the rest of the ultrabasic body to the extent of 1 or 2 per cent.

The refractive index varies from 1.778 to 1.786. As the grains are generally less than 0.2 mm in diameter, no measurements of specific gravity have been attempted. The variety is probably ceylonite or pleonaste. The colour is close to moderate yellowish green 10 GY 4/4, with variation in hue and absorption towards light olive 10 Y 5/4.

Regional metamorphism has caused the partial recrystallization of the ultrabasic rocks to produce hornblende. There is no primary hornblende. Near the contacts with the country rocks it is abundant, but towards the centre of the mass it is rarer, being of the order of 10% or less. Hornblendites are developed adjacent to the pegmatite at 109010.

The optical properties of the hornblende vary over a well-defined range, viz:— $\gamma$  1.640-1.655 (mean 1.645);  $2V_x$   $75^\circ$ - $90^\circ$  (mean  $85^\circ$ );  $Z \wedge c$   $17^\circ$ - $21^\circ$  (mean  $18^\circ$ );  $\beta$  0.017-0.022 (mean 0.019). These properties vary independently and so no generalizations can be made regarding the trends or changes in the composition of the hornblende. The composition is evidently near to tremolite with Mg:Fe = 85:15. In hand specimen the hornblende is dark green, but in thin section it is almost colourless, except in some rocks rich in hornblende. The strongest colours recorded were X very pale yellowish green (10 GY 8/2), Y pale yellow-green (10 GY 7/2) and Z pale green (5 G 7/2) with absorption  $X < Y < Z$ . In the centre of the body hornblende has formed from olivine and pyroxene, but near the margins and adjacent to pegmatite, the serpentinous groundmass has sometimes recrystallized to give hornblende. Where hornblende occurs as an alteration product of olivine, both included in bronzite and in mesh-textured antigorite, this has produced interesting results in the mesh texture; cores of olivine may be seen surrounded by successive rims of antigorite, hornblende and antigorite. The sequence was evidently partial serpentinization of olivine, then alteration of the outer part of the remaining olivine to hornblende, followed by renewed serpentinization of the olivine.

Three distinct *serpentine minerals* are recognized,  $\alpha$  and  $\gamma$  chrysotile and antigorite. *Alpha chrysotile* is characterized by negative elongation (Tertsch 1921, p. 188) and  $\beta \leq 1.560$  (Nagy and Faust 1956, p. 821). It occurs in fresh mesh texture particularly where there are olivine relics. *Gamma chrysotile* has positive elongation,  $\beta \leq 1.560$  and is found in fresh mesh textures and also in late veins.

*Antigorite* is present in four textural forms, the most interesting of which is the “oriented mesh texture”. Initially mesh texture was characterized by each “grain” containing radially oriented chrysotile. When seen under crossed nicols, insertion of the gypsum plate gives the field evenly balanced blue and orange interference colours in adjacent quadrants. Re-

TABLE I

Estimation of the composition of pyroxenes (from the optical data diagram of Winchell and Winchell 1951, p. 406).

Specimen	$2V\gamma$	$\gamma$	Enstatite	Ferrosilite	$\frac{Al_2O_3}{H} \frac{Al_2O_3}{Si_2O_6}$
39725	$78^\circ$	1.670	79%	11%	10%
39726	$87^\circ$	1.675	68%	14%	18%
39728	$81^\circ$	1.676	70%	11%	19%
39729	$78^\circ$	1.676	73%	11%	16%
39735	$84^\circ$	1.670	71%	14%	15%
39736	$84^\circ$	1.676	71%	14%	15%
39737	$88^\circ$	1.669	70%	16%	14%
39738	$83^\circ$	1.673	71%	13%	16%
39749	$90^\circ$	1.671	69%	16%	15%
39750	$107^\circ$	1.678	60%	25%	15%

crystallization of the chrysotile to antigorite did not destroy the meshes but the previously radial arrangement was replaced by a parallel orientation. With the recrystallized antigorite, insertion of the gypsum plate then gives the field alternately blue and orange interference colours on rotation. The orientation may be dominantly parallel throughout the whole of a thin section. The relationship of this orientation to the regional tectonic axes has not been determined, for it is not known yet whether the orientation is parallel locally, or parallel throughout the whole of the ultrabasic body. This recrystallization may be related to the regional metamorphism, as the regional metamorphism would affect the temperature and the availability of the ions  $Al^{+++}$  and  $Fe^{+++}$ . Suggested processes for the development of antigorite from chrysotile were outlined by Nagy (1953), and Wilkinson (1953, p. 315) noted that in the alpine-type serpentinites of Queensland, chrysotile has recrystallized to antigorite at a grade equivalent to the albite-epidote facies.

Antigorite also occurs in patches of similar dimensions to the pyroxene porphyroblasts. These patches either have knitted-texture, which is similar to mesh texture, with the exception that the meshes are of the order of 0.02 mm in diameter, or else take the form of anhedral structureless pseudomorphs after pyroxene. In both cases the texture of the original rock is usually preserved. Another mode of occurrence is in veins, in which the antigoritic lamellae are disposed at right angles to the plane of the vein. Strings of magnetite grains are frequently arranged parallel to and within these veins. Antigorite with this texture is also found irregularly distributed separating patches of undisturbed mesh texture. Recrystallization of chrysotile or antigorite with minor contemporaneous movement, which has partially destroyed the original mesh texture, would give rise to such antigorite-magnetite veins. The refractive index  $\beta = 1.566-1.572$  (mean 1.568). The birefringence was estimated to be consistently about 0.003, which is rather low for antigorite.

*Magnetite* is found in all the ultrabasic rocks except the hornblendites. It is nearly always a product of serpentinization either of olivine or bronzite, or of the reaction of a serpentine mineral with spinel. Magnetite does not occur in hornblendites and is normally corroded in rocks rich in hornblende. Inclusions in pyroxene may be primary magnetite, but these are rare and will not be considered further. The common association of chlorite with magnetite is interesting for two reasons. First, the associated minerals may have been formed by the break-down of one previous mineral containing the sesquioxides  $Fe_2O_3$  and  $Al_2O_3$  and second, the chlorite only rarely contains more than 15% of ferro-antigorite or daphnite.

*Chlorite* appears to be derived entirely from the reaction of aluminous minerals with serpentine, or as a result of the introduction of alumina along veins into serpentinites. It is common to all rocks containing serpentine and most of those affected by hydrothermal activity.

The refractive index  $\beta$  varies between 1.590 and 1.573; the birefringence is usually 0.006, with buff polarization colours, but varies to give very low order anomalous blues; 2V is variable being up to about  $+30^\circ$  in some clinochlore. Thus, the common chlorite is aluminous, i.e. clinochlore. Silicification associated with either talc or antigorite has led to the formation of diabantite in specimen 39765 and probably penninite in specimen 39751 (Hey 1954, pp. 280-284).

The development of clinochlore from serpentine and spinel has been discussed previously; the association of magnetite and clinochlore laminae is described here. The associated laminae occur both as discrete "grains" scattered through the rock and also in well-defined veins such as those in specimen 39727. The alumina necessary to produce clinochlore was probably introduced along fissures, where it reacted with the serpentine to produce clinochlore plus magnetite. The laminated form of the magnetite could be due to either the crystalloblastic forces of the chlorite which expelled iron ore parallel with the 001 face, or, the formation of a chlorite supersaturated with iron, which was later deposited by exsolution in laminae parallel to 001. The clinochlore may have reacted later with antigorite and given rise to the negative penninite (low alumina), which is commonly interleaved with clinochlore. A similar transition from optically positive to optically negative chlorite has been noted by Francis (1956, p. 213). The associated laminae are always idioblastic towards, and appear to be later than antigorite.

Chlorite was also formed by the hydrothermal alteration of pyroxene and probably olivine, which produced books frequently up to 2 cm in diameter with very little magnetite. Continued hydrothermal activity sometimes led to the formation of talc. Alteration to talc involved addition of silica and proceeded from embayments, to sieve-textured inclusions of chlorite in talc, and ultimately probably to pure talc. During this process the character of the chlorite itself changed from the early aluminous clinochlore to the more siliceous diabantite.

Alteration of chlorite also gave rise to *vermiculite* locally. At 109010 there is a talc-vermiculite-hornblende schist, and at 107010 an equivalent rock consists of clinochlore and hornblende. Over a space of about twenty feet, on one side the chlorite has all been altered to vermiculite, while on the other side there are only traces of alteration. Specimen 39765 shows apparent equilibrium between talc and vermiculite, both of which appear to have formed at the expense of chlorite. Some vermiculite is idioblastic towards talc, but much of it is evidently replaced, heavily embayed, chlorite.

The stage at which vermiculite formed is obscure. The evidence in specimen 39765 could indicate that some chlorite was being steatitized and simultaneously other chlorite was being converted to vermiculite, which was incapable of being steatitized. Further, there is the difficulty presented by almost adjacent rocks having fresh chlorite or vermiculite. The problems associated with vermiculite have been investigated by Barshad (1948), who concluded that they were

essentially micas with the K replaced by Mg or Ca. He recognized four types; vermiculite as described above; vermiculite-biotite mixtures; vermiculite-chlorite mixtures; and biotite-chlorite mixtures. By utilizing the base exchange capacity he could convert three of these types to biotites. The vermiculite-chlorite mixtures, however, while otherwise similar were not so in this respect (Barshad 1948, pp. 675-677). It is probable that the vermiculites described here are vermiculite-chlorite mixtures, as they are obviously derived from chlorites. The flakes do not exfoliate appreciably when heated.

The common occurrence of vermiculite near two pegmatites indicates that hydrothermal action was involved in its genesis. Alternatively, the hydrothermal action gave rise to chlorite which, on weathering, was converted to vermiculite.

Talc and anthophyllite are hydrothermal alteration products of the ultrabasic rocks. Anthophyllite never appears to be in equilibrium with the surrounding minerals, but seems to be an intermediate product between the unaltered rock and talc. This accords with the findings of Bowen and Tuttle (1949, pp. 450-452), and Yoder (1952, pp. 609-614) who considered that the stability field of anthophyllite existed in a water-deficient region (a condition which would be unlikely to obtain adjacent to a pegmatite during steatitization).

These minerals generally occur together, often with clinocllore. Hydrous emanations from the dolerite have resulted in very irregular masses of inter-mixed talc and anthophyllite, which may be roughly pseudomorphous after bronzite. The pegmatites are responsible for larger masses of talc sheathed in fine needles of anthophyllite. In such anthophyllite  $\gamma$  varies between 1.625 and 1.631, indicating approximately 95% of magnesian anthophyllite (Rabbitt 1948, p. 295).

It is interesting to note that serpentization of amphiboles has not been found in rocks containing significant proportions of talc.

Talc is the most silicified magnesian silicate found, being the last member of series which might be written:—

forsterite—enstatite—anthophyllite—talc

At Nunyle, talc appears to be the only member of that series capable of coexisting with quartz and its association with anthophyllite is an expression of silica deficiency in the rocks.

#### Rock Facies\*

Three equilibrium mineral assemblages can be recognized; these are:

Olivine	}	≡	Bronzite peridotite
Bronzite			
Spinel			
Hornblende	≡	Hornblendite	
Antigorite	}	≡	Serpentinite
Magnetite			
Chlcrite			

\* The word facies is used here to express an environment in which the most important variables are temperature and composition.

The percentage of minerals belonging to each assemblage for every specimen examined (specimens with abundant talc and anthophyllite have been excluded), has been computed and the results plotted (Figure 5). Thus two hornblendites and seven serpentinites are the only rocks containing minerals all of which belong to a single assemblage. The remaining points represent specimens containing mixtures of the three assemblages.

A quick examination of Figure 5 shows that rocks are likely to occur with mixtures of the three assemblages in all proportions. The majority of the rocks, however, have a ratio approaching hornblendite: bronzite peridotite = 1:4. The subdivisions within the triangle divide the rocks into those described as bronzite peridotites, serpentinites and hornblendic bronzite peridotites respectively.

The minerals of the bronzite peridotite assemblage evidently represent the facies which obtained during the intrusion. All the minerals are more or less altered so that no bronzite peridotites remain, which do not show the effects of serpentization, regional metamorphism, or more commonly, both. This assemblage is important for it is the parent of both the hornblendites and the serpentinites.

The hornblendites probably represent the metamorphic facies of regional metamorphism. All other minerals appear to have been absorbed into the hornblende, which has a composition near to tremolite. The effects of regional metamorphism are naturally very noticeable near the contacts with the country rocks, for in the centre of the ultrabasic mass hornblende comprises less than 10 per cent. of the rock, whereas within one hundred feet of the margins hornblende commonly makes up more than 40 per cent. of the rock.

The serpentinites could have represented the green schist metamorphic facies of Turner and Verhoogen (1951, p. 472). Chrysotile was unstable under the regional metamorphism, but chrysotile and magnetite must have been stable minerals during serpentization. There are

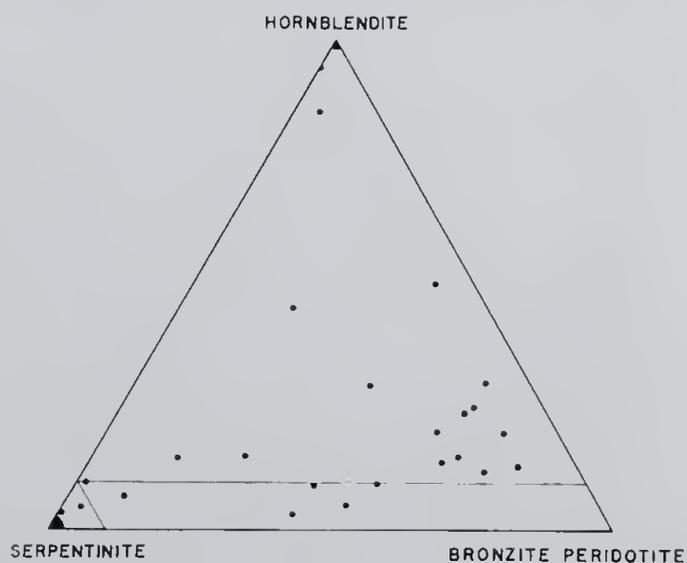
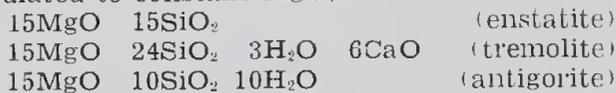


Fig. 5.—"Rock Facies" diagram.

certain reactions between chlorites and talc within this assemblage, but these are only adjustments of chemical compositions and not changes of mineral types.

All these assemblages are of the same parentage and the minerals of all of them may be found today, often within a single specimen. Therefore, while pressure and temperature conditions might have favoured various assemblages from time to time, only in certain localities were the reactions completed, and the equilibrium assemblages attained. To explain the reason for this failure, let each facies be represented by the characteristic mineral, say enstatite, tremolite, and antigorite. The formulae of these, calculated to constant MgO, are: —



From this it is apparent that there can be no change of assemblage without the requisite chemical conditions. Also, a rock of one bulk composition is not represented in another facies by a rock of the same bulk composition.

Lime, silica and water must have been available for the formation of hornblendites; similarly water was required for serpentinization. The details of these reactions are not understood, but the general trends are clear. Mention has been made above of the probability of regional metamorphism being responsible for the recrystallization of chrysotile to antigorite. If so, then the absence of lime has inhibited the formation of hornblende.

The relationship of serpentinization to regional metamorphism is shown by the interrelations of antigorite and hornblende. In some localities hornblende is partly serpentinized, while elsewhere it appears to have grown at the expense of antigorite. Thus, there is a confusing picture of penecontemporaneous serpentinization and regional metamorphism.

If the bronzite peridotite was intruded during regional metamorphism, abundant water included in the "magma" would cause serpentinization at temperatures below 500°C (Bowen and Tuttle 1949, p. 453). Introduction of lime at the margins could cause crystallization of tremolite, while at the same time excess silica from pegmatites would produce anthophyllite and talc bodies. All these reactions could run at temperatures of the order of 400°C to 500°C and changes of pressure would have had little effect on the mineral assemblages (Yoder 1952, p. 618). The remaining variable, the chemical environment, has been the most significant factor in determining the rock facies.

The existence of a partly open system, in which dominant water produced serpentinites and the presence of lime produced hornblendites, has been demonstrated. At the same time the degree of permeability of the system is expressed by the abundance of hornblende near the margins and its comparative rarity in some of the central parts of the body.

#### *Serpentinization*

Although the problem of serpentinization has not been studied in detail, the following observations are relevant.

The origin of the serpentinizing fluids is controversial, and in current literature there are three general theories. First, the fluids formed part of the magma; second, they were derived from adjacent rocks (i.e. connate water from sediments, or hydrous emanations from granites); third, they were of supergene origin. At Nunyle, the country rocks were already partly metamorphosed at the time of the intrusion, and were gneisses and pyroxene-bearing granulites. If the main period of metamorphism was after the intrusion, it is difficult to imagine how some of the country rocks were "upgraded" to hypersthene-bearing granulites, while only small amounts of tremolite were produced in the ultrabasic body. It is therefore considered that the bronzite peridotite was intruded into relatively anhydrous gneisses and pyroxene-bearing granulites, which could not have contained the water necessary for serpentinization.

Serpentinization must have occurred at considerable depth, as it preceded at least part of the regional metamorphism, thus eliminating the possibility of supergene serpentinization. The country rock could not have contributed sufficient water so the remaining possibility is that the fluids formed part of the "magma". Notwithstanding the work of Bowen and Tuttle (1949, pp. 439-460), the existence of a magma, which had the composition of the primary peridotite magma of Hess (1938) is indicated by field observations at Nunyle.

#### *Hydrothermal Activity and Late Veins*

The ultrabasic body has been considered in terms of three distinct rock facies, each of which is defined by a group of minerals. In this section the veins and minor activities within the body are considered.

The earliest vein found is the pyroxene-rich vein (cf. specimen 39727), in which occurs the last crystallization of anhydrous magnesian silicates. This vein is considered to have formed after the intrusion but before serpentinization, as the vein is not dislocated by the intrusion, and there is no relic antigorite included in the pyroxene. A suggested origin for veins of this type is given by Bowen and Tuttle (1949, p. 460). Water vapour saturated with SiO<sub>2</sub> moving through a fissure in dunite would convert the wall rocks to pyroxenite, producing, in effect, a dyke of pyroxenite cutting dunite.

The ultrabasic rocks were then serpentinized and metamorphosed. During the later stages of metamorphism they were intruded by pegmatites which gave rise to the minerals anthophyllite, talc and chlorite. The main chemical effect of the pegmatites was the addition of silica probably with minor quantities of alumina.

The pegmatites are clearly post-serpentinization. Magnetite grains, which must have originated during serpentinization, have been corroded by amphiboles which crystallized during the pegmatite intrusion. Later serpentinization was probably on a very reduced scale.

Antigorite and magnetite-clinochlore veins appear to have been approximately contemporaneous. They are probably the result of late adjustments of the solidified intrusion as is indicated

by the brecciated bronzite peridotite and the small displacements along magnetite-clinochlore veins. Regional metamorphism must have continued during the formation of these veins, though they are later than the main period of hornblende formation, and included amphibole usually shows some serpentinization.

Chrysotile veins are the youngest structures observed in the rocks, which accords with the observations of Wilkinson (1953, p. 309). They consist of cross-fibre chrysotile and are therefore more recent than the regional metamorphism. The majority of the narrower veins are uniform, but the wider ones may show variation in birefringence in zones parallel to the vein.

Anthophyllite-chlorite and anthophyllite-talc-chlorite veins are found in several localities. In each case there is a close field relationship with a dolerite dyke, and at 019240 the minerals talc and clinochlore occur in joints abutting an inch-thick dolerite. Since these veins are generally extremely thin and may be some distance from their parent dolerite, it is considered that the formation of anthophyllite, talc and chlorite must have occurred at relatively low temperatures. The minerals in the veins described here are characteristically anhedral and form only partial replacements of bronzite peridotite, whereas pegmatite activity generally altered the mineralogy extensively.

Calcium metasomatism related to the dolerite intrusion has converted some of the ultrabasic rocks to rodingites. This will be described below under the heading: The Rodingite Suite. No magnesite or chalcedony has been found in the area mapped.

### Evolution of the Ultrabasic Body

The history of the ultrabasic body is outlined in Table II. Certain age relations could not be determined; for instance the chrysotile veins are clearly later than the regional metamorphism but their inter-relations with the dolerite have not been observed. Similarly a number of substages in regional metamorphism cannot be placed with certainty in chronological order. Chrysotile could not persist during regional metamorphism, and thus the end of regional metamorphism is placed at the last appearance of antigorite.

### The Rodingite Suite

#### Petrography

Along the western edge of the ultrabasic mass, rocks are found composed of the minerals garnet, prehnite, clinozoisite, diopside and chlorite, which are the characteristic minerals of "rodingites". They are essentially lime-rich ultrabasic rocks and have the outstanding characteristic of light colour and relatively high specific gravity (c. 3.0-3.5). None of these rocks have been found in place or in solid outcrop and in two cases specimens were collected from stone heaps which had been made by farmers to facilitate cultivation. Therefore the locations given for specimens serve only to indicate their general positions. The apparent field distribution is along the contact of the ultrabasic mass with the gneisses; however, as the ground slopes upwards to the dolerite dyke only about 100 feet to the east rodingite boulders could have moved to their present positions from the

TABLE II  
Time sequence in the ultrabasic body

Stage	Product	Evidence of Relative Age
1. "Magma" genesis	dunitic "magma"	
2. Silicification of "magma"	bronzite porphyroblasts	Olivine is idiomorphic towards bronzite; platy orientation of bronzite shows it is pre-intrusion
3. Intrusion	lenticular mass of bronzite peridotite	transgressive contacts with country rocks
4. Further silicification of intrusion	pyroxene-rich veins	pyroxene vein would have been dislocated during intrusion, hence it is post intrusion
5. Serpentinization and regional metamorphism	mesh-textured chrysotile, and magnetite	initial serpentinization process
(Thermal metamorphism)	mesh-textured antigorite	probably contemporaneous with hornblende formation
(Hornblendization)	hornblende bronzite peridotite	
(Pegmatite intrusion)	talc anthophyllite and chlorite, also hornblendites	corroded magnetite grains indicate post-serpentinization
(Adjustments in consolidated bronzite-peridotite)	brecciated bronzite peridotite; antigorite and magnetite-clinochlore veins	hornblende occurs in the fragments, but not in the groundmass of the breccia; displacements along the veins have destroyed mesh texture
(Late serpentinization)	serpentinized hornblende	serpentine mineral appears to be antigoritic, therefore it was formed during regional metamorphism
6. Dolerite intrusion (hydrothermal activity and Ca metasomatism)	talc, anthophyllite and clinochlore; also rodingites	Dolerite intrusion was clearly post regional metamorphism
Late veining	chrysotile veins	persistent chrysotile probably post regional metamorphism

contact of the dolerite. Alternatively, the rodingites could have originated in the intervening ultrabasic material between the dolerite and the gneisses.

*Garnet rodingite*.—Specimen 39773 was found at 005108 in mixed float consisting of dolerite, pegmatite and weathered bronzite peridotite. No other rocks of this type have been found. The specimen is about 12" by 9" by 5"; at one end it is a uniform dark greenish rock of uneven hardness and from this it grades through a blotchy green, pink and white sugary rock to a dense, white, fine-grained "cherty" rock at the other end.

The dark greenish rock is composed of sub-round garnets in a chloritic groundmass. The garnet is in discrete colourless grains up to 3 mm in diameter, and in granular masses; it is weakly birefringent and makes up about 50% of the rock. Flakes of chlorite (pynochlorite) (approx. 40%) 0.5 mm by 0.1 mm fill most of the interstices between the grains of garnet. Irregular grains of diopside (approx. 10%) are distributed throughout the chloritic groundmass. Chromite is present as rare euhedra or irregular translucent brown grains up to 0.1 mm in diameter.

The blotchy green, pink and white sugary rock is similar but contains only about 20% of chlorite, the pink colour being due to iron stains. The "cherty" rock is a fine-grained mass of nearly pure garnet (grossularite). This mass of garnet is traversed by yellow veins of diopside up to 1 mm wide. Also in the cherty rock are rare dark brown grains of allanite. Deep red iron staining is common in radiating cracks surrounding the allanite grains. The garnet adjacent to the allanite is noticeably more birefringent than that elsewhere.

*Prehnite rodingite*.—Specimen 39774 was collected from a stone heap at 005106. It is dense, white, "cherty", and of uniform hardness. Prehnite with its inclusions constitutes more than 90% of the rock and occurs in three ways: first as subhedral crystals, averaging 0.7 mm by 0.4 mm with curved fractures and abundant minute inclusions of high refractive index; second as clearer equant grains with coarse sutured contacts, which are up to 0.3 mm in diameter, and are arranged in more or less continuous strings; third as apparently formless masses with mottled interference colours. Examination of this material in suitable immersion oils revealed fine grains, averaging 0.05 mm in diameter which have sutured contacts with a material of much higher refractive index. This material has  $n = 1.70$  approx. and is probably zoisite. The remainder of the rock is made up of subhedral diopside prisms averaging about 0.4 mm in length.

*Clinzoisite-diopside rodingite*.—Several boulders of the clinzoisite-diopside rodingite were found at the contact of the ultrabasic rocks with the country rocks at 015086. Specimen 39775 from this heap has a yellowish white groundmass enclosing sub-lenticular grey patches up to 3 mm in diameter. The groundmass consists of subhedral prisms of diopside up to 3 mm long,

which are altered to clinzoisite and epidote around the margins. The grey patches are crystals of clinzoisite, which are up to 3 mm long, have simple twins on 001 and on 100 and are strongly zoned. Associated with the clinzoisite are veins composed of fine equant granules of epidote in a chloritic groundmass. The veins are about 1 mm wide and comprise 5% of the rock.

*Diopside-prehnite rodingite*.—Specimen 39776 was collected from the creek bed 100 feet west and 2,300 feet north of the south-west corner of the area. It is mottled grey with black spots and is traversed by numerous sub-parallel veins, up to 5 mm wide, of transversely oriented actinolite. Examination of the thin section with the naked eye and comparison with thin sections of bronzite peridotite shows a remarkable similarity in texture. Bronzite porphyroblasts have been replaced by clear prehnite grains with zoisite inclusions and the antigoritic groundmass has been replaced by murky prehnite with abundant fine inclusions and anhedral prisms of diopside. The diopside is commonly altered to amphibole or chlorite. Unfortunately, none of the original minerals of the bronzite peridotite remain. The texture however is unmistakable. This particular rodingite is an altered bronzite peridotite.

#### Petrogenesis

The rodingite suite conforms to the chemical and mineralogical requirements of the rocks described by Marshall (1911, pp. 31-35), except in the presence of zoisite. The frequent occurrence of zoisite in rocks of this type was recognized by Grange (1927, p. 162).

In 1927 Grange reviewed the previous work on rodingites, and concluded that they were formed by the garnetization of gabbros. Grange considered that prehnite and grossularite were secondary after feldspar, but direct evidence that garnet formed after feldspar was not available; serpentinization of diallage was suggested as a source of lime and silica for these reactions.

Similar rocks have been described by various authors including Miles (1951) and Baker (1957).

The association of rodingites with ultrabasic rocks requires that ultrabasic rocks play an essential role in their formation. The present author considers that garnetization of gabbros is inadequate to explain the origin of the rodingites described here.

The rodingites from Nunyle show no relic gabbroic textures, but specimen 39776 has a texture derived from the bronzite peridotite, and specimen 39773 shows the association of garnet rodingite with a chloritic rock. These rocks are the result of alteration of ultrabasic rocks, and not of gabbros. Furthermore the serpentinization of calcic pyroxene cannot be invoked as a source of lime, since lime-rich minerals are not present in the bronzite peridotite.

The probable mode of formation of these rodingites therefore appears to be lime and alumina metasomatism of bronzite peridotites. Considering serpentine as the original mineral, the

constituents of the rodingite suite could be derived as follows:—

1.  $2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2$  (serpentine) +  $3\text{CaO} + 4\text{SiO}_2 = 3(\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2)$  (diopside) +  $2\text{H}_2\text{O}$ .
2.  $2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2$  (serpentine) +  $3\text{CaO} + \text{Al}_2\text{O}_3 + \text{SiO}_2 = 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$  (grossularite) +  $2\text{H}_2\text{O} + 3\text{MgO}$ .
3.  $2(2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2)$  (serpentine) +  $6\text{CaO} + 5\text{SiO}_2 + 3\text{Al}_2\text{O}_3 = 3(2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot \text{H}_2\text{O})$  (prehnite) +  $\text{H}_2\text{O} + 6\text{MgO}$ .
4.  $4(\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2)$  (diopside) +  $3\text{Al}_2\text{O}_3 + \text{H}_2\text{O} = 4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot \text{H}_2\text{O}$  (clinzoisite) +  $2\text{SiO}_2 + 4\text{MgO}$ .

The reactions involve addition of lime, silica, alumina and water, and the removal of water, magnesia and silica. The removed oxides could be represented by the actinolite veins in specimen 39776.

The equations 1, 2 and 4 appear to be petrographically sound. Equation 3 is not supported by the petrography and prehnite is more probably derived by means of a two-stage reaction with either intermediate diopside or grossularite. The formation of prehnite by the decomposition of grossularite was recognized by Marshall (1911, p. 34), though it is probable that the prehnite, which is pseudomorphous after bronzite, was formed in some other manner.

The source of the metasomatic fluids was certainly neither the ultrabasic rocks nor the pegmatites but probably the quartz dolerite dykes which contain abundant alumina and lime. However, there are two difficulties connected with such a source; first, hydrothermal action clearly connected with the dolerite has given rise to talc and anthophyllite; second, the later stages of dolerite intrusion were sodic rather than calcic. Nevertheless, the present author considers that this rodingite suite is the product of fluids derived from the dolerite dyke acting on the bronzite peridotite.

### The Country Rocks

#### Introduction

The country rocks in the area studied consist of gneisses, quartzites and basic granulites. There are not granite batholiths in the immediate vicinity, though in places the gneisses are intruded by narrow dioritic dykes, which are a few feet wide.

Gneisses make up most of the rocks in the district and vary from almost massive to strongly foliated and lineated. Half a mile to the east and west of the ultrabasic body the trends in the gneisses are remarkably uniform and the dip is steep to the east. To the south of the area the trends are disturbed by an east-west trending fault or shear zone along which the northern block appears to have moved east. Outcrops of gneiss are fair on the hill slopes and excellent in the creek beds.

The quartzites occupy a north-south strip of country which varies from 300 feet wide to 600 feet depending on the dip and other structural features. They are generally coarse-grained and in the north-west corner of the area, euhedral quartz crystals, up to 6" in length, are common. Foliation and lineation are well-developed in the quartzite except

where they are obscured by the very coarse grain-size. No cross-bedding, ripple marks or other primary sedimentary structures have been observed in the area. The quartzite probably had rather impure bands which gave rise to garnetiferous quartzite; this rock has only been seen on talus slopes and its stratigraphic location within the quartzite is unknown. Lenses or bands of basic granulites occur within the quartzite. Benches and belts of red soil traversing the quartzite indicate that these are common, but proof in the form of solid outcrops is seldom available. Outcrops of quartzite are good, constituting the highest features in the area.

The basic granulites appear as lenses and boudins in the gneiss and quartzite, and are generally of the order of 10 to 20 feet wide. Outcrops are only fair except in the creek beds, where boudin structures are well-developed and original beds may be traced as strings of discrete boudins. It is probable that the basic granulites occur everywhere as boudins and lenses, and no continuous bands remain, but the general paucity of outcrop of this rock type makes this uncertain. Foliation is not well-developed but lineation is evident on close examination in hand specimen. The basic granulites have been studied in detail as they are the best metamorphic facies indicators in the area.

#### Metamorphic Facies

Recognition of the grade of metamorphism is generally dependant on the presence of a diagnostic mineral assemblage and at Nunyle such assemblages are rare, so that no conclusion has been reached regarding the exact metamorphic grade of the country rocks at the time the bronzite peridotite was intruded. In the absence of diagnostic assemblages, a study of all the assemblages in the country rocks has indicated a definite trend in the metamorphism of the area.

Seven mineral assemblages occur in the country rocks:

1. Hypersthene-andesine-hornblende.
2. Diopside-andesine-hornblende.
3. Microcline-oligoclase-biotite-quartz.
4. Quartz-muscovite.
5. Oligoclase-hornblende-biotite.
6. Chlorite-muscovite-epidote-actinolite.
7. Saussurite-hornblende-quartz.

Of these, the first four evidently represent the metamorphic facies prior to the intrusion of the bronzite peridotite. Granoblastic textures, with little or no sign of corrosion occur in rocks containing these assemblages. Assemblages 3 and 4 have no diagnostic value, but 1 and 2 indicate high amphibolite or granulite facies. Abundant greenish yellow hornblende may be due to F- or (OH)- in the rock inhibiting the development of more than one type of pyroxene and so masking the exact facies assemblage.

Assemblage 5 has resulted from down-grading of 1 and 2. The hornblende is green containing small blebs of quartz and is characteristically coarser in grain-size than the greenish yellow hornblende in assemblages 1 and 2.

Assemblage 6 is of the lowest metamorphic grade and occurs only in a shear zone, which passes through 118063. The temperature had fallen before the shearing, so that the rocks within the zone have recorded the intensified retrogressive metamorphism.

Assemblage 7 has resulted from saussuritization adjacent to the dolerite dyke at 012233. A similar assemblage of hornblende-saussurite-chlorite is partly developed at 194063.

The highest metamorphic grade was attained some time before the intrusion of the bronzite peridotite, when all the basic rocks contained pyroxene. The temperature fell prior to the bronzite peridotite intrusion so that at the time of the intrusion, where there was differential movement and possibly the introduction of OH-, pyroxene-andesine-hornblende recrystallized to oligoclase-hornblende (which may represent low amphibolite facies). Shearing took place at still lower temperatures producing low grade rocks in restricted loci. Minor subsequent alteration has been caused throughout all the country rocks by fluids which accompanied the dolerite intrusion.

#### Petrogenesis

All of these rocks have been completely recrystallized, and, with the exception of bedding, no primary structures are preserved. The bulk composition has probably not altered greatly, except in the addition of alkalis to the gneiss.

The gneisses and quartzite are lineated, bedded and appear to be conformable.

The origin of the basic granulites has been clearly demonstrated by Prider (1944, p. 121), who described and analysed rocks similar to those at Nunyle. Originally these were tholeiitic flows or sills which recrystallized to form pyroxene-andesine-hornblende granulites, some of which were later altered to oligoclase-hornblende granulites. During this alteration there was no significant change in the bulk composition.

At Nunyle the alteration to oligoclase-hornblende granulites has only occurred in critical localities where there have been structural adjustments with attendant rock flowage.

#### Summary and Economic Considerations

The rocks at Nunyle consist of gneisses, quartzites and interbedded pyroxene-andesine-hornblende granulites, similar to those of the Jimperding "Series" described elsewhere. They have been developed by metamorphism accompanied by regional folding, of the original sandstones, sandy claystones and tholeiitic sills or flows.

After the main period of folding the bronzite peridotite was injected. During the intrusion, gneiss and basic granulites were mobilized in certain critical localities, with the result that some of the pyroxene-andesine-hornblende granulites were converted to oligoclase-hornblende granulites. At the same time there was further folding of the quartzite.

Intrusion of pegmatite dykes followed the consolidation of the bronzite peridotite. Emanations

from these produced talc, anthophyllite and clinocllore in the ultrabasic mass.

The rocks were subsequently intruded by dolerite dykes, which caused epidotization in the country rocks and minor hydrothermal alteration in the ultrabasic mass, and were probably also responsible for the formation of the rodingites.

The high Mg/Fe ratio and lack of associated gabbro place the Nunyle bronzite peridotite in the class of alpine type serpentinites. Alpine type serpentinites rarely carry metallic mineralization but may be favourable loci for chrysotile asbestos deposits. As only moderate thermal metamorphism will cause alteration of chrysotile to antigorite Archaean deposits are not likely to have survived. It would be interesting to know if the late chrysotile veins have formed as a result of continued serpentinization of high temperature silicates or by solution of antigorite and redeposition of chrysotile.

In the past by far the greatest production of chrysotile has come from rocks of post-Archaean age but there are significant producing mines situated within the shield areas. The ultrabasic mass at Nunyle is small and contains a very low percentage of chrysotile. Other serpentinites of similar age will certainly be found in the district as geological mapping proceeds and it is possible that one of these may prove to be of economic interest.

#### Acknowledgments

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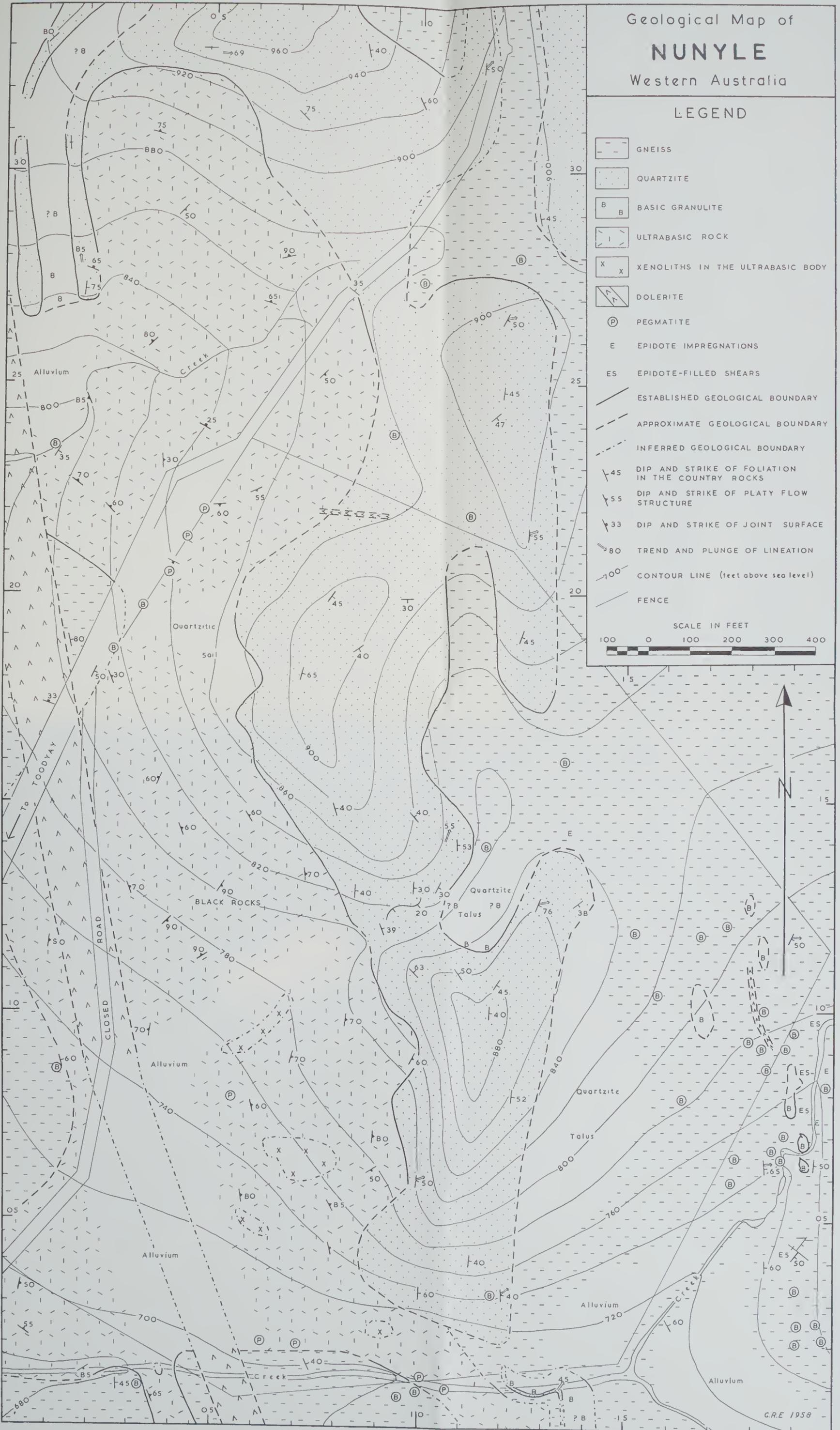
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Geological Map of  
**NUNYLE**  
 Western Australia

LEGEND

-  GNEISS
-  QUARTZITE
-  BASIC GRANULITE
-  ULTRABASIC ROCK
-  XENOLITHS IN THE ULTRABASIC BODY
-  DOLERITE
-  PEGMATITE
-  EPIDOTE IMPREGNATIONS
-  EPIDOTE-FILLED SHEARS
-  ESTABLISHED GEOLOGICAL BOUNDARY
-  APPROXIMATE GEOLOGICAL BOUNDARY
-  INFERRED GEOLOGICAL BOUNDARY
-  45 DIP AND STRIKE OF FOLIATION IN THE COUNTRY ROCKS
-  55 DIP AND STRIKE OF PLATY FLOW STRUCTURE
-  33 DIP AND STRIKE OF JOINT SURFACE
-  80 TREND AND PLUNGE OF LINEATION
-  100 CONTOUR LINE (feet above sea level)
-  FENCE





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## 5.—Homing Behaviour in the Quokka, *Setonix brachyurus* (Quoy and Gaimard) (Marsupialia)

By W. C. Packer\*

Manuscript received—16th October, 1962

Quokkas collected in the settlement area of Rottnest Island exhibit homing behaviour following translocation over distances of up to 1.75 miles, the maximum distance tested. Within familiar territory they are able to orient themselves rapidly and behave appropriately in relation to the physical character of the habitat but behave inappropriately in unknown areas. It is not clear, however, whether homing involves true orientation and navigation or a random-search technique. The area within the settlement in which any individual animal was recaptured was extremely variable in size but in most cases probably did not represent the complete home range.

### Introduction

Dunnet (1962) and other investigators (unpublished data) suggest that the quokka (*Setonix brachyurus*) is generally rather restricted in its movements, although this may vary considerably from population to population. Dunnet found that the animals have relatively restricted individual ranges on the eastern end of Rottnest Island but have been recaptured over distances of up to 2,000 yards from the original site of marking. He suggests, however, that those on the western end of the island are more restricted in their range (no more than 300 yards on the basis of limited data).

Following from these observations, the question arose as to whether or not the quokka possessed the ability to return to its home area if translocated from it. Associated with this is the question of the size of the individual ranges.

### Methods and Materials

Rottnest Island, 12 miles west of Perth, Western Australia, supports a large population of quokkas. There is a tourist resort at the eastern end of the island, and with the exception of one series (see below) all of the animals were taken from this settlement area. Although not typical quokka habitat in any sense, this area was chosen because the animals there are accustomed to people and can be approached closely. This allowed one to identify marked animals without the need for physically handling them subsequent to marking.

Each animal was marked in two ways. They were fitted with plastic collars which bore individually recognizable symbols of reflective tape (see Ealey and Dunnet 1956) which were easily distinguishable with the naked eye at distances of 10 to 20 feet. A numbered operculum tag (see Dunnet 1956) covered with red reflection tape, was fastened to the pinna of one ear. This greatly reduced the time spent in locating

marked animals since this marker was easily visible in the beam of a head-torch up to 100 feet and stood out clearly when the animal was facing directly toward or away from the observer at which times the collar was obscured.

In January and February, 1961 (mid-summer) four series of animals were collected in the southern end of the settlement and marked. The release points for these series, Bungalow No. 1 at the northern most end of the settlement, Herschell Lake, Lake Bagdad and Parakeet Swamp, are shown in Figure 1 and numbered, respectively 1 to 4. At the same time two additional series were marked but not translocated. One of these came from the southern end of the settlement and served as the control and the other was captured at the fresh-water soak on the north shore of Herschell Lake.

The settlement area was searched for marked animals about three times a week for six weeks and then at irregular intervals until the middle of May. All recaptures were visual sightings only, and all were recorded in order to obtain a measure of the individual ranges.

During January and February, environmental conditions are quite severe for the quokka. Over most of the island, fresh water is available only from soaks along the edges of the lakes. The lakes themselves are highly saline with a chlorinity of approximately 70 parts per thousand and in Bagdad and Herschell (Hodgkin 1959).



Fig. 1.—Map of eastern half of Rottnest Island, Western Australia, showing release points (1-4) of translocated quokkas.

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Most of the vegetation is dry also. The settlement area at this time is an "oasis" where leaking taps and friendly tourists keep the animals supplied with water and food. As a result, the animals here are never as poor physiologically as their "non-civilized" cousins (unpublished data).

In the event that the settlement was an exceptionally attractive area during the summer, so producing atypical homing results, a small series of animals was translocated from the settlement to the Lake Bagdad site in August, 1961 (mid-winter). At this time of the year fresh water is widely available, the vegetation is green and tourists are few. The control series consisted of animals marked the previous summer and seen in the settlement on the two evenings when the translocated series was collected. Because of other commitments on the mainland, the settlement was searched for marked animals only at irregular intervals over the next two months.

### Results

The number of animals marked in each series and the number and per cent. recaptured one or more times in the settlement area are shown in Table I. The per cent. of summer animals returning to the settlement decreased as distance of translocation increased, but there is no significant difference between the three closest points on the basis of a chi-square test. A significant decrease in the number making the return is found, however, in the group released at Parakeet Swamp when compared to the other sites ( $\chi^2 = 13.74$ , 1.d.f.). The proportion of the settlement control animals recaptured is somewhat greater than that of translocated animals from the three closest points but is not significantly different ( $\chi^2 = 2.87$ , 1.d.f.).

When the work was partially repeated during the winter the number of the translocated animals returning from the Bagdad site was significantly less than during the summer ( $\chi^2 = 3.95$ , 1.d.f.). While the control series was small, the results are comparable with the summer controls.

The non-translocated series marked at Herschell Lake requires special comment. These animals represent a nearby but relatively distinct population of quokka. Only one of this

series was ever seen in the settlement. Prior to this recapture this individual was observed in an intermediate location between Herschell Lake and the settlement but was never recaptured subsequently. Of the other 19 animals in the series, 12 were never recaptured except along the soak at which they had been collected originally; two were recaptured at Herschell and on the golf course which in part separates the lake from the settlement; and two were recaptured only on the golf course. Three were never recaptured.

The release points for the translocated series were checked on the two nights following release and at irregular intervals after that. No marked animals were seen except on the first night. Traverses by road over the north-east corner of the island were made as often as possible, but no marked animals were seen except at the rubbish dump (point D on Fig. 1) which at that time supported a large population of quokkas. These included one from Herschell, two from Bagdad and four from Parakeet. These animals were not seen on every occasion, but they were never recaptured subsequently in the settlement or elsewhere.

There was no significant difference between the sexes in the translocated series as to whether they homed or not ( $\chi^2 = 0.85$ , 1 d.f.), and there is no evidence to suggest that age was a factor either, although no animals less than 18-20 months old were tested.

The number of animals returning from Bagdad during the winter was significantly less than in the summer ( $\chi^2 = 3.95$ , with 1 d.f.), but whether this is because of more favourable environmental conditions during the winter is not clear. Except for the few summer animals that apparently established new ranges around the rubbish dump, none of the translocated animals who failed to return to the settlement were seen. It is not known whether they set up new ranges elsewhere or if they even survived.

A total of 419 recaptures of marked animals was made, comprising 176 of controls and 243 of translocated animals. The frequency of recapture ranged between 1 and 14 with a medium of 5.4. Although the area in which any one animal was recaptured probably does not represent its home range (see Discussion), nevertheless, certain measurements can be made utilizing the locations of recapture, i.e., area and proximity to marking site of subsequent recapture.

Area:—The site of original capture and of all recaptures for each animal was plotted, and the area enclosed within a polygon, formed by connecting the most peripheral of these points, was calculated. The size of the area thus obtained was extremely variable and ranged from approximately 3,900 to 178,000 square feet with a median of 26,300 square feet. The values were not normally distributed about the mean (c.41,700 square feet) but were skewed toward the low side. The relationship between area and number of recaptures was also extremely variable and ranged from 10 recaptures within an area of 5,400 square feet to three recaptures within 151,500 square feet. The minimum number of

TABLE I

Number of quokkas marked and recaptured and distance translocated.

Series	Distance from capture site	Number marked	Recapture 1 or more times in settlement	
			No.	%
Summer				
Bungalow I	0.33 mile	14	12	85.7
Herschell L.	0.67 mile	23	19	82.6
L. Bagdad	1.25 mile	25	19	76.0
Parakeet Swamp	1.75 mile	25	10	40.0
Settlement controls		32	30	93.8
Herschell controls		20	1	5.0
Winter				
L. Bagdad	1.25 mile	21	10	47.6
Controls		10	9	90.0

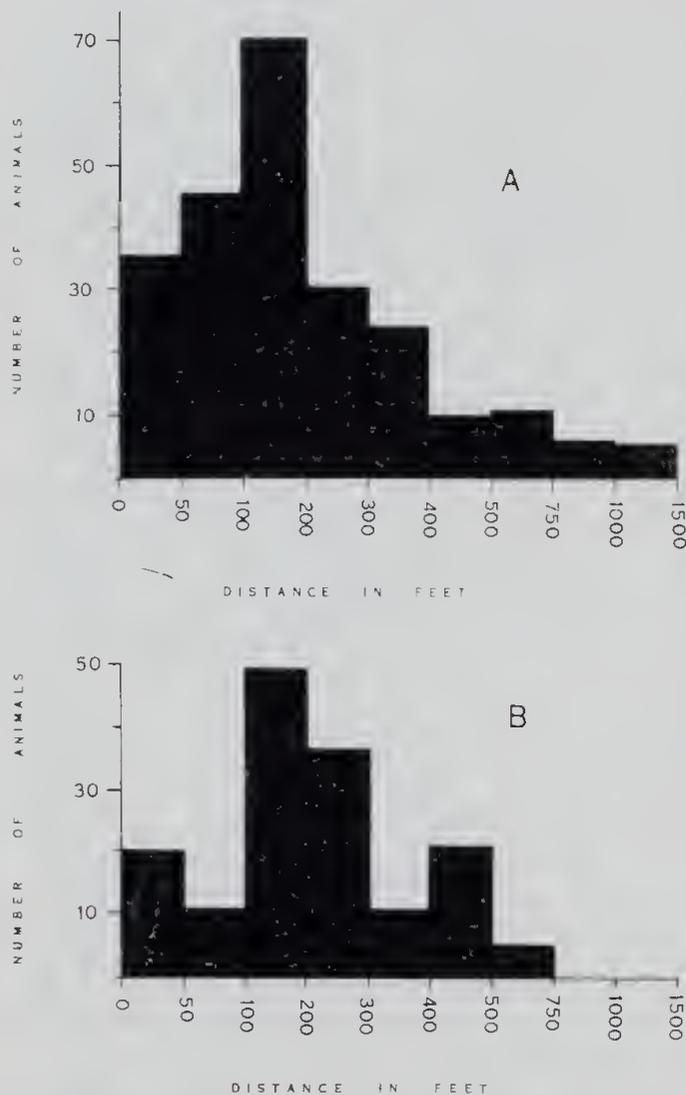


Fig. 2.—Distance of all recaptures from the site of marking of (A) summer translocated animals and (B) non-translocated summer animals; grouped for various distance classes.

recaptures required to establish the size of the range could not be determined from the data.

Proximity of recapture:—No true measure can be made of the precision of the return because of a lack of knowledge of the nature of the home range and of how to interpret the position of the original capture site. Nevertheless, it is interesting to note how close subsequent recaptures were made to the point of marking.

Figure 2 shows the frequency distribution of the distance between the site of original marking and all subsequent recaptures for the (A) summer translocated animals and (B) settlement controls. The distances are grouped within classes of varying magnitude. The shape of these curves varies somewhat with significantly more of the recaptures of the translocated series being made within 100 feet of the marking site than is the case with the non-translocated individuals ( $\chi^2 = 5.17, 1 \text{ d.f.}$ ). In both cases, however, the mode of the distribution is obtained when each of the four translocated series is plotted separately.

Figure 3 shows the frequencies of recapture at various distances for the first and for the closest recapture. The distribution of the distances of first recapture (Fig. 3 A and C) are somewhat different from each other, while those for the closest point (Fig. 3 B and D) are generally comparable. The reason for the greater disparity in the two graphs for the translocated animals can be traced to the fact that in almost one-half the cases (27 out of 60) the animals moved closer to the marking site subsequent to the first recapture. Only one-third (10 out of 30) of the controls made a comparable move. However, the first recapture point in control animals was generally closer to the marking site than with the translocated animals. Even so, the number of non-translocated animals first recaptured within 100 feet of the marking site was not significantly greater than among the translocated animals ( $\chi^2 = 0.90, 1 \text{ d.f.}$ ).

One further comparison is worthy of note. The area in which the winter controls were recaptured overlapped the area in which these same animals were found during the summer in eight of the nine cases; and in the one which did not overlap, the two areas were separated only by about 100 feet. This would suggest that there is no change in location, at least in this portion of the home range, between summer and winter. The winter areas were

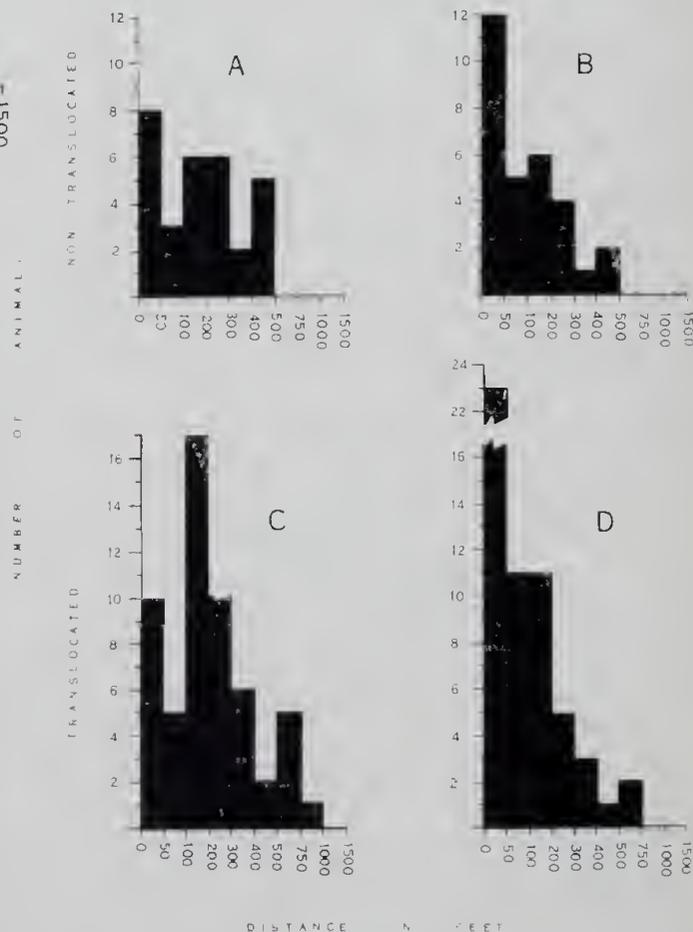


Fig. 3.—Frequency distribution of the distance between the site of marking and the 1st recapture point (A & C) and the closest recapture point (B & D) for translocated and non-translocated animals in the summer.

generally small, but this may have been a function of fewer recaptures over a shorter period of time.

### Discussion

These results clearly demonstrate the existence of homing behaviour in the quokka. Whether this is achieved through true orientation and navigation or by some random-search technique is not known. Regardless, it must be extremely efficient judging not only by the per cent. of recovery but also by the speed with which it is performed. Among the animals translocated to Bungalow No. 1 and to Herschell Lake, one from each series had returned within 24 hours. By the fifth night after release twelve had returned from Herschell and animals translocated to Bagdad during the summer were recaptured three days after release. No accurate measure can be made for return from Parakeet Swamp or from Bagdad during the winter because it was not possible to continue the survey daily; however, five animals from Parakeet (one-half the total) were recaptured the eleventh night after release and four from Bagdad (almost one-half) were recaptured on the sixth night after release.

The possibility that some of the animals may have visited the release point in the course of excursions away from the settlement cannot be disregarded. On the basis of Dunnet's (1962) observations, animals from the southern part of the settlement could range as far as the two closest release points. All that can be said here on this point is that no control animal from the settlement was ever seen at either of these two points, and only one animal marked at Herschell Lake was ever seen in the settlement. It is unfortunate that this latter individual was never recaptured again.

Although homing in this species may not involve navigation, a series of unplanned observations in the course of this work clearly suggests that the quokka is able to orient itself rapidly within its home area and to respond appropriately. The fresh water soak at which animals were collected for the non-translocated series at Herschell runs for about 200 yards along the edge of the lake. During the summer the level of the lake is reduced, and the shore is 20 to 50 feet wide. Behind this rises a wall of Pleistocene dune limestone which shows a bench and notch configuration resulting from fluctuation of sea-level during geologically recent times; this is figured by Teichert (1950) for one of the other lakes. The animals move freely over this cliff on pathways.

The animals in this non-translocated series were collected, placed in bags, taken to the settlement, marked and then returned to the shore of the lake and released. Upon release most of them appeared to be in an excited state and rapidly moved off up or down the beach or up the cliff-face. On the other hand, some of the translocated animals released at Herschell, although handled in the same way, responded quite differently. When released on the shore, they too moved off rapidly; but if they happened to be heading toward the water, they just kept going, regardless. They could be

followed in the water in the beam of a head-torch for at least 100 feet. This behaviour was never observed in the control series; and the quokka has never been observed to enter the salt lakes except very rarely when chased by man, although they frequently waded in one or two inches of water around the edges of the fresh-water swamps during the winter. The morning following release, three dead animals (not included in Table I) were found washed up on the shore.

Arising from these observations, an attempt was made to see if the quokka could and would orient within a restricted area. For this purpose an octagonal enclosure 150 feet in diameter was built. The terrain was such that the only visible landmark was the lighthouse which is situated on the highest point in the centre of the island. Single animals were released by remote control in the centre of the area and were captured in traps situated at the eight angles. All tests were run on clear, moonless nights and involved animals captured in different directions from the enclosure and at various distances up to two miles. As can be seen in Figure 4a, the animals were captured at random around the enclosure in relation to the home direction. In a series of preliminary experiments, the animals responded negatively in relation to the observer, but after modification of the apparatus this no longer occurred (Figure 4b).

Although the number of animals tested was relatively small, there is nothing to suggest that under the conditions of the experiment additional animals would have changed the results. Animals taken from one-quarter mile away were no better in their orientation than those from the settlement two miles away. This is somewhat unexpected, since the near-by individuals were from an area from which animals are known to move to the site of the enclosure. Those animals might be expected to be familiar with the area and, therefore, to return to the home area by the most direct route. While these results do not support an hypothesis involving true orientation and navigation as a factor in homing, it is probably too early to say that the mechanism involves only random-search. Different techniques will be required to differentiate the two.

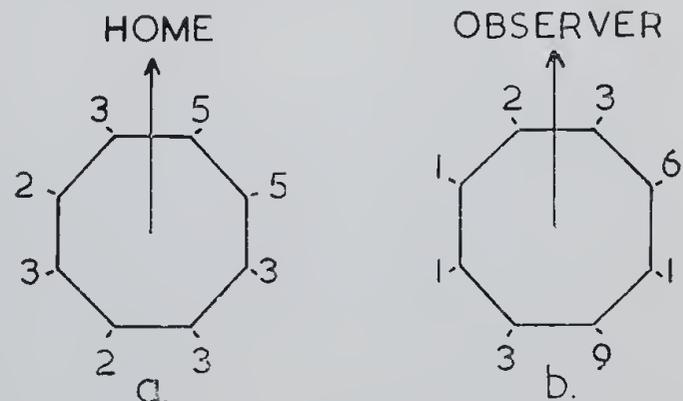


Fig. 4.—Position of recapture within an enclosure in relation to (a) the home area and (b) the observer.

An interpretation of the individual areas within the settlement in which recaptures were made is difficult to make. The method used in determining the size of these areas was essentially the minimum area method used by several authors (reviewed by Brown, 1962), although in the present work the points represent visual sightings, not trap captures; and, therefore, the matter of boundary strips does not arise.

The area certainly does not correspond to the home range, at least as that term is applied by Burt (1943). Many of the smaller areas, particularly those in which ten or more recaptures were made, are open, grassy plots providing no diurnal shelter. In these cases the animals probably spend the day either in the near-by scrub or else under a building from which they emerge at night to occupy a small range in which they feed and possibly mate. On the basis of the present data, it is suggested that this is the general situation for this species, although the size of the area will vary with the individual. Excursions of various lengths with various frequencies may occur, perhaps influenced at the present site by the activities of tourists. A discussion of the relationship between excursions and the home range concept is beyond the scope of this paper.

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**Journal**  
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Vol. 46

Part 2

6.—Studies in the Diagenesis of Some Western Australian Sedimentary  
Rocks

Presidential Address, 1962

By J. E. Glover, B.Sc., Ph.D.\*

*Delivered—16th July, 1962.*

Textures arising from diagenesis in some Western Australian sedimentary rocks are described, and particular emphasis is placed on determination of the order in which the diagenetic minerals have been developed. Rocks studied in detail include specimens from the Clark Sandstone, Septimus Limestone, Cockatoo Sandstone, Birdrong Formation, Arrowsmith Sandstone, Enokurra Sandstone and Mokadine Formation, and many others are described briefly.

As recommended by Gilbert and Turner (1949) the universal stage has been used to clarify relationships between adjacent authigenic minerals, and to obtain optical and morphological data. It has enabled fairly detailed investigation of some optical properties of K-feldspars in the Clark Sandstone, Mokadine Formation and Arrowsmith Sandstone. The stage is particularly useful for the study of textures in which relatively hard and soft minerals are adjacent, for example quartz and calcite or feldspar and barite. Such mineral pairs are commonly separated by faces of one of the minerals, and these faces, which can be recognized and determined rather easily with the stage, are often otherwise overlooked.

An attempt has been made to summarize the main causes of diagenesis, and to categorize resultant textures according to their origin. Some textures do not conclusively demonstrate the order of formation of the authigenic minerals, but many do, and the latter are almost as useful petrologically in sedimentary rocks as standard or well-known textures are in igneous and metamorphic rocks. The diagenetic textures are divided into (a) enlargement textures, which include simple enlargement textures, indentation textures and enclosure textures, (b) pressure-solution textures, (c) micro-drusy textures, which include simple and composite micro-drusy textures, (d) reorganization textures and, (e) replacement textures.

Reference is made to much of the literature on sedimentary petrology in Western Australia.

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**Introduction**

The study of sedimentary rocks in thin section has received increasing attention during the last fifteen or twenty years. Contrary to earlier practice, general petrographic texts now tend to allot sedimentary rocks as much space as igneous and metamorphic rocks, and several

new texts devoted entirely to the petrology of sedimentary rocks have appeared. This is not to say that sedimentary petrology has reached the position of igneous and metamorphic petrology, in which perhaps most advances in our understanding of petrogenesis come from attempts to duplicate in the laboratory conditions under which the rocks and their constituent minerals form. Thus, although increasing attention is being paid to synthesis of minerals common in sediments, and to their response to various physico-chemical conditions, there is still scope for much petrogenetic inference from microscopic studies of the naturally occurring sedimentary rocks.\*

One of the most rewarding avenues for such studies is in the investigation of the minerals and textures arising from diagenesis. A surprisingly complex diagenetic sequence may be unravelled by detailed examination of a rock whose petrogenesis is at first apparently simple.

#### *Use of the Term Diagenesis*

Diagenesis has been variously defined. According to Pettijohn (1957, p. 648) the term refers primarily to reactions which take place within a sediment between one mineral and another, or between one or several minerals and interstitial or supernatant fluids. Most authors agree that diagenesis is a low-temperature phenomenon that grades with increase in temperature, into metamorphism. In this paper diagenesis will be divided into early and late diagenesis, though no attempt will be made to define their limits precisely.

Siever's discussion of early diagenesis seems the most satisfactory. Siever (1962, p. 140) considers early diagenesis to include that stage in the history of a sediment during which it is buried only up to a few tens of feet. It is bacterially active, is not greatly compacted, has high porosity and water content, may be moderately permeable, and is subject to the upward passage of waters from compacting sediments below.

Changes attributed to late diagenesis may persist until weathering of the exposed rock: in fact the processes of diagenesis and weathering, though distinguished by many authors, must be gradational.

There is much petrographic evidence for the reality of the distinction between early and late diagenesis, but two examples will suffice here. Calcareous concretions that preserve fishes (see Weeks 1957) are obviously of early origin. On the other hand Topkaya (1950) describes Jurassic conglomerates from Arvel in Switzerland which are free of authigenic silicates despite the fact that they have been partly derived from Triassic formations now exceptionally rich in them. This is evidence of late diagenesis, for the authigenic minerals could have formed only after the erosion of the Triassic rocks.

\* It is strange that sedimentary petrology should have lagged behind igneous and metamorphic petrology. The first rock to be examined in thin section with a microscope and polarized light was a sediment (Sorby 1851), and Sorby later published widely on sedimentary petrology, maintaining an interest for many years in such contemporary sedimentological problems as dolomitization and the formation of aragonite (Sorby 1904).

One of the main problems has been to decide when diagenesis becomes metamorphism. It has been suggested by Packham and Crook (1960, p. 404) that retention of the original clastic fabric of the rock would indicate that it had been subjected only to diagenesis, whereas extensive modification, involving substitution of hornfelsic or schistose fabrics, would demonstrate metamorphism. There is no difficulty in distinguishing diagenesis from metamorphism in most of the rocks discussed below. Some of them, as indicated later, have been intruded by dolerite. Apart from that, none has been metamorphosed in the sense of having been heated by intrusions, strongly folded or generally sheared; nor are any adjacent to later igneous bodies that might have metasomatized them. Further details about their age, location and tectonic setting can be obtained from McWhae *et al.* (1958).

#### *Aims of the Investigation*

The purpose of this paper is to show how texture may demonstrate the order in which diagenetic processes have taken place, and how it can reveal some of the causes of those processes. This has been done before, notably by Gilbert (1949) and Gilbert and Turner (1949), and comprehensive reviews of the literature on diagenesis have been given by Pettijohn (1957) and Carozzi (1960). Although the techniques used here are similar to those of Gilbert and Turner, there are several reasons, stated immediately below, why presentation of the results of this study is warranted. Firstly, reference is made to all known papers dealing with diagenesis in Western Australian rocks. Secondly petrographic descriptions of some of the sedimentary rocks treated here have not previously appeared in the rather sparse Western Australian literature. Thirdly, some of the textures are different from those described elsewhere. Finally, an attempt is made to group the various diagenetic textures with similar origins into categories, so that their petrologic interpretation is thereby facilitated.

### **The Universal Stage in Sedimentary Petrology**

#### *General Advantages*

Gilbert and Turner point out that the universal stage is particularly valuable in the microscopic investigation of sedimentary rocks, and state that it is essential in a modern sedimentary laboratory. They use the stage to determine the optical properties of the minerals, and the crystalline faces developed, and to observe the three-dimensional interrelationships of the minerals. Faces are identified tentatively by noting their relationship to optical directions within the crystal, and their identity is confirmed by measuring angles between the faces and comparing them with published data, notably those in Dana (1899). Gilbert and Turner note, as was found in the present investigation, that appropriate tilt on the stage reveals crystalline faces quite unsuspected following routine microscopic examination of authigenic minerals. They recommend the Federow procedure in which all measured directions and

planes are plotted on a stereographic or equal-area projection net. Details of procedures are clearly set forth by them, and will not be repeated here.

#### Detection of Crystal Faces

Where the boundary between two authigenic minerals is planar, the plane is commonly a face of one of the minerals. The fact that a boundary is planar can only be seen if the plane is essentially parallel to the microscope axis: if it is oblique the boundary does not appear sharp and is represented by a narrow band in which the two minerals, perhaps with very different optical properties, overlap. Moreover, unless both minerals have a similar resistance to abrasion, irregularities due to grinding can cause an inclined planar boundary to appear uneven. This effect, which is common with such mineral pairs as quartz and barite, quartz and calcite, and quartz and dolomite, is illustrated in Fig. 1, and Plate I, Figs. 1 and 2. The only reliable way to establish the planar nature of boundaries between such minerals and hence to discover crystal faces is by tilting until the plane is parallel to the microscope axis.

#### Examination of Replacement Textures

Where carbonate cement completely encloses quartz grains it commonly penetrates their margins and partly replaces the quartz. On the other hand, the margins of well-rounded grains that have undergone no replacement may show apparent irregularities for reasons indicated in the previous paragraph and these irregularities may suggest marginal replacement. Appropriate tilt, revealing smooth, rounded margins devoid of re-entrants, prevents misinterpretation.

#### Diagenetic Minerals and Textures

Textures resulting from diagenesis are considered below, the constituent minerals are described, and the order of their formation is discussed. Certain diagenetic textures are commonly associated with particular lithologies, and some textures are virtually restricted to one lithologic type. For this reason, the nature of the textures is illustrated by describing the mineral relationships commonly encountered in some of the main types of sedimentary rock. Discussion of the ultimate cause of diagenetic growth and solution of minerals is however left to a later section of this paper.



Fig. 1.—Diagrammatic sketch of unmounted thin section of quartz-barite rock. Quartz (stippled) and barite (cleaved) meet in a plane. However, grinding has lowered the level of the softer barite with respect to quartz, and has plucked out cleavages, forming rough valleys. The quartz-barite boundary, viewed from above, appears highly uneven. The planar nature of the contact will be evident only if the section is tilted so that the plane is parallel, or almost parallel, to the microscope axis.

#### Feldspathic and Arkosic Sandstones

**Clark Sandstone.**—The Clark Sandstone (Traves 1955) of the Carlton Basin, in north-eastern Western Australia, is a highly fossiliferous, reddish or green, glauconitic, Cambrian sandstone. It is faulted but not strongly folded, and it is not intruded by later igneous rocks. The preservation of abundant brachiopods and trilobites, and much unaltered glauconite, shows that the remarkable outgrowths on quartz and feldspar observed in this study must be ascribed to diagenesis rather than metamorphism.

The specimen examined (No. 48629\*, from the Clark Jump Up, on the Carlton-Legune track, about 35 miles east of Wyndham) is a weakly lithified, porous, well-sorted, medium-grained sandstone with the following composition (by volume): quartz 63%, glauconite 16%, K-feldspar 9%, rock fragments (fine-grained quartzite, mica schist, chert) 6%, muscovite < 1%, and a red, mainly haematitic, matrix 6%. Most quartz and feldspar grains, before enlargement, were somewhat rounded, and some were well rounded.

Almost every quartz and feldspar grain has been enlarged, and where there has been space quartz has developed prisms and rhombohedra, and feldspar has developed prisms and basal and side pinacoids. Glauconite, generally regarded as a product of early marine diagenesis, is present as ovoid pellets. The authigenic quartz and feldspar formed after the glauconite, as shown by the way in which they are moulded on glauconite grains upon which they impinged during growth. Many quartz and feldspar grains are therefore partly bounded by crystal faces, and partly by rounded concave surfaces where they abut the glauconite. Some of the glauconite grains have yielded by gliding on micro-faults within the pellets, apparently because of squeezing and fracturing by the force of the growing quartz and feldspar (Plate I, figs. 3 and 4). This indicates that the authigenic quartz and feldspar formed after at least moderate compaction of the sandstone, for in an unconsolidated sand the glauconite pellets would have been moved aside rather than broken.

The cores of the K-feldspar grains are adularia ( $2V_a$  from  $57\frac{1}{2}^\circ$  to  $68^\circ$ ) or microcline (except for one unusual grain with a composite core of adularia and microcline). Cleavage can commonly be seen passing without break or change of direction, from both types of core to the authigenic rim, but any twinning in the core is sharply truncated at its boundary with the rim (Plate I, Figs. 5 and 6). The 001, 010 and 110 cleavages and faces were identified by measuring the angles between their normals and X, Y and Z, and comparing them with Nikitin's data (see Gilbert and Turner 1949, Table IV). These measurements, which were made with the universal stage, also served to confirm the identity of the core, for they enable distinction between untwinned microcline and adularia.

The authigenic rims have remarkable optical properties, but due to their narrowness, numerous inclusions and patchy extinction, precise

\* Numbers refer to the General Collection of the Department of Geology, University of Western Australia.

measurements are possible only on selected grains. Patchy extinction is not accompanied by obvious bending or distortion of cleavage. The angles between the principal optical directions and the normal to 010 and 001 correspond approximately with those quoted by Nikitin for orthoclase. This correspondence can clearly not be everywhere precise in rims with patchy extinction, for the patchiness is caused by variations of up to 6° in the principal optical directions. Thus Z commonly departs by several degrees from the normal to 010 and the rims are not everywhere monoclinic. Moreover, there is generally a variation of 2V within the one rim. The maximum variation observed within one rim is from 11° to 45.5°, and the overall range is from 11° to 64° (see Table I). This range of 2V in K-feldspar would thus include the minerals, as sometimes defined, adularia (2V<sub>a</sub> = 50° - 70°), orthoclase (2V<sub>a</sub> = 25° - 50°), and sanidine (2V<sub>a</sub> = 0° - 25°, optic plane ⊥ 010) [see Chaisson (1950) for the optical classification used here]. No grains whose optical plane is parallel to 010 (i.e. "high" sanidine) were observed.

All of the authigenic feldspar described above came from one hand specimen 2 in. x 2 in. x 1 in., and the considerable range in 2V between different grains, and within individual grains, is puzzling. Variations in the optical properties of potassic feldspars are said to depend upon (1) compositional differences, (2) submicroscopic intergrowths due to unmixing, and (3) degree of Si/Al order (see Hewlett 1959). Neither the composition of intrastratal solutions at any given time, which influences the composition of the feldspar precipitated, nor the cooling history of the feldspar, which affects the degree of unmixing, and of Si/Al order, can have varied much. This suggests the influence of other, highly localized factors. Differences between the clastic cores, which are seed crystals, could cause precipitation of slightly different material on each. Perhaps slight compositional differences within one core could cause or even accentuate, differences in material precipitated in different parts of the one rim. The shape and volume of the intergranular pores may have affected the rate of passage of solutions in a significant way. This, however, is speculation; no reason can confidently be advanced, at present, for the variations in 2V between different authigenic rims, and within individual rims. No explanation is offered, either, for the remarkably low values of some readings (see Table I).

*Mokadine Formation.*—The Mokadine Formation, of probable Proterozoic age, crops out on the eastern margin of the Perth Basin near Moora. It is a sequence of arkose, feldspathic sandstone, siltstone, and claystone that has been intruded by dolerite dykes. Authigenic growths on detrital quartz grains are mentioned by Logan and Chase (1961) in their brief description of the petrography of the formation. The specimen described in this investigation (No. 36909, collected from just above the type section of the underlying Dalaroo Siltstone) is a brown, strongly lithified, moderately well-sorted, fine-to-medium-grained arkose and it does not appear to have been altered by dolerite intru-

sions, the nearest exposed dyke being ¼-mile distant. It has the following composition (by volume): quartz 65%, K-feldspar 25%, opaque iron-ore grains, largely changed to haematite, 8%, and interstitial haematite and limonite, 2%. The quartz includes a few fine-grained quartzite grains. The K-feldspar includes microcline and adularia (2V<sub>a</sub> down to 58°), and ranges from clear fresh grains to grains that have been completely converted to grey and yellow-brown clay minerals. The interstitial iron oxide is present mainly as a film that outlines the clastic grains, which range from sub-angular to very well rounded.

TABLE I

*Variations in the optic axial angles of authigenic feldspar in the Clark Sandstone. Values greater than 25° are reproducible to within 1°, and values less than 25° are reproducible to within 2°.*

Clastic Core	2V <sub>a</sub> of authigenic rim
Microcline	17°
Microcline (2V <sub>a</sub> = 80°)	47°, 37½°
Adularia (2V <sub>a</sub> = 68°)	24°, 22½°
Microcline (2V <sub>a</sub> = 82½°)	64°
Adularia (2V <sub>a</sub> = 61°)	45½°, 43°, 24°, 11°
Microcline	41°, 18°
Microcline intergrown with adularia (2V <sub>a</sub> = 57½°)	43½°, 41½°
Microcline	25½°

Almost all quartz and many K-feldspar grains have been authigenically enlarged. Secondary quartz is abundant, forming about 5% of the rock, and secondary K-feldspar makes up perhaps 0.5%. The following points are significant:

1. A few clastic quartz grains penetrate each other to give minor and poorly developed microstylolitic intergrowths. Quartz grains commonly penetrate feldspar grains by as much as 0.025 mm without development of microstylolitic boundaries, and the feldspar has apparently undergone almost all the solution in such pairs (see Plate II, Fig. 1). Much less frequently a fairly sharp-cornered feldspar grain slightly penetrates the flattish surface of a quartz grain, showing that initial shape and perhaps crystallographic orientation influence the final relationship of the two minerals. Feldspar grains are also penetrated by each other. No clastic grains have been penetrated by authigenic outgrowths, so compaction preceded authigenesis, which was a late diagenetic feature. The volume of secondary material is far greater than that available from local solution by clastic grains at their point of contact, and most of it must have come from elsewhere.

2. Boundaries between quartz outgrowths are either irregular, or roughly planar, but the planes generally do not seem to correspond to common rational faces of either grain. Outgrowths of quartz and feldspar meet in boundaries that occasionally correspond to the 001 face of the feldspar, but are more often approximate planes that are not rational faces of either grain. These relationships may mean that times

of growth of the minerals overlapped (see Gilbert and Turner 1949, p. 13).

3. Each feldspar growth is kaolinized to about the same degree as its clastic core. This shows that most kaolinization occurred after formation of the authigenic rims, so that the clastic feldspars were practically unaltered when deposited. Kaolinization has apparently lowered the optic axial angle of some grains, for some readings on clastic microcline cores are as low as  $72^\circ$ , about  $10^\circ$  lower than those normally quoted for the mineral. As the rims are also altered, their range in  $2V_a$  from  $68^\circ$  to  $77^\circ$  gives no reliable indication of their nature.

4. Many authigenic rims on microcline grains have uneven extinction, apparently a vague continuation of the crosshatching (albite and pericline twins) of the core. It has been suggested that crosshatching indicates inversion from an earlier, high-temperature monoclinic form (Laves 1950), and the fact that authigenic (low-temperature) microcline described by Baskin (1956) does not show crosshatching, seems to accord with this view. Baskin's grains show no clastic cores and have a type of fourling twin, and their unusual morphology may well result from cold formation. On the other hand the poorly developed extension of crosshatching from clastic cores to rims in microcline of the Mokadine Formation does not necessarily mean that they grew at high temperature. These rims seem to have their structure determined by that of the core rather than by temperature of formation, for they are crystallographically continuous with the adjacent part of the core. The same effect is observed with strained quartz grains, whose rims show wavy extinction continuous with that of the adjacent quartz, and with plagioclase, the twinning of which extends from the core into the rim (see Plate II, Fig 4). The vague extension of crosshatching noticed here therefore probably has no significance in terms of temperature. However, if the type of crosshatching just described is not an indication of high temperature formation, it is strange that it is not more common.

It is not known whether authigenic quartz and feldspar replaced an earlier mineral cement, or whether they grew in voids between the grains. Logan and Chase (1961) found specks of undigested calcite in the authigenic quartz cement of arkoses in the Mokadine Formation examined by them, but no calcite could be detected in this rock. The only incorporated materials are the iron oxide coatings outlining the clastic grains.

*Arrowsmith Sandstone.*—The Arrowsmith Sandstone is an unfossiliferous, lower Palaeozoic or Proterozoic formation exposed in the north-eastern part of the Perth Basin near Arrino. All specimens so far examined by the author are well-sorted, medium-to coarse-grained arkoses, and many of them contain almost as much lithic material as feldspar, and therefore they nearly grade into lithic sandstones. The lithic fragments include sericite-quartz schist, composite quartz-feldspar grains, and myrmekite, but the most abundant are volcanic fragments. A previous account of the petrography (Glover 1960b) drew attention to

authigenic quartz and chlorite, but re-examination with the universal stage has revealed a complex diagenetic sequence.

Specimen Pf2\* is an arkose with the following composition (by volume): quartz 40%, feldspar 27%, volcanic fragments 13%, other lithic fragments 13%, authigenic cement 6%, other minerals 1%. The grains are angular to well rounded, and there is slight pressure-solution on some boundaries of adjacent grains, causing penetration of one by the other, generally without discernible micro-stylolitic intergrowth.

Almost all clastic grains are covered by a thin brown film that generally appears as a very faint stain on the grain surface. This film is only 0.002 mm thick in cross section, and is composed of one, or in places, two or three layers or flakes of a brown mineral with fairly high relief. The mineral is pleochroic from red-brown to yellow, with absorption greatest when the flakes are elongated parallel to the polarizer, but it is too thin for other optical properties to be measured or even clearly observed. The mineral seems most closely allied to brown mica, and it may represent the transformation product of a thin argillaceous coating on the sand grains. It has disappeared locally where pressure-solution has caused slight interpenetration of clastic grains.

Other authigenic minerals beside the brown, mica-like mineral, are quartz, pale green almost isotropic chlorite, and feldspar. The feldspar is untwinned, with relief less than quartz, and usually has patchy extinction.  $2V_a$  ranges between  $43^\circ$  and  $55^\circ$  with an average of  $50^\circ$  (10 grains) and typical measurements of the angles between X, Y and Z and the pole of the main cleavage are as follows (the corresponding angles between 001 and X, Y and Z for orthoclase, as given by Nikitin, are quoted in brackets):

$$X \wedge \perp \text{ cleavage} = 81.5^\circ (85^\circ).$$

$$Y \wedge \perp \text{ cleavage} = 9^\circ (5^\circ).$$

$$Z \wedge \perp \text{ cleavage} = 88.5^\circ (90^\circ).$$

The feldspar is close to the orthoclase-adularia boundary, according to the classification of Chaisson (1950). It is uncertain whether the differences between the optical measurements given above and those of orthoclase taken from Nikitin are due to experimental errors arising from the smallness of the grains and their uneven extinction, or whether there is a slight departure from monoclinic optics.

The authigenic minerals listed occupy the spaces between clastic grains, and examples of the resultant diagenetic textures are illustrated below. Plate II, Fig. 2, shows one of the simplest arrangements. The minerals lining the void are a brown, mica-like mineral on the surfaces of the clastic grains, chlorite which has a serrated fringe toward the centre of the void as though it had grown inward, and feldspar in the centre. This texture would not arise from replacement of an earlier cement, but is consistent with precipitation in an empty pore space. As with similar drusy textures, which form by precipitation from fluids in cavities, the first-formed mineral must be the outermost, and the last-

\* Specimen number assigned by West Australian Petroleum Pty., Ltd.

formed the innermost. In the texture illustrated in Plate II, Fig. 2, the brown, mica-like mineral formed first, the chlorite second, and the feldspar last. Some of the intergranular microdrusy textures are more complex, and there have been minor variations in the order of formation of the minerals: nevertheless, the basic pattern is the same, and the brown mica-like mineral is always the first, with chlorite either second or third.

In some places there is a similar texture in which quartz is substituted for feldspar. In the texture illustrated in Plate II, Fig. 3, quartz forms both before chlorite and after it. The most complex texture is shown in Fig. 6b, where quartz forms before chlorite and both quartz and feldspar form after it. The last-formed quartz has perfectly developed prism faces and, as the mineral was growing into a void, it must have formed before the feldspar. The order of development in this texture was therefore (1) brown mica-like mineral, (2) quartz, (3) chlorite, (4) quartz, (5) feldspar.

Elsewhere in the Arrowsmith Sandstone similar textures, but with development of slightly different minerals, are encountered. The composition of the chlorite changes, and its colour and birefringence vary perceptibly. The texture shown in Plate II, Fig. 4, is notable, for it shows how albite twinning of plagioclase [determined by the curves set forth by Turner (1947) as  $An_3$ ] persists into outgrowths. The original clastic grain is outlined by the brown micaceous mineral.

Any reasonable conjecture regarding the origin of the diagenetic textures in the Arrowsmith Sandstone must seek to account for the presence together of up to four minerals in the spaces between the clastic grains, and should explain their sequence and arrangement. The following hypothesis appears to satisfy these conditions. A well-sorted sand, with most of the mud winnowed out to deeper water, is assumed to have compacted to a porous sandstone. Slight pressure-solution causing minor penetration of clastic grains accompanied this compaction, or was brought about by later earth movement. The thin film adhering to the grains was dissolved at their points of contact: it is not clear when this mineral, probably originally argillaceous, was changed to the brown mica-like mineral that now coats the grains. In any case, in one form or another, it must have preceded the diagenetic chlorite, quartz and feldspar, which were precipitated from percolating waters. These waters, which varied in composition both in time and place, were magnesian, potassic, sodic and siliceous, and all the solutes would have been available within the formation itself, as it contains volcanic fragments, microcline, orthoclase, sodic plagioclase and quartz. Precipitation could have taken place at any time after compaction of the sediment in the late Proterozoic or early Palaeozoic. It is conceivable that equilibrium between the fluid and surrounding rock was established several times, only to be disturbed by flowage of the interstitial fluids caused by earth movements. If so, processes leading to attainment of the final texture might have persisted even for millions

of years. It might indeed be speculated whether future techniques will allow absolute dating of authigenic minerals in such textures. The dates obtained could well apply to tectonic events, such as folding or uplift, that brought about the disequilibrium mentioned above.

*Enokurra Sandstone.*—The Enokurra Sandstone is an unfossiliferous Proterozoic or lower Palaeozoic formation exposed in the north-eastern part of the Perth Basin, near Yandanooka. It consists of fine- to very coarse-grained sandstone which is locally conglomeratic, and shows well-developed cross-bedding. It has been described previously by McWhae *et al.* (1958), Glover (1960b) and Bastian (1961).

The specimen investigated here (No. 38725, from 3 miles northeast of Yandanooka) is a coarse-grained arkose with the following approximate composition (by volume): quartz 67%, feldspar (microcline and oligoclase) 15%, lithic fragments (mainly gneiss) 14%, other minerals (muscovite, garnet, opaque grains, clay-sized material, (?) limonite, haematite) 4%. The clastic grains are outlined by a patchy coating of haematite. Cementation has been effected partly by muscovite and patches of sericitic to clay-sized material, and partly by secondary quartz. The secondary quartz fills many of the spaces between the clastic grains, and is usually in optical continuity with one or more of the visible quartz grains. In places, outgrowths from several grains meet in more or less planar surfaces, but none have so far been identified as rational crystal faces. Also present in these areas of authigenic quartz is a fringe of colourless to very pale-green sericite ( $2V_a = 38^\circ$ ) adhering to the brown, iron-stained clastic grain surfaces. The fringe, which is made up of minute flakes at right angles to the grain surfaces, is commonly difficult to observe, even under crossed nicols, for the interference colours of the minute flakes are hard to distinguish from those of the surrounding authigenic quartz (see Plate II, Fig 5).

The texture here is basically the same as that observed in the Arrowsmith Sandstone, and could have arisen only by precipitation in voids between grains. A few of the clastic grains penetrate each other, and some of the contacts are micro-stylolitic. Even if quartz dissolved at the points of contact of these grains were deposited nearby in voids, in the manner envisaged by Waldschmidt (1941), there would have been insufficient available from that source to account for all the secondary quartz in the rock. Moreover, some other source for the sericite would be necessary. Precipitation from potassic and siliceous solutions percolating through the porous rocks was the probable cause of this diagenetic texture.

#### Quartz Sandstones

One of the most common types of diagenesis is the enlargement of quartz grains, especially in well-sorted quartz sandstones such as some from the Birdrong Formation, Cockatoo Sandstone and Wogatti Sandstone. Diagenetic enlargement of quartz is also common in feldspathic sandstones from the Clark Sandstone, Mokadine Formation, Arrowsmith Sandstone, and Enokurra Sandstone, discussed earlier in

this paper. Petrologic descriptions of sandstones in the Billeranga Beds, Wenmillia Formation and Moora Group that contain abundant secondary quartz have been given by Arriens and Lalor (1959), Ranford and Shaw (1960) and Logan and Chase (1961) respectively. More petrographic work will undoubtedly confirm the widespread nature of authigenic quartz in unmetamorphosed Western Australian sandstones: for example recent petrographic descriptions of sediments from the Canning Basin by Johnson and Dallwitz (*in* Veevers and Wells 1961) mention it in the Noonkanbah Formation, Grant Formation, Godfrey Beds and Kidson Beds. Solution of quartz is also an important process in sedimentary rocks, but in sandstones it is most usually found where there is an abundant calcareous, ferruginous or argillaceous matrix or cement. The dissolved quartz is almost always replaced by the cementing material. However, solution processes and their resultant textures are considered elsewhere (p. 44 *et seq.*).

The sandstone illustrated in Fig. 2 shows the type of texture that results from enlargement of quartz grains in a well-sorted quartz sandstone, where the growth does not fill the pore spaces between grains. This sandstone is from the Cretaceous Birdrong Formation in the western part of the Carnarvon Basin. The original rounded shapes of many grains have been outlined, apparently by a coating of the same argillaceous material that now partly occupies the pores. Some of the grains are in direct contact with each other, but there seems to have been no pressure-solution, and the secondary quartz must come from another source. Boundaries between secondary quartz outgrowths in adjacent grains are planar, and all measured planes are prisms or rhombohedra of one or the other of the grains.

Relationships between the grains are worth studying, for the light they may throw on the process of crystallization in a porous sandstone. For example, in Fig. 2 the contacts between grain A and grains D and B are a rhombohedron and a prism respectively of grain A, indicating that growth on these faces had been completed before the quartz of grains D and B grew out to meet them. Similarly, grain D finished growing before grain C along their common boundary, and grain C in turn finished before grain B. Thus the sequence, beginning with the first to complete its growth, is A, D, C, and B. The position in this sequence of grain E is unknown, except that it finished crystallization before adjacent parts of grain C. The sequence inferred above does not imply that individual grains accomplished all their growth one after the other, during separate and distinct intervals of time. Their growth almost certainly overlapped, as the rock was sufficiently porous to allow fluids to percolate widely.

An example of quartz sandstone in which silicification has almost completely filled spaces between the grains is specimen 48624 from the Devonian Cockatoo Sandstone of the Bonaparte Gulf Basin. The formation is made up mainly of cross-bedded sandstones, and specimen 48624 comes from Cockatoo Springs, about 65 miles

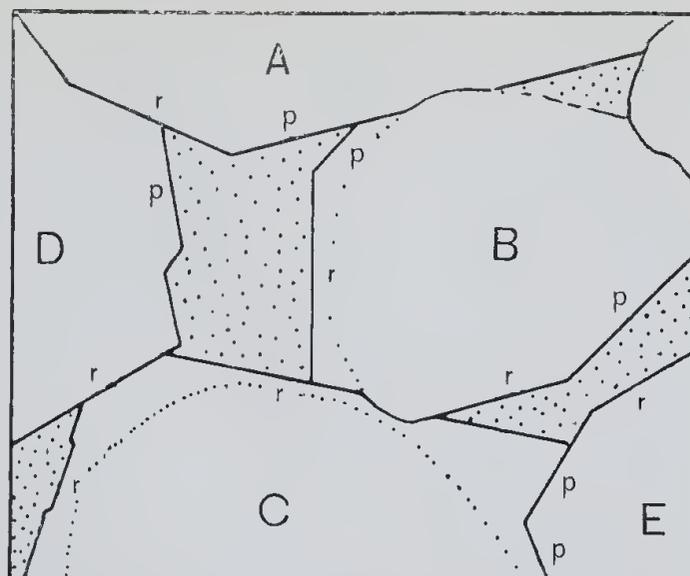


Fig. 2.—Authigenic enlargement of quartz in sandstone from the Birdrong Formation (Rough Range Bore No. 1, core 7, 3,633-3,636 ft). The stippled areas are partly filled with clay-sized material. Quartz crystal faces are indicated by p (prism) and r (rhombohedron). The sketch is slightly idealized to show faces clearly. Width of field 0.6 mm.

east-south-east of Wyndham. It is made up of rounded quartz grains with a haematite coating (85%), authigenic cement (11%) and other minerals including microcline and adularia with authigenic outgrowths, quartzite fragments, green tourmaline, muscovite, and kaolinized composite grains. Numerous planar boundaries can be identified as common faces of quartz, but other boundaries are not strictly planar; of the latter some almost correspond to rational faces, but many cannot be identified. Some apparently irregular or curved faces appear to be made up of many very small planes. This texture is apparently that which would have developed in sandstones of the Birdrong Formation, had silicification proceeded to the point where most outgrowths interfered with each other. The tendency for the development of some rational crystallographic faces, despite mutual interference, has also been observed in sandstones studied elsewhere (Basumallick 1962).

Most authigenic outgrowths on the rare K-feldspars have developed faces, among which 001, 010, 110 and 130 have been identified. Some of the feldspar outgrowths abut the clastic cores of the quartz grains, and have been moulded by them. This is the same as the texture illustrated in Fig. 5e, and is proof that the authigenic feldspar preceded the authigenic quartz in this rock.

#### *Calcareous and Dolomitic Rocks*

Many clastic limestones are mineralogically and texturally simple. On the other hand, numerous calcareous and dolomitic rocks, ranging from calcareous or dolomitic quartz sandstones to limestone, contain complex suites of diagenetic minerals, of which the most usual are pyrite, glauconite, quartz, opal, chalcedony, albite, orthoclase, microcline, calcite and dolomite. The order of formation of these minerals may often be established by their textural re-

relationships. Some textures, and thus some corresponding sequences of formation, appear to be more usual than others. The reason for the common presence of authigenic siliceous minerals in carbonate rocks has been debated for a long time, but satisfactory explanations are only now being advanced. Textures from Western Australian calcareous and dolomitic rocks will now be considered.

*Clastic Limestones.*—Our understanding of the genesis of clastic limestones has increased greatly in the last ten years, particularly with the research into the formation of Recent limestones on the Bahama Banks by Illing (1954), and later workers. The classification of Folk (1959) incorporates much of the new information on the significance of textures in these rocks. The only published petrologic work on Western Australian calcarenites (Glover 1955) deals in introductory fashion with Devonian rocks from the Lennard Shelf, Canning Basin, but was done before the results of Illing's work were known. Devonian clastic limestones of the Canning Basin, because of their abundance, strong outcrop, and lack of metamorphism, would be especially suitable for the type of detailed quantitative petrographic investigation carried out by Stauffer (1962). Moreover, they are associated with well-exposed reefs and in places provide excellent examples of dolomitization for study.

Two clastic limestones are illustrated here to show textures arising from partial cementation of a calcarenite from the Pleistocene Coastal Limestone at Shark Bay (Plate III, Fig. 1) and complete cementation of an oolite from the Devonian of the Lennard Shelf (Plate III, Fig. 2). Both textures are formed by precipitation of calcite from solutions in voids, and can readily be distinguished from textures due to recrystallization of a fine matrix (Fig. 6e).

*Dolomitic Quartz Sandstone.*—Specimen 43799 is from the Palaeozoic sequence in the Bonaparte Gulf Basin and is a fine-grained, silicified, dolomitic quartz sandstone containing quartz (88%), dolomite (10%), pyrite (2%), and traces of other minerals (zircon, tourmaline, black iron-ore, and microcline). The

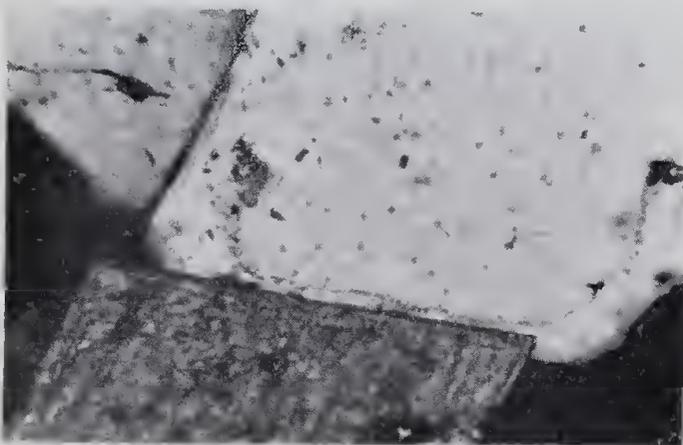


Fig. 3.—Indentation texture in dolomitic quartz sandstone (No. 43799). Dolomite is partly surrounded by authigenic quartz. The clastic core of the quartz grain is clearly shown. This texture does not reveal whether the dolomite or quartz grew first. Crossed nicols. Width of field 0.25 mm.



Fig. 4.—Indentation texture in dolomitic quartz sandstone (No. 43799) showing special case where dolomite is partly surrounded by authigenic quartz, but has been moulded onto the clastic core. Dolomite grew before the authigenic quartz. Crossed nicols. Width of field 0.25 mm.

clastic quartz grains are fairly well sorted and generally well rounded, and the sandstone is undoubtedly a mature, multicycle sediment. There are three authigenic minerals; pyrite, dolomite and quartz. Pyrite is present mainly as irregularly shaped grains with scattered cubic and octahedral forms, and as rare, minute spherical grains. Small pyrite grains are included in some dolomite rhombs and secondary quartz, and pyritic films partly outline the cores of some of the secondarily enlarged quartz grains. Pyrite therefore preceded both minerals. Many small dolomite rhombs are completely enclosed by secondary quartz, but it is notable that dolomite never penetrates the detrital quartz cores. Where enclosed dolomite impinges against detrital quartz, the shape of the contact is governed entirely by the shape of the original quartz grain (see Figs 4, 5e and 5f). The relationships conclusively show that dolomite grew before authigenic quartz. Therefore the order of formation of the diagenetic minerals is: pyrite first, dolomite second and quartz third. A remarkable feature of some dolomite boundaries is that they are parallel to the margins of clastic grains, but are separated from them by a thin film of authigenic quartz. This shows that some dolomite grains have been slightly replaced by the last-formed mineral, quartz.

*Septimus Limestone.*—Textures that are fairly widespread in Western Australian Palaeozoic limestones are found in a calcareous sandy dolomitic rock from the Carboniferous Septimus Limestone in the Bonaparte Gulf Basin. The rock studied (No. 36879, from the foot of Mt. Septimus on the northern side) is slightly weathered and is made up mainly of sparry calcite (6%), quartz (40%), and dolomite (53%). The dolomite has a striking appearance as it contains large, brown, opaque limonitic

zones which represent the light-grey zones of clay-sized impurities found in unweathered rocks of the formation (Plate III, Fig. 3). Brachiopod and crinoid fragments are abundant elsewhere in the formation but are sparse in this specimen. Many of the quartz grains were initially well rounded but are now angular from enlargement. The environment of deposition seems to have been neritic, and there are three diagenetic changes of importance; namely formation of the zoned dolomite, formation of the sparry calcite, and growth of the quartz.

Zoned dolomite crystals have been recorded elsewhere by numerous workers, including Gilbert (*in* Williams, Turner and Gilbert 1954, pp. 350-351), Pettijohn (1957, pp. 422-3) and Taft (1961). The last-named author describes dolomite, probably forming at present near the sediment-water interface in Florida, which contains dark cores apparently of organic matter. It does not therefore seem necessary to postulate two periods of growth to account for the dark and clear zones in dolomite of the Septimus Limestone, for by analogy with the Florida dolomite the mineral is most likely to have formed in a marl or impure calcilutite matrix, the impurities of which were arranged to form the dark zones. The patches of sparry calcite certainly represent a recrystallized matrix for they are too large to have been precipitated in pores between clastic crystals, and furthermore, they do not have the micro-drusy texture characteristic of calcite precipitated in pores. Non-calcareous material must therefore have been expelled during recrystallization. There is other evidence to support the view that the dark zones of the dolomite are impurities derived from a matrix which has since recrystallized and expelled non-calcareous material. Dolomite crystals that replace clay-sized matrices rarely have a preferred orientation, whereas dolomite that replaces calcite crystals, such as crinoid fragments, generally adopts the same crystallographic orientation as the replaced calcite crystal. In this rock numbers of differently oriented, zoned dolomite crystals are found in the one sparry calcite crystal, indicating replacement of a fine matrix before its recrystallization (see Plate III, Fig. 3).

Dolomite formed before the quartz outgrowths, for although it is commonly partly surrounded by secondary quartz, it never penetrates clastic quartz grains when it abuts them. However, the relationship between the dolomite and quartz is more complex than indicated, for the secondary quartz has partly replaced some dolomite, leaving irregular boundaries between them, but has not attacked other dolomite, so that their boundaries are planar. All planar boundaries between secondary quartz and dolomite are dolomite faces. On the other hand, all planes developed between quartz and calcite are quartz faces. This suggests, but does not prove, that the secondary quartz grew after the dolomite but before transformation of the matrix to sparry calcite.

It is worth noting that where adjacent calcite and dolomite are replaced by the same quartz outgrowth, the quartz commonly penetrates more deeply into the calcite than into the clear marginal parts of the dolomite crystal. This,

and the fact that some dolomite is enclosed but not replaced by quartz, indicates that it was less prone to replacement by quartz than the calcitic matrix.

The diagenetic history of the rock, as tentatively deduced from its textures, can now be summarized. The original sediment is believed to have been a shelly and sandy impure calcareous mud (or marl.) The first mineral to form was dolomite, which partly replaced the matrix, perhaps before significant consolidation, and arranged included non-calcareous material in zones. Then the quartz grains were enlarged, the secondary quartz partly surrounding dolomite crystals and partly replacing them, but evidently replacing the adjacent calcitic matrix more easily. Finally, perhaps because of the pressure of compaction, the remaining matrix was converted to coarse crystalline calcite, and impurities were dissolved and squeezed out.

*Miscellaneous Silicified Limestones.*—A detailed description of a partly silicified limestone, the Sakmarian Woolaga Limestone Member of the Holmwood Shale, in the Irwin River Basin, has been given by G. Playford (1958, pp. 53-62). Playford describes a diagenetic sequence that includes intrastratal solution (producing vugs), reorganization of calcite, and finally, partial replacement by chalcedony.

The best known sedimentary sequence in Western Australia whose lithology is ascribed to silicification of limestone is that of the Coomberdale Chert, a formation over 3,300 feet thick within the Moora Group. The chert has been described by Logan and Chase (1961) as a novaculite made up of microcrystalline quartz, with only rare chalcedony. They cite considerable evidence to support their theory of replacement, including the observed transition of dolomitic limestone to chert, the presence of siliceous fossils and oolites believed to have been originally calcareous, relict carbonate inclusions in the chert, siliceous rhombs apparently after dolomite, and quartz overgrowths on detrital quartz in some clastic members. Some of the original limestone is silicified only along joints, showing that the process occurred after lithification.

Many American and European limestones and dolomites yield, on solution, residues of fine-grained, euhedral authigenic quartz and feldspar, generally without recognizable clastic cores. Mere cataloguing of the literature on these minerals, which were the first to be recognized as authigenic, would unduly lengthen this paper, but most early references are in Boswell (1933). Authigenic quartz, feldspar and tourmaline have been recorded from dolomite in the Gap Creek Formation (Glover 1955, p. 3) but generally there has been little attempt at extraction of such residues from other Western Australian limestones.

#### *De-silicated Rocks*

The replacement of carbonate minerals by various forms of silica is not a one-way process, and it is probably at least as usual for carbonate to replace silica. Penetration of rounded quartz grains by the calcareous matrix of sandstones is an unmistakable and rather common

indication of this type of replacement (Plate III, Fig. 4) and it is not unusual for the corroding calcite to form deep re-entrants or even to split the quartz grain in two. In Western Australia, clear examples of these replacement textures are found in parts of the Pleistocene Coastal Limestone [see Glover *in* Ride *et al.* (1962, p. 23); and Hodgson *in* Hodgson *et al.* (1962)]. Hodgson has also described rocks from the Cheyne Bay area in which quartz grains are corroded by opal, limonite and goethite, and he suggests that these minerals replaced a calcilutite matrix that was initially responsible for the corrosion. Although the formation of iron oxide cements may generally be a function of weathering rather than diagenesis, if it causes quartz to dissolve and be available for later precipitation perhaps at considerable depth, it clearly has diagenetic significance. Many ferruginous sandstones in Western Australia contain corroded quartz grains, as for example those described by McLellan (*in* Brien and McLellan 1962) from the Cockleshell Gully sandstone, but there has not been enough work to justify generalization about the role of the ferruginous cement.

#### *Miscellaneous Diagenetic Minerals and Textures*

**Glaucouite.**—The mineral glaucouite, a product of early marine diagenesis, which has been mentioned in the discussion of the Clark Sandstone, has been recorded from the following Western Australian units: Clark Sandstone (Cambrian); Emanuel Formation, Pander Greensand (Ordovician); Blina Shale (Triassic); Langey Siltstone, Callawa Formation (Jurassic); Birdrong Formation, Muderong Shale, Windalia Radiolarite, Alinga Formation, Toolonga Calcilutite, Pcepingee Greensand, Molecap Greensand, Gingin Chalk, Poison Hill Greensand, South Perth Formation, Madura Shale (Cretaceous); Boongerooda Greensand, Wadera Calcarenite (Palaeocene); Jubilee Calcarenite, Giralia Calcarenite, Osborne Formation, Plantagenet Beds (Eocene). Glaucouite is present in other formations, and the known number of occurrences will probably increase with further drilling. Veevers and Wells (1961 p. 146) point out that glaucouite is found in practically all subsurface occurrences of Mesozoic finer grained rocks in the Canning Basin, and its absence in outcrops is almost certainly due to removal by weathering. Hodgson (1962) has discussed the origin of the glaucouite in the Plantagenet Beds at Cheyne Bay and concludes that much of it has been derived from mica.

**Phosphatic Minerals.**—Phosphatic nodules have been recorded from several Western Australian units, namely Bogadi Greywacke (Permian); Colalura Sandstone, Bringo Shale (Jurassic); Molecap Greensand, Poison Hill Greensand (Cretaceous). The phosphatic nodules in the Colalura Sandstone and Bringo Shale have been described by P. E. Playford (1959) who considers that they grew before burial in the sediment, possibly by growth from coprolitic cores. Fossil wood replaced by collophane occurs in the Colalura Sandstone.

The best known phosphate deposits are near Dandaragan in the Molecap Greensand, where

calcium phosphate (collophane) nodules are also associated with phosphatized wood. Other phosphatic minerals present in places in the matrix, and apparently derived from collophane, are dufrenite, vivianite, beraunite, wavellite and minylite (Matheson 1948). Matheson believed that the phosphatic material was initially dissolved from organic remains and deposited as collophane nodules during sedimentation and for some time after, before consolidation of the sediments.

A pale to dark-brown mineral that replaces shell fragments in the Pleistocene Coastal Limestone was tentatively identified as collophane by Hodgson (*in* Hodgson *et al.* 1962), and its identification has been confirmed by chemical tests (Hodgson, personal communication). The mineral is very widely but sparsely distributed in the formation, and has been seen by the present author from Shark Bay and Rottnest Island, generally comprising less than one per cent. of the rock. It is possible that during the Pleistocene there were numerous widely scattered and short-lived pockets of very high organic activity, in which the shells became phosphatized. The eustatic fluctuations of the Pleistocene would have depleted populations of these localized environments only to allow them to become strongly established elsewhere. The phosphatized shells would be incorporated in the repeatedly reworked terrigenous and organogenic detritus, and thus attain their present wide but sparse distribution.

**Gearksutite.**—The rare mineral gearksutite, a hydrous fluoride of aluminium and calcium, has been described from a phosphatic layer near the base of the Cretaceous Poison Hill Greensand, about two miles east of Gingin, by Simpson (1920). He ascribes its formation to growth *in situ*, from interaction between solutions of the nearby minerals fluorapatite (present as nodules) and gibbsite (a constituent of overlying laterite). The reaction postulated by Simpson seems to be on the borderline of late diagenesis and weathering.

**Jarosite.**—The secondary mineral jarosite has been noted by Prider (1943, p. 39) in the Precambrian Cardup Shale and by Clarke *et al.* (1951) in Permian formations of the Irwin River area. The latter authors believed that euxenic conditions led to formation of pyrite or marcasite, from which the jarosite was later developed. This view accords with the origin suggested for jarosite in Mexico by Pough (1941), and in Yorkshire by Hartley (1957). As with gearksutite, its formation is due to either late diagenesis or weathering, depending on arbitrary definition.

**Tourmaline.**—Many quartz sandstones contain rare but widely distributed grains of clastic tourmaline showing authigenic outgrowths. Clarke *et al.* (1954, p. 20) have described authigenic elbaite on rounded schorlite grains from quartzites of the Precambrian Mt. Barren Group, but it should be noted that these rocks have been metamorphosed. Prider (1943, p. 41) has described tourmaline euhedra from the Precambrian Cardup Shale, but again there is doubt

about their origin, and they may be metasomatic.

**Concretions.**—Concretions, mainly calcite and limonite, are common in many Western Australian sediments, but they have generally not been the subject of detailed studies. Calcareous and sideritic concretions from the Learmonth Formation, Carnarvon Basin, have been described, and evidence for their formation before much compaction of the rock has been cited (Glover 1960a). Barite concretions are known from the Wogatti Sandstone and Gearle Siltstone of the Carnarvon Basin. The varied concretions in sedimentary rocks of the Irwin River area have been suggested as a subject of research by Clarke *et al.* (1951, p. 47).

**Kaolinite.**—Crystalline kaolinite, apparently of authigenic origin, is found in sandy claystone of the Wagina Sandstone, 13 miles east-northeast of Mingenew. The specimen examined with the universal stage consists of a clay mineral (80%), angular quartz grains (18%), opaque material (2%) and muscovite and biotite (<1%). The clay mineral, which was shown to be kaolinite by differential thermal analysis, is present in two forms. Most of the clay consists of a brown paste, but scattered through it are pale-brown, anhedral to subhedral crystals about 0.3 mm long. These crystals have uneven extinction, and their main cleavage is generally parallel to the bedding, but some are bent and have a vermicular form. A few grains, when cut parallel to their cleavage, show pseudo-hexagonal habit due to lines of minute inclusions arranged at 60° (Plate III, Fig. 5).  $2V_{\alpha}$  ranges from 7° to 40° (20 readings), and most values are between 15° and 30°, a little lower than those generally quoted for the mineral.

Kaolinite is too soft to survive transport as large crystals, and these must have grown in the sedimentary rock. Post-compactional growth due to percolation of solutions can be ruled out, as the rock is impervious. The grains therefore probably grew before compaction, or during compaction as fluids were squeezed out.

**Allophanoids.**—A white, isotropic, tubercose mineral, probably an allophanoid, has been recorded by Prider (1948, pp. 112-113) as an authigenic constituent in the finer grades of the ferruginous sandstones of probable late Mesozoic age at Ridge Hill.

### Outstanding Causes of Diagenesis

#### *Reactions Near the Sediment-water Interface*

It is generally accepted that much glauconite and collophane have formed by reactions on or just below the sediment-water interface, and the evidence has been summarized in Carozzi (1960) and other recent texts. This origin accords well with the appearance of the glauconite and collophane seen in this investigation, and with their relationship to other minerals. Pyrite is another mineral that is commonly of early diagenetic origin, and it is found in many rocks containing glauconite and collophane. It has long been suspected that much of the pyrite of black organic shales has been precipitated by sulphate-reducing bacteria, and the process has been described recently for sediments on the

McMurdo Sound region of Antarctica by Barghoorn and Nichols (1961). Love (1958) believed that residues left after solution in nitric acid of framboidal pyrite from the Lower Carboniferous Oil Shale of Scotland, were the remains of such bacteria. The present writer obtained similar residues from the Jurassic Learmonth Formation of Western Australia, but described them as remains of organic fragments including spores, which were etched and frayed (but not much compressed) during pyritization. The spores and other organic fragments were thought to have provided micro-environments of putrefaction in which the pyrite grew by bacterial action (Glover 1960a).

Pyrite, as minute spherical and subspherical grains and as crystals (commonly cubes and octahedra) often occupies the cells of wood fragments, and has evidently formed before compaction of the wood. It is found in some calcareous and sideritic concretions that also contain virtually uncompressed fossils and must themselves have formed early. It is frequently included in dolomite rhombs and in quartz outgrowths, clear evidence that it formed before them. In ancient sediments, therefore, pyrite is often demonstrably one of the first products of diagenesis, and its common association with organic detritus accords with bacterial origin in a reducing environment.

Ricour (1960) has drawn attention to the possibility of bacterial origin for dolomite, and that mineral is certainly the first diagenetic product to have formed after pyrite in the Western Australian sediments examined, and it could therefore have grown in reducing muds. There is no doubt that dolomite has formed before the sparry calcite matrix of some limestone (see the description of Septimus Limestone), but its origin warrants fuller comment, and will be considered later.

Limestones commonly contain authigenic quartz and feldspar euhedra (that is, completely authigenic grains as distinct from the secondary outgrowths on elastic cores found in many sandstones), and many early workers attributed them to growth in the original calcareous mud. There are generally no significant clues to indicate whether growth was early or late. However, there are rare records of authigenic feldspars in shales and siltstones (Gruner and Thiel 1937) and it is hard to see how these feldspars could have formed after lithification, for the rocks would presumably have been impervious to solutions that might have precipitated them.

Much of the literature on diagenesis, particularly early diagenesis, assumes that it is promoted or assisted by the presence of organic matter. Sujkowski (1958, p. 2694) emphasized this view in his discussion of the agents of diagenesis and stated "Water is the main agent of diagenesis and organic matter is an auxiliary."

#### *Compaction*

Many mineralogic changes in fine-grained sediments such as claystones and shales, and in sediments with an abundant clay-sized fraction, such as greywackes, seem to have been caused at least partly by compaction. These changes includes the formation of micas, chlorites and

coarse kaolinite crystals in claystones and shales, and the growth of chlorites and other flakey minerals that penetrate sand grains (with corresponding solution of quartz) in greywackes. It is unlikely, in view of the impermeability of these rocks, that solutions could have circulated in them after lithification. Lutites compact most rapidly during and shortly after deposition (Jones 1944) and although there may be slow compaction during deepening burial, the abundant liquids squeezed through the compacting rocks in the early stages probably assist in the changes listed above.

The formation of sparry calcite from calcilutite, apparently caused by compaction in some limestones, is commonly accompanied by expulsion of carbonaceous matter, clay minerals and other finely divided impurities. This can be demonstrated in dolomitic limestones where dolomite crystals have replaced some of the matrix and are grey from zones of included impurities, whereas later recrystallization of the surrounding matrix has left it clear and sparry.

Other changes generally ascribed to compaction include development of macro- and micro-stylolites in limestones (Stockdale 1922, Dunnington 1954).

Waldschmidt (1941) suggested that pressure between quartz grains of sandstones at their points of contact leads to solution, development of micro-stylolitic contacts and precipitation of the quartz nearby on grain boundaries where pressure is less. This is probably responsible for some redistribution of quartz in sandstones, but as Pettijohn (1957, p. 657) points out, many micro-stylolitic contacts in sandstones are between the enlarged grains rather than adjacent detrital areas. Pettijohn earlier (1949, p. 481) attributed all well-developed sutures between enlarged grains to orogenic deformation after authigenic growth, and all examples so far observed by the present writer have been in deformed rocks.

Purely physical effects of compaction are seen in the bending of micas and chlorites around sand grains, and in the flattening of some fossil remains.

#### *Intrastrata! Solution and Precipitation.*

The main causes of diagenesis in arenites are solution and precipitation by fluids percolating between the grains. The chief fluid by virtue of its ubiquity, is undoubtedly water, but the possible diagenetic effects of oil have provoked little attention. Kulbicki and Millot (1960) consider the role of oil in some early Palaeozoic Saharan sandstones, and conclude that it has preserved kaolinite from the effects of salt waters, which elsewhere in the sequence have altered it to illite.

*Solution.*—Textural evidence of solution is afforded by the raggedness of many heavy minerals, particularly ferromagnesian silicates, and this is generally best observed in grain mounts of heavy minerals concentrated from disaggregated sedimentary rocks. The susceptibility to solution of many heavy minerals has long been recognized, notably by Bramlette (1929, 1941), Edelman and Douglas (1932), and Smithson (1941). Pettijohn (1957) has summed up much of the literature on the subject. However, not only the heavy minerals are affected. Textures resulting from the solution of quartz and feldspar grains, and of lithic fragments, are readily evident in thin sections of many Western Australian sandstones. The grains show ragged boundaries, re-entrants and even skeletal textures, and are mostly replaced by carbonate or ferruginous cement. Many examples of corrosion of sand grains by diagenesis have been reported in the recent literature, and in fact it is now appreciated that surface textures such as frosting and pitting may be due to shallow corrosion as well as to abrasion\*. A significant feature of this corrosion is that it provides an apparent source for much of the material that elsewhere forms the authigenic outgrowths on quartz, feldspar, and other minerals.

\* Strangely enough, frosting is said to be produced both by etching (Walker 1957) and by deposition of secondary silica (Humphries 1961).

### PLATE I

Fig. 1.—Barite-cemented quartz sandstone from the Jurassic Wogatti Formation (Rough Range No. 1 Bore, core 9, 3,738-3,752 ft), as seen with the universal stage. The three quartz grains (light grey, no cleavage) appear to have irregular boundaries with the barite (dark grey, cleavage). Plane polarized light. Width of field 0.4 mm.

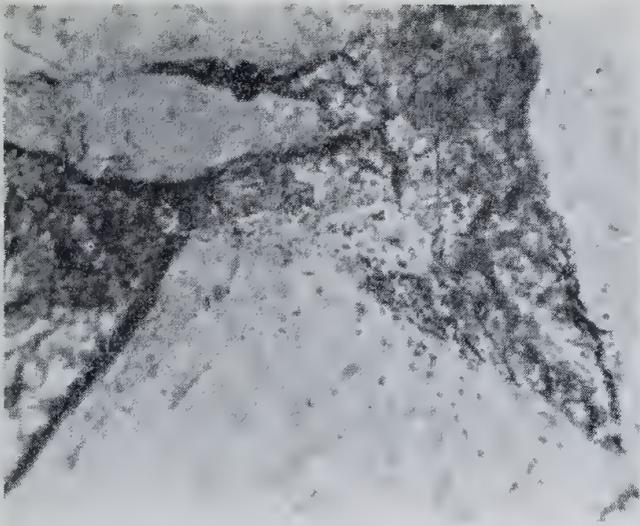
Fig. 2.—Same field as in Fig. 1 after tilt of the stage through 25°. An authigenic quartz outgrowth with at least three faces is evident, and other faces can be detected with different tilt. Plane polarized light.

Fig. 3.—Glaucouite and quartz in the Clark Sandstone (No. 48629). Authigenic quartz outgrowths tend to be moulded by the glaucouite pellet, which is crossed by a small crack or micro-fault. Glaucouite to the right of the crack is securely wedged between two quartz grains, but below the crack it has been displaced about 0.02 mm, apparently by growth of the quartz grain in the lower left of the field. Plane polarized light. Width of field 0.6 mm.

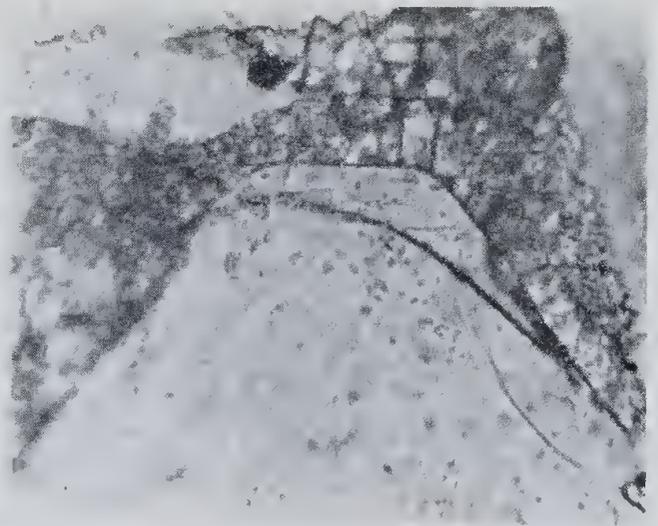
Fig. 4.—Glaucouite and K-feldspar in the Clark Sandstone (No. 48629). The core of the feldspar, which cannot be sharply distinguished from the authigenic rim in the photograph is microcline. The rim has patchy extinction with 2V negative, about 64°, and is adularia. 001 cleavage (parallel to the well-developed faces) and 110 cleavage pass from core to rim. The authigenic feldspar is moulded against the glaucouite, and its growth has apparently caused the glaucouite to yield along a small fault. Plane polarized light. Width of field 0.6 mm.

Fig. 5.—Microcline with an authigenic rim in the Clark Sandstone (No. 48629). The rim has slightly uneven extinction, is crowded with haematite inclusions, and has optics close to sanidine. In the rim 2V ranges, in different places, from 41° to 18° (approx.). 001 and 010 cleavages are present in the core, and the 001 cleavage can be seen passing from the core to the rim. Plane polarized light. Width of field 0.35 mm.

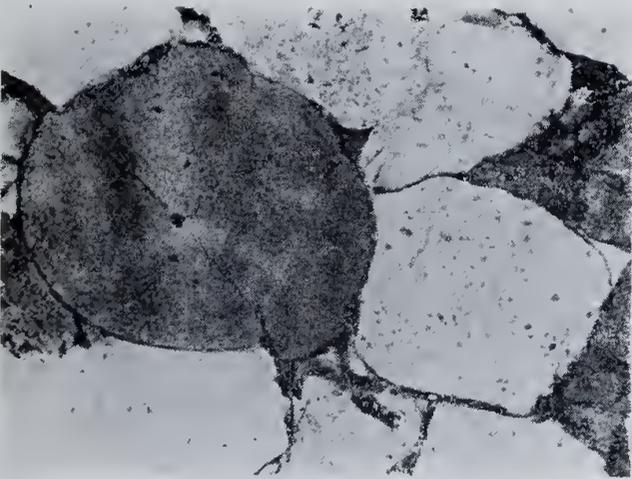
Fig. 6.—Same feldspar grain as in Fig. 5 under crossed nicols. Note how the wedge-like albite twins of the microcline core stop at the margins of the authigenic feldspar. Other grains are glaucouite (right), feldspar (upper left) and quartz.



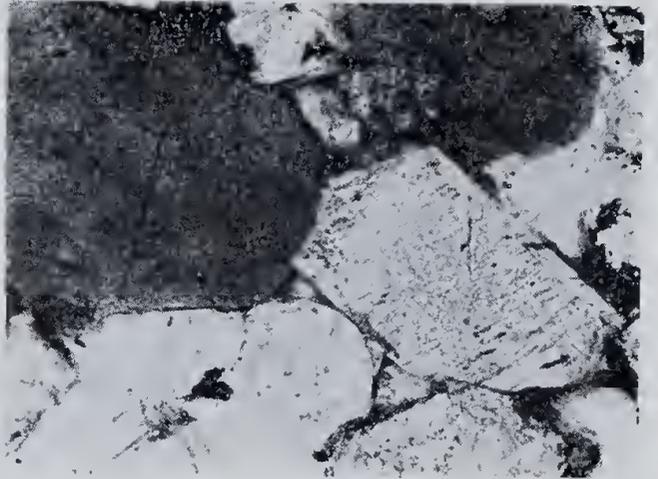
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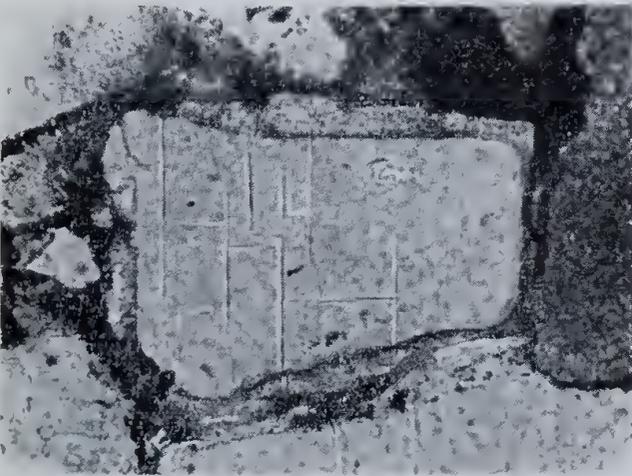
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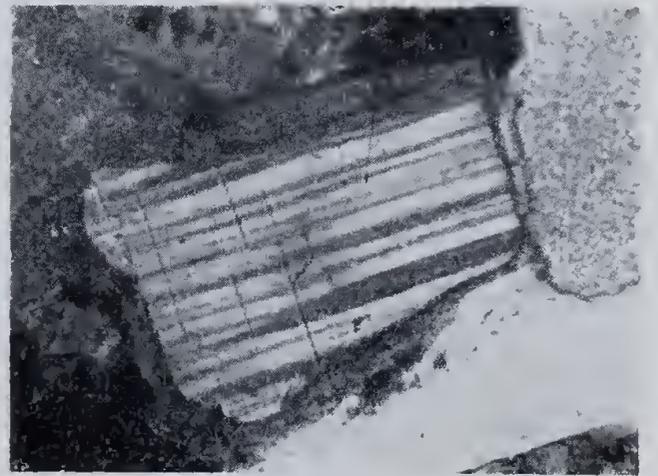
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PLATE I

*Precipitation.*—Precipitation from intrastatal solutions is a major factor in the diagenesis of arenites, and accounts for most outgrowths on quartz and feldspar. Pressure-solution of grains at their contacts, and precipitation nearby on grain boundaries where pressure is less, is probably responsible for some redistribution of quartz. However, pressure-solution is only a minor feature of the texture of most West Australian sandstones examined, and the process seems inadequate to account for the abundant secondary quartz in many of them. Moreover, some silicified sandstones show no pressure-solution effects and it can only be concluded that the quartz grains have acted as seed crystals and have been enlarged by percolating siliceous solutions. The same process is responsible for enlargement of feldspar grains.

Naturally, sand grains do not act as seed crystals if they are not themselves crystals, but are fragments of opaline or chalcedonic chert, schist, slate, volcanic glass or fine-grained volcanic rock, or if they are pellets and ooliths composed of clay-sized calcareous material. Shell fragments (except echinoderms, which break into coarsely crystalline debris) do not act as seeds. Therefore in lithic sandstones and calcarenites many pores between clastic grains can not be filled with minerals that are optically continuous with the clastic fragments. These pores instead are commonly filled with prismatic or fibrous minerals with their length toward the centre of the cavity, or else they are lined with several concentric mineral bands. Both of these textures could probably arise only by precipitation from circulating solutions. Finally, a significant point of negative evidence favouring precipitation from circulating solutions is the general absence of enlarged grains in greywackes and sandy lutites, where post-compactional circulation of fluids is practically impossible. These rocks often con-

tain corroded quartz and feldspar grains, and the dissolved material was probably removed by the solutions squeezed out during compaction, to be made available for precipitation elsewhere.

One of the problems connected with the precipitated material is whether or not it normally travels a long way before deposition. There is evidence that it often does not, for it is characteristic of many authigenic minerals that they are most abundant in those sediments which are able to supply their component elements. Thus it was pointed out by Gilbert (*in* Williams, Turner and Gilbert 1954) that quartz cement is abundant only in quartz-rich sandstones, authigenic feldspars are found chiefly where there is also detrital feldspar, and carbonate cements, although found in all types of sandstones, are invariably formed wherever the original sand contained primary carbonate. He also points out that laumontite and chlorite are generally found in sandstones containing volcanic fragments and are much less abundant in others, and lists several Tertiary Californian sandstones with volcanic detritus and chlorite cement. Montmorillonoid, a mineral that resembles chlorite in containing magnesium, has been described coating grains in late Tertiary lithic (volcanic) sandstones in California by Lerbeckmo (1957), and authigenic chlorite is described in similar sandstones from Mazakhstan by Chernikov (1960). Australian chloritic sandstones with volcanic detritus include the Arrowsmith Sandstone (pp. 37-38) and numerous Permian and Triassic sandstones from the Bowen Basin, Queensland. A local exception to the generalization seems to be the Poole Sandstone of the Canning Basin, Western Australia, which is a feldspathic sandstone with chlorite shells around the grains, but apparently no volcanic material (Johnson and Dallwitz *in* Veevers and Wells 1961, p. 267). As Gilbert also noted,

## PLATE II

Fig. 1.—Slightly kaolinized arkose from the Mokadine Formation (No. 36909). All grains except for opaques and the three clear quartz grains at bottom left are K-feldspar. Authigenic quartz and feldspar outgrowths have practically eliminated pore space. None of the boundaries of authigenic material in this field corresponds precisely with a common crystal face. A quartz grain has slightly penetrated the long feldspar grain, and the clear microcline (centre, right) has slightly penetrated the kaolinized adularia below it. The penetrations were probably caused by compaction before authigenesis. Plane polarized light. Width of field 0.6 mm.

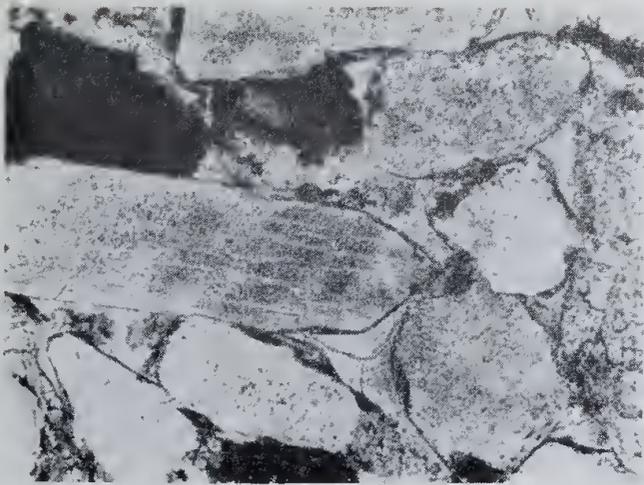
Fig. 2.—Micro-drusy texture in the Arrowsmith Sandstone (No. Pf2). Clastic grains are K-feldspar (left, with cleavage) and quartz. The cavity between them has been filled by three minerals, which are, from the outside: (1) a thin film of brown mica-like mineral, (2) a pale green chlorite layer with minute serrations directed toward the centre of the cavity, and (3) an infilling of orthoclase ( $2V_{\alpha} = 43^{\circ}$ ). A little chlorite, probably projecting from a surface just grazed by the section, can be seen apparently within the orthoclase. Width of field 0.3 mm. Plane polarized light.

Fig. 3.—Micro-drusy texture in the Arrowsmith Sandstone (No. Pf2). The cavity on the right has been filled with three minerals which are, from the outside: (1) a thin film of brown mica-like mineral, (2) a pale green chlorite with minute serrations directed toward the centre of the cavity, and (3) an infilling of adularia ( $2V_{\alpha} = 55^{\circ}$ ). The sequence is different in the cavity on the left and is, from the outside: (1) the mica-like mineral, (2) quartz (visible only on the lower right of the cavity), (3) chlorite, and (4) quartz, optically continuous with (2). Dark clastic grains are iron-stained volcanic fragments, and others are quartz and feldspar. Plane polarized light. Width of field 0.6 mm.

Fig. 4.—Authigenic enlargement of plagioclase ( $An_5$ ) in the Arrowsmith Sandstone (No. Pf61). Twinning continuous without interruption into the rim (lower right). The grey mineral is calcite; clastic fragments include quartz, K-feldspar and opaques. Crossed nicols. Width of field 0.9 mm.

Fig. 5.—Micro-drusy texture in Enokurra Sandstone (No. 38725). A fringe of sericite whose minute flakes point toward the centre of the cavity, adheres to the iron-stained surfaces of the clastic grains. This was the first authigenic mineral to form. The rest of the cavity is filled with quartz, most of it optically continuous with the clastic grain in extinction (lower left). Crossed nicols. Width of field 0.3 mm.

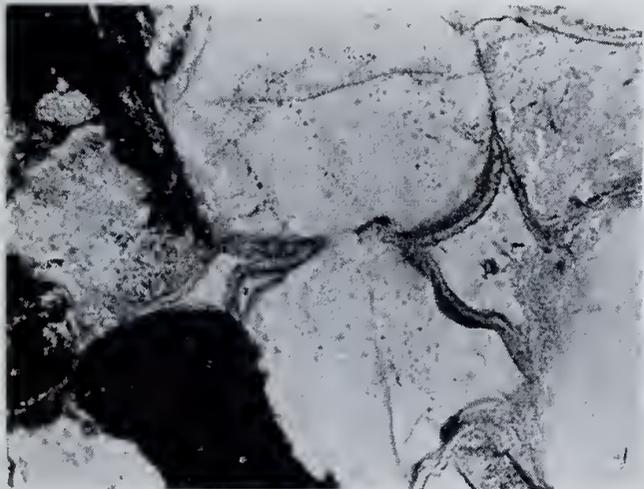
Fig. 6.—Authigenic quartz in the Cockatoo Sandstone (No. 48624). Most of the pore space has been filled. Some boundaries correspond to common crystal faces, but many do not, and some are curved. The clastic grains are outlined by a film of haematite. Plane polarized light. Width of field 1 mm.



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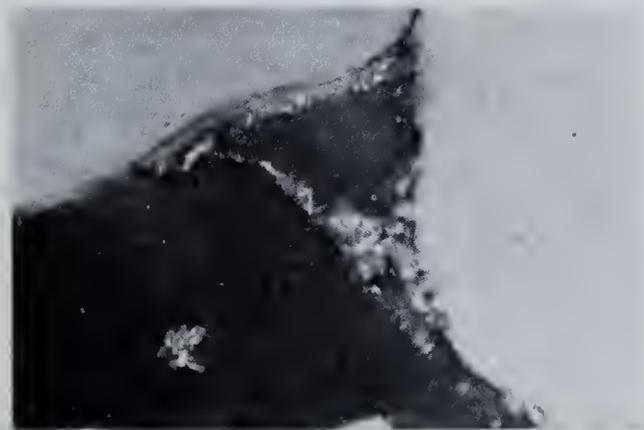
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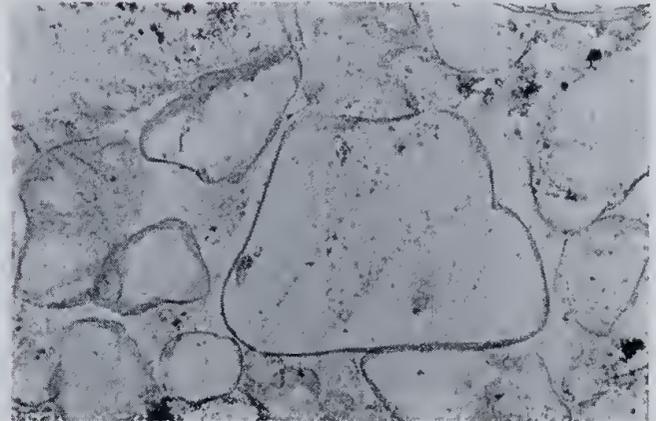
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PLATE II.

part of the tendency for particular cements to concentrate in certain sandstones is due to the presence of sand grains which act as crystal nuclei on which cement of the same composition is precipitated. This holds with quartz and feldspar, but not with chlorite, so the presence of the latter in sandstones with volcanic material is generally convincing evidence for its local derivation. It must clearly be understood that the preceding discussion applies to precipitated chlorite, and not to that which results from reorganization of the finely divided matrix in rocks such as greywackes and shales.

The replacement of carbonate in many limestones by quartz, chalcedony, opal and feldspar seems contrary to the general principle of intrastatal (as opposed to interstratal) origin for the solutions. There can be no doubt that many such solutions have originated elsewhere in more siliceous strata, but the replacement process is sufficiently complex to warrant brief separate treatment below.

*The Carbonate-silica Relationship.*—Silicification of carbonates has to be considered with its reverse process, the equally common carbonation of silica and silicates in calcareous sandstones and other rocks. The considerable literature on the chert problem, particularly as it applies to the distinction between primary and secondary chert, is well summarized in Pettijohn (1957), and will not be reviewed here. Some of the views about the causes of replacement, where it can be demonstrated, will, however, be mentioned.

Much of the discussion about replacement has hinged on the chemistry of calcite and amorphous silica, particularly on their solubility under different pH conditions. It has been shown that at 25°C the solubility of amorphous silica is practically independent of pH except where it exceeds pH9, when the silica becomes increasingly soluble with increase in alkalinity (see Krauskopf 1959). On the other hand, calcite becomes less soluble with increase in pH.

Recent papers to use these data include that of Rouge *et al.* (1959) who explained a decrease in quartz and silicates of certain limestones as they became more strongly dolomitized by assuming that the quartz and silicates dissolved because of the increased pH that caused dolo-

mitization. Examples of chert replacing carbonate and vice versa in the same rocks have been cited by Walker (1962) and ascribed either to variations in pH where the interstitial waters are highly alkaline (pH > 9) or to variations in temperature attendant on deep burial. The prospect of sufficiently high pH values for these reactions in the natural environment has also been accepted by Dapples (1962, p. 917), but not by Siever (1962) who has discounted the significance of pH, and has put forward the idea that clays act as semi-permeable membranes causing solution of carbonate and precipitation of silica. He has also appealed to several other mechanisms.

Generalizations about the distribution of authigenic quartz, chalcedony and opal are possible, though much is still unknown about their origin. Quartz forms very commonly as outgrowths on clastic quartz nuclei in many rocks including calcareous sandstones and sandy limestones, and these outgrowths are generally fairly free of inclusions. Quartz also grows as minute, widely distributed euhedra without obvious clastic cores in some limestones, but the euhedra are often crowded with carbonate inclusions.\* Authigenic feldspar assumes both forms, but is far less common. Fine-grained to micro-crystalline quartz forms many cherts, some of which, like the Coomberdale Chert, are considered to be epigenetic. Chalcedony also replaces carbonate widely, but opal generally seems to be Tertiary or younger, and it tends mainly to replace clay-sized carbonate, though it is not restricted to that lithology. Most pre-Tertiary opal has probably crystallized to micro-crystalline and fine-grained quartz. Selective replacement by different forms of silica often leaves precise details of the original texture as in Plate III, Fig. 6. It has been assumed by Millot *et al.* (1959) that percolating waters with low concentrations of dissolved silica cause precipitation of quartz, whereas solutions with high concentrations, and often many impurities, result in opal and chalcedony. However, the

\* Although quartz and feldspar euhedra in limestones were the first generally recognized products of authigenesis they have yielded practically no textural evidence of their time of formation, variously suggested as very early to late in the history of the limestone.

### PLATE III

Fig. 1.—Micro-drusy texture in the Coastal Limestone (No. 50267). Calcite fibres partly cement a coarse-grained calcarenite. Plane polarized light. Width of field 0.8 mm.

Fig. 2.—Micro drusy texture in an oolite from Devonian limestones of the Lennard Shelf (No. 50269). Sparry calcite completely fills the voids between individual ooliths. Plane polarized light. Width of field 1.75 mm.

Fig. 3.—Dolomite and sparry calcite in the Septimus Limestone (No. 36879). There are a few quartz grains in the top right corner. All calcite is part of the one crystal (see cleavage). Slight weathering has oxidized iron and emphasizes the zone of impurities in each dolomite rhomb. The dolomite crystals show no preferred orientation, and apparently grew in an impure calcareous mud which later crystallized to sparry calcite, expelling impurities. Plane polarized light. Width of field 1 mm.

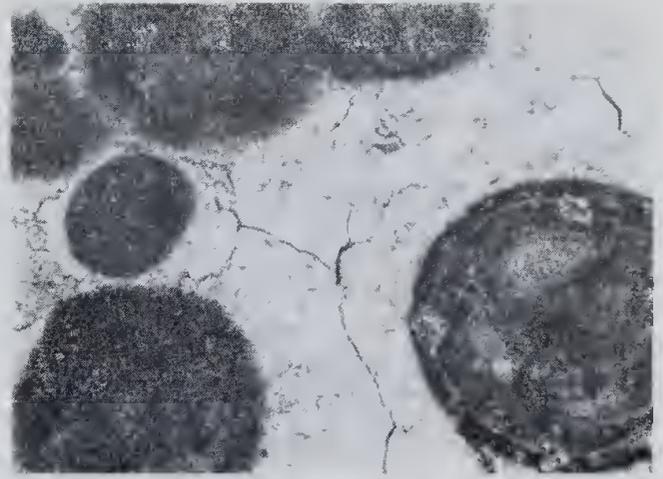
Fig. 4.—Replacement in Coastal Limestone (No. 8656). Rounded quartz grains are partly replaced by a finely divided clay-calcite matrix. Plane polarized light. Width of field 3.6 mm.

Fig. 5.—Authigenic kaolinite showing pseudo-hexagonal structure due to lines of inclusions, in sandy claystone of the Wagina Sandstone (No. 36927). The matrix is finely divided kaolinite, and there are a few quartz grains. Plane polarized light. Width of field 0.6 mm.

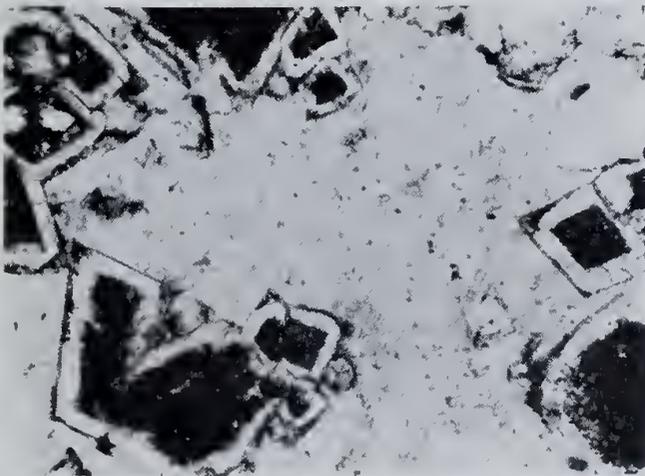
Fig. 6.—Silicification in the Toolonga Calcilutite (No. 50263, from 1-mile north-west of Yaringa North Homestead). This silicification is not widespread, but is very selective. Foraminifera are replaced by chalcedonic quartz, and the groundmass is opal with calcareous inclusion. Glauconite (not shown here) is not replaced. Plane polarized light. Width of field 1 mm.



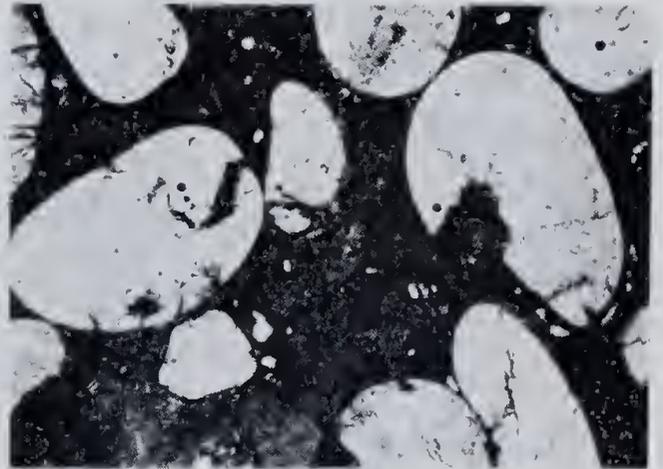
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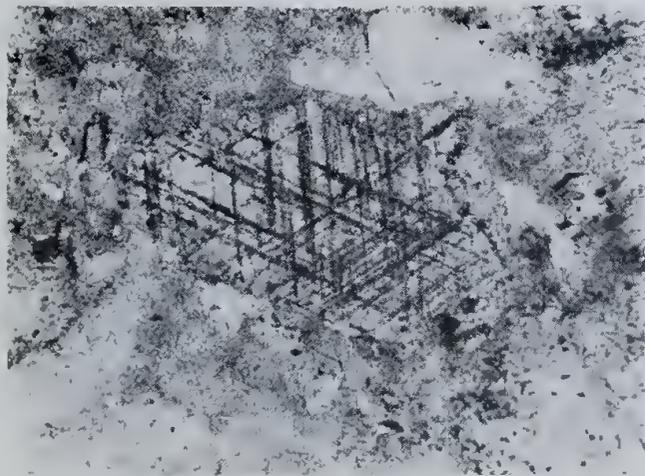
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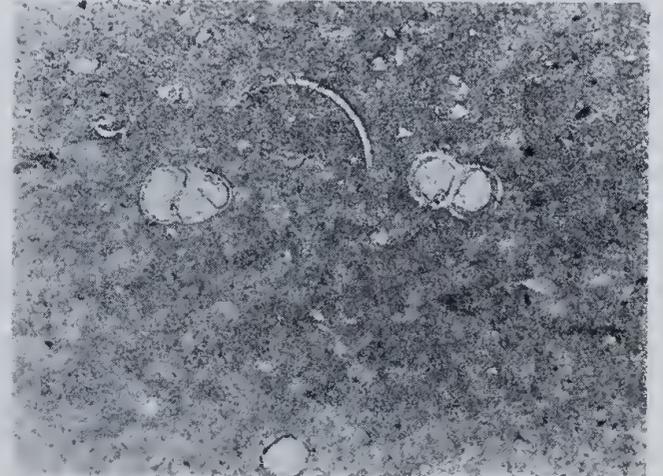
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PLATE III.

tendency observed by Millot (1960, p. 143) for chalcedony to predominate in replacement of carbonate later suggested to him that some intrinsic feature of the calcite itself might influence the type of mineralization. It will be evident from the above summary that much is yet to be determined about carbonate-silica relationships in sedimentary rocks, and that one of the best foundations for advancement is still in the amassing and recording of petrographic data.

#### *The Dolomite Problem*

Dolomite is one of the enigmas of sedimentary petrology. It is common in Precambrian and Palaeozoic limestones, less common in Mesozoic limestones, unusual in Tertiary and Quaternary limestones, and apparently forms at present under only exceptional circumstances. Examples of its present day formation are described by Alderman (1959), Miller (1961) and Taft (1961), comprehensive discussions of the origin of the mineral are given by Fairbridge (1957), Pettijohn (1957) and Carozzi (1960), and a recent description of its laboratory synthesis is presented by Siegel (1961).

The texture of many dolomitic rocks points to formation of the dolomite in partly compacted muds below the sediment-water interface, where it is unaffected by wave or current action. The dolomitic grains are euhedral, and commonly enclose pyrite, showing that they form after that early diagenetic mineral. These features are consistent with the general absence of dolomite at present in shallow, unconsolidated marine muds. On the other hand the texture of most dolomitic rocks indicates that the dolomite

had finished growing before their final consolidation. For example, dolomite is found in some shales and the impermeability of those rocks seems to preclude precipitation of the mineral from percolating solutions after their final compaction. Furthermore, the textures of many limestones show that dolomite formed before micro-stylolites and before crystallization of sparry calcite from calcilutite, both of which are probably results of intense compaction. It is also probable that the porosity of many dolomitic rocks indicates formation of dolomite before solution of interstitial calcite, for the dolomite seems to have served as the framework from which the calcite was leached. Finally, in this respect, it should be noted that much dolomite has clearly preceded authigenic quartz in some sandstones, although in others the reverse relationship has been established. The above textural features, taken together, would apply very well to dolomite that formed as compaction began, but before those diagenetic features that commonly accompany the last stages of consolidation.

Some dolomite, however, probably forms as a product of late diagenesis in consolidated rocks. Other dolomite undoubtedly forms very early in evaporites. Recently Sabins (1962) has recognised rounded "primary" dolomite in Cretaceous sandstones and states that it formed before burial of the sediment, and hence was subject to abrasion and sorting. Primary dolomite is said by Sabins to be restricted to marine sandstones, and he lists 42 formations containing it.

Fig. 5

#### *Enlargement Textures*

##### *Simple Enlargement Textures*

- (a) Calcarenite showing sparry calcite in crystallographic continuity with crinoid debris. Stippled fragments are calcareous pellets.
- (b) Quartz sandstone with quartz outgrowths crystallographically continuous with clastic cores. Note faces. Lightly stippled areas represent pores.
- (c) Quartz sandstone with pores completely occupied with secondary quartz. Some outgrowths bounded by plane surfaces, some not. No sutured boundaries.

##### *Indentation Textures*

- (d) Dolomitic sandy marl in which dolomite is partly surrounded by, or has partly penetrated, quartz outgrowths. Texture does not reveal whether quartz or dolomite grew first.
- (e) Dolomitic sandy marl, same as (d), except one of the dolomite grains is moulded onto a clastic quartz core. Dolomite therefore preceded secondary quartz.

##### *Enclosure texture*

- (f) Dolomitic sandstone with dolomite completely enclosed by quartz. Dolomite therefore formed first, and order is confirmed by moulded dolomite (upper centre). Note how a moulded dolomite has retreated marginally (left centre) due to slight solution during silicification.

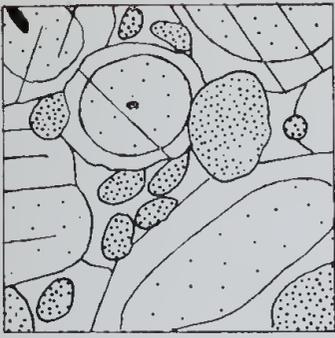
#### *Pressure-solution Textures*

- (g) Quartz sandstone with clastic grains showing sutured boundaries due to compaction, deformation or both. Secondary quartz(s) fills voids, may have come partly or completely from quartz dissolved along sutured contacts.
- (h) Calcarenite with micro-stylolite due to compaction. Micro-stylolite outlined by iron-stained argillaceous matter and small quartz grains, both insoluble in the particular conditions of its formation here. Sparse distribution of quartz in rock suggests compaction equivalent to field of view.
- (i) Quartzite with sutured boundaries between outgrowths due to deformation after diagenesis. As much a metamorphic as a diagenetic texture.

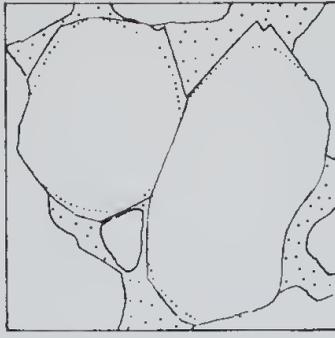
#### *Micro-drusy Textures*

##### *Simple Micro-drusy Textures*

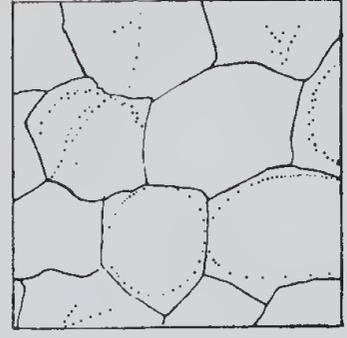
- (j) Calcarenite partly cemented with fibrous calcite. Fibres are elongated normal to grain boundaries.
- (k) Calcarenite completely cemented with sparry calcite. Long axes of calcite crystals are normal to grain boundaries.
- (l) Lithic (volcanic) sandstone cemented by fibrous chlorite. Texture basically the same as in (j) and (k).



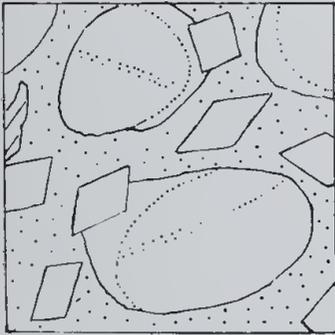
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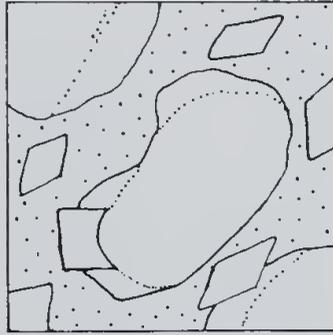
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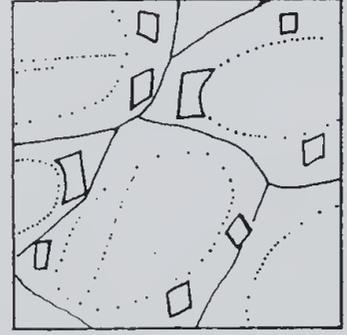
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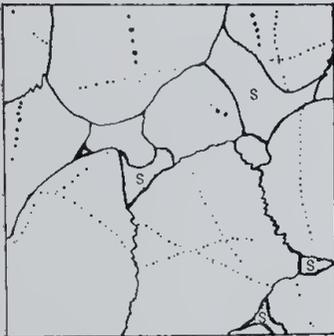
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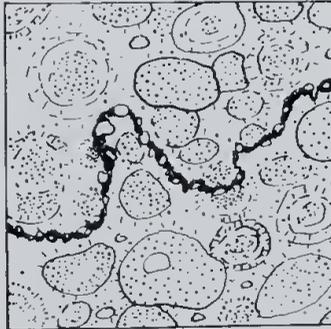
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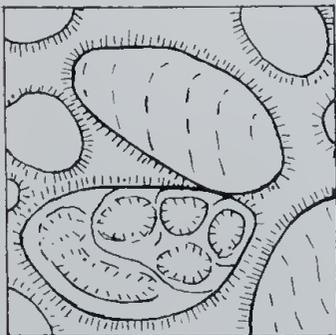
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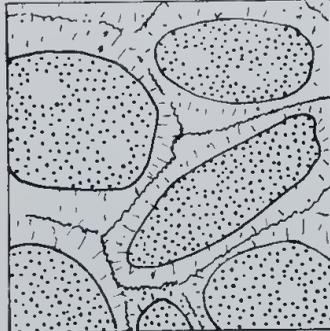
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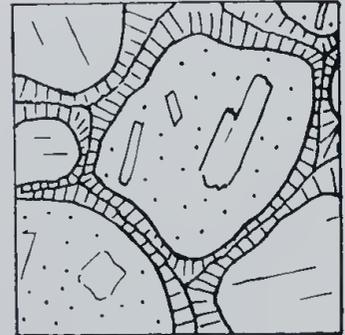
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Fig. 5.  
51

To sum up, dolomite almost certainly forms in different ways, and may grow early (by direct precipitation in marine sandstones during sedimentation, or by evaporation) or late (replacing other diagenetic minerals in porous rocks). However, textures in ancient rocks suggest that most dolomite in limestones forms during initial compaction, but before final consolidation. Perhaps the composition of Precambrian and Palaeozoic atmospheres helped to account for its abundance during those eras, as Ronov (1959) believes. A hypothesis which explains the required concentration of magnesia from sea water is that of Adams and Rhodes (1960) who postulate alteration of limestones by magnesia-rich solutions seeping from evaporite lagoons. Further information from the drilling of areas where reefs are now growing seems desirable, though it must be agreed with Ladd *et al.* (1953) that the drilling of atolls has so far yielded puzzling results.

### Common Diagenetic Textures and their Interpretation.

Diagenesis, like magmatic crystallization and metamorphism, causes many textures, and, as with those processes, certain basic textures appear again and again. These textures fall in the following categories: enlargement textures, pressure-solution textures, pore-filling or micro-drusy textures, reorganization textures, and replacement textures. Most of them have been encountered in the rocks described earlier, and they are now represented diagrammatically in Figs. 5 and 6. A discussion of their main features and significance follows below.

#### Enlargement Textures

All enlargement textures are the result of precipitation of minerals on crystal nuclei of the same or similar composition and the best examples are found in porous arenites, where solutions are able to circulate freely. However,

some outgrowths have replaced earlier minerals which partly filled the cavities, and these outgrowths may contain clues in the form of minute inclusions.

*Simple Enlargement Textures.*—Tourmaline and other heavy minerals grow either small projections, or faces, but crystalline calcitic debris, quartz and feldspar usually grow large, simple and well-developed faces, except where prevented by mutual interference (see Figs. 5a, 5b, 5c). The commonly developed faces are, in calcite, rhombohedra; in quartz, prisms and rhombohedra; and in feldspar, basal and side pinacoids and prisms (110 and 130). Faces which are less common in feldspar, but are not rare, include the pyramid (111) and dome (101).

*Indentation Textures.*—Authigenic outgrowths on one mineral may partly surround, or be partly penetrated, by another authigenic mineral to give an indentation texture. This texture, illustrated in Fig. 5d, does not reveal which of the two minerals grew first. However, in the special case where one of the authigenic minerals has grown so that it is moulded against the clastic core of the other, the moulded mineral has been the first to grow (Fig. 5e).

*Enclosure Textures.*—These are a development of the indentation texture in which the authigenic rim of one mineral grows sufficiently to include a second authigenic mineral. The included mineral forms first (Fig. 5f).

#### Pressure-solution Textures

The secondary quartz of some sandstones has been attributed to pressure-solution effects. Where quartz grains impinge on each other under intense pressure, they partly dissolve at points of contact, and interlock with micro-stylolitic boundaries. The dissolved quartz is supposed to precipitate in adjacent pores, where pressure is less. The common association of secondary quartz and micro-stylolitic contacts

Fig. 6

#### Micro-drusy Textures (continued)

##### Composite Micro-drusy Textures

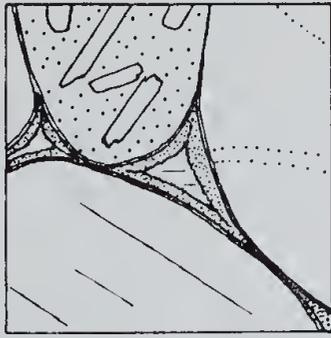
- (a) Lithic (volcanic) sandstone with pores filled by three minerals which are, from the outside, a micaceous mineral, chlorite (stippled), and feldspar. Note how minute chlorite serrations are directed inward. The micaceous mineral may be a reconstituted clay film on the clastic grains. The order of formation was (1) micaceous mineral (or its precursor), (2) chlorite, (3) feldspar. (Based on a diagenetic sequence in Arrowsmith Sandstone.)
- (b) Lithic (volcanic) sandstone showing the following diagenetic sequence: (1) micaceous mineral, (2) quartz, (3) chlorite, (4) quartz (note euhedrism), (5) feldspar. (Based on a diagenetic sequence in Arrowsmith Sandstone.)

#### Reorganization Textures

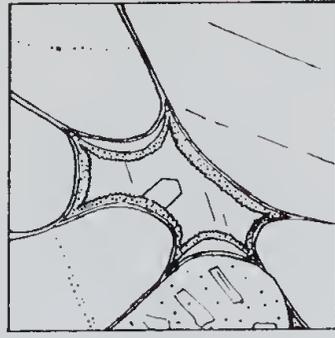
- (c) Claystone with vermicular kaolinite crystals. Fragility of the crystals is proof of *in situ* formation.
- (d) Greywacke with chlorite-sericite matrix, formed from clay-sized detritus. The new flaky minerals penetrate margins of clastic fragments, making this partly a replacement texture also.
- (e) Fontainebleau sandstone, in which calcite has reorganized to form large crystals.

#### Replacement Textures

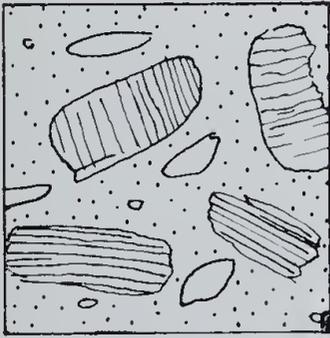
- (f) Calcilutite partly replaced by quartz euhedra with calcareous inclusions. The long fragment is calcite.
- (g) Shelly limestone with shells partly replaced by chalcedony, and matrix dolomitized. The dolomite has zonal inclusions—see also (j). Unreplaced shelly material has recrystallized.
- (h) Quartz sandstone cemented by sparry barite. The original pyritic and argillaceous matrix is represented by patches of argillaceous impurity, and isolated pyrite grains.
- (i) Ferruginous quartz sandstone in which quartz grains are apparently corroded by the ferruginous matrix. One quartz grain shows an outgrowth, product of an earlier diagenetic phase. The texture resembles that where carbonate corrodes quartz, and many such sandstones may be caused by replacement of calcite by iron oxide.
- (j) A complex but fairly common texture, in which dolomite has partly replaced the matrix of a sandy marl. Carbonaceous and argillaceous inclusions form a dark zone in each dolomite rhomb. There has been later recrystallization of the matrix to sparry calcite, with expulsion of impurities.



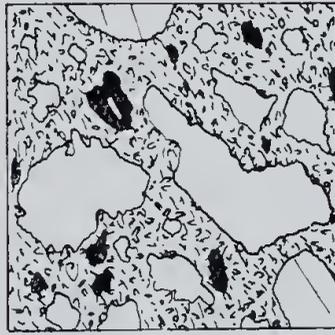
a



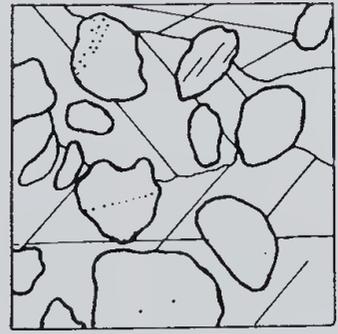
b



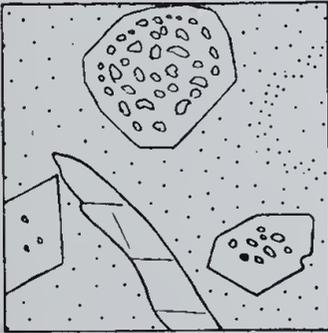
c



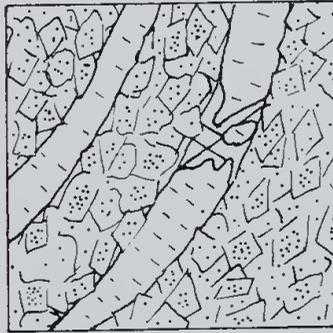
d



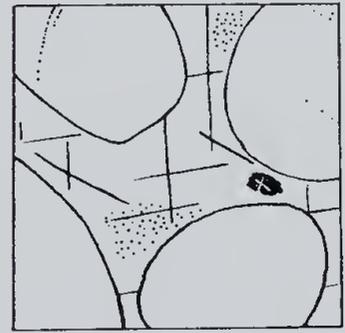
e



f



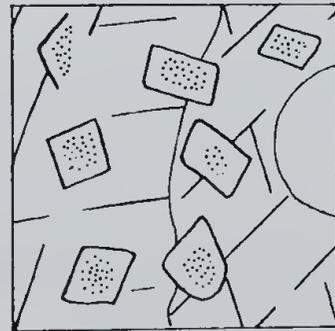
g



h



i



j

Fig. 6.  
53

seems to accord with this origin, but there is often too much quartz to be explained by the micro-stylolites. Appeal must then be made to intrastratal solutions for at least part of the quartz. In some sandstones (better called quartzites), micro-stylolitic boundaries are confined to adjacent outgrowths, a texture probably due to imposition of great load, or faulting or folding, after diagenetic enlargement. These textures are therefore practically metamorphic. Micro-stylolites that traverse the rock, cutting across grains, are another form of pressure-solution common in limestones, but not absent from quartzites. Textures arising from pressure-solution are illustrated in Figs. 5g, 5h, 5i.

#### *Pore-filling or Micro-drusy Textures*

All micro-drusy textures are believed to form by precipitation in porous rocks, generally arenites. They differ from enlargement textures in that clastic grains do not act as nuclei on which the precipitated material grows in crystallographic continuity. This is because the clastic fragments are non-crystalline (e.g. volcanic glass, some chert), or are aggregates of minute crystals (e.g. schist, shale, fine-grained volcanic rock, ooliths, pellets, etc.) rather than single crystals, or because they are single crystals, chemically very different from the precipitated material (e.g. quartz grains and chlorite cement). The authigenic minerals may form a fringe on which the serrations are normal to grain surfaces and point into the cavity, or they may form a series of elongate crystals or fibres normal to grain surfaces and directed into the cavity. This texture is practically proof of growth in an empty pore cavity, another difference from enlargement textures, some of which are due to replacement of earlier pore-filling material.

*Simple Micro-drusy Textures.*—Simple textures, involving one authigenic mineral, are illustrated in Figs. 5j, 5k, 5l.

*Composite Micro-drusy Textures.*—Composite textures may involve several authigenic minerals, of which the outermost are the first to form, and the innermost the last. See Figs. 6a, 6b.

#### *Reorganization Textures*

Reorganization textures are like replacement textures (discussed below) except that in the former the substituted material is chemically the same as, or similar to, the original material. The reorganization is generally to a coarser crystalline form such as the change from calcilutite to sparry calcite, or from the clay-sized matrix of greywacke to aggregates of chlorite, mica, and other flaky minerals. Other changes are from finely divided clay minerals to coarse vermicular crystals, and from aragonite to calcite in fossil material, although the latter does not involve coarsening. Most reorganization textures seem to have been the result of compaction. Some of them are illustrated in Figs. 6c, 6d, 6e.

#### *Replacement Textures*

Replacement textures are very common diagenetic features of sedimentary rocks, and some are illustrated in Figs. 6f-j. They are ap-

parently the result of almost simultaneous solution and precipitation, and in those lutites which are practically impervious to the passage of solutions, the process probably took place during compaction and the expulsion of contained fluids. As already noted, some enlargement textures can also be classified as replacement textures.

#### Conclusions

There is no reason to suppose that the processes leading to diagenesis are less complex than those leading to solidification of magmas, or to metamorphism. Nevertheless, they are becoming increasingly well understood, and consequently the examination of diagenetic textures should lead to petrologic inference as reliable and useful as that resulting from examination of igneous and metamorphic textures. The scheme set forth above is an attempt to group diagenetic textures so that they form a useful and simple guide to the origin of the sedimentary rocks in which they occur.

#### Acknowledgments

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## 7.—Round Australite Core from Graball, Western Australia

By George Baker\*

*Manuscript received—20th November, 1962.*

A large round australite core found at Graball, Western Australia weighs 168 grams and is 57 mm in diameter and 34.5 mm thick. It is the fourth largest known australite and the second largest known round core.

A sculpture pattern of flow swirls and pits on the posterior surface is apparently of primary origin, produced in an extra-terrestrial environment.

Meandrine grooves, crater-like depressions, and minute pits on the anterior surface, are due largely to differential solution-etching in soils. They are limited to a thermally stressed surface left after considerable ablation of the primary form. Ablation was by frictional heating during aerodynamically stable transit at ultrasupersonic velocity through the earth's atmosphere. A well-developed flaked equatorial zone was evidently initiated circumferentially around the edge of the specimen during the end phases of high-speed infall, and subsequently became etched by terrestrial weathering.

### Introduction

A large round australite core, discovered in 1952 on the roadside near Graball telephone exchange, approximately seven miles north-west of Mt. Walker, near Narembeen, 155 miles east of Perth, Western Australia, has recently been brought to notice through the courtesy of Mr. W. H. Cleverly of the School of Mines, Kalgoorlie, and Mr. W. Meacock of the Mt. Walker Government School, Western Australia.

The specimen, weighing 168 grams, was kindly loaned by the owner, Mr. W. Berry, of Mt. Walker, Western Australia, for examination. Only three other australites are known to be heavier than this specimen, each of them weighing over 200 grams.

Three casts of the specimen, prepared in "Artificial Stone" at the Geology Department, University of Melbourne, are lodged: one in the University of Melbourne geological collection, one in the tektite collection of the National Museum of Victoria, and one in the author's private collection of tektites.

### Size of Specimen

The round australite core has a diameter of nearly 57 mm and a depth (thickness) of 34.5 mm. It weighs 168.28 grams, a value exceeded by only three other australites. The largest is a fractured oval-shaped form weighing 238 grams from Warralakin, Western Australia (Baker 1962a); the next is a large round australite core weighing 218 grams from Lake Yealering, Western Australia, described by Fenner (1955) as a lens form; the third largest is a boat-shaped form weighing 208.9 grams from

Karoonda, South Australia (Fenner 1955, Plate VII Nos. 3 and 4). The Graball specimen is thus the second largest known round core type of australite; it shows comparable sculpture patterns to those on the larger Lake Yealering round australite core figured by Fenner (1955, Plate VII, Nos 1 and 2).

The specific gravity of the Graball specimen, determined in distilled water ( $T = 19.3^{\circ}\text{C}.$ ) on an air-damped chemical balance, is 2.434. From the specific gravity—silica relationships of tektites, this value indicates a silica content of approximately 72 per cent.

### Structure and Sculpture

The specimen is reasonably well preserved, and shows the following features:

*Posterior surface.*—The posterior surface (Plate I, A), which remained directed back along the flight path during ultrasupersonic atmospheric flight earthwards, shows no features assignable to the effects of aerodynamic heating and ablation or aerodynamic sculpturing, hence its sculpture pattern is considered to have been developed in an extra-terrestrial milieu. It has been but slightly modified by terrestrial erosion since landing on the earth's surface a few thousand years ago.

An artificially chipped area around the region of the rear pole on the posterior surface, is approximately 10 mm in diameter. It reveals the characteristic vitreous lustre of freshly broken tektite glass (Plate I, A). The sub-conchoidal fracture surface shows secondary ripple fracture lines and carries five "knobs" up to 1.5 mm in diameter which are unusual structural features on the broken surfaces of fractured australites generally.

The rest of the posterior surface has principally a primary sculpture pattern of flow swirls showing schlieren, in places arranged in complex fold-like structures. Round to elongated pits averaging 1 mm in diameter, occur towards the edges of the posterior surface (Plate I, A). After removing soil constituents from the pits, their walls revealed a lacquer-like lustre produced by a process of natural solution-etching which has also brought out some of the fine schlieren on the pit walls. The general surface of the tektite at the level of the pit openings, however, shows a rather duller, almost sub-vitreous lustre.

*Flaked equatorial zone.*—The flaked equatorial zone (Plate II, A and B) occurs circumferentially in the mid-regions of the specimen as viewed in side aspect. It is approximately 10 mm broad. The rim separating it from the

\* C.S.I.R.O. Mineragraphic Investigations, c/o Geology Department, University of Melbourne, Parkville, N.2, Victoria.

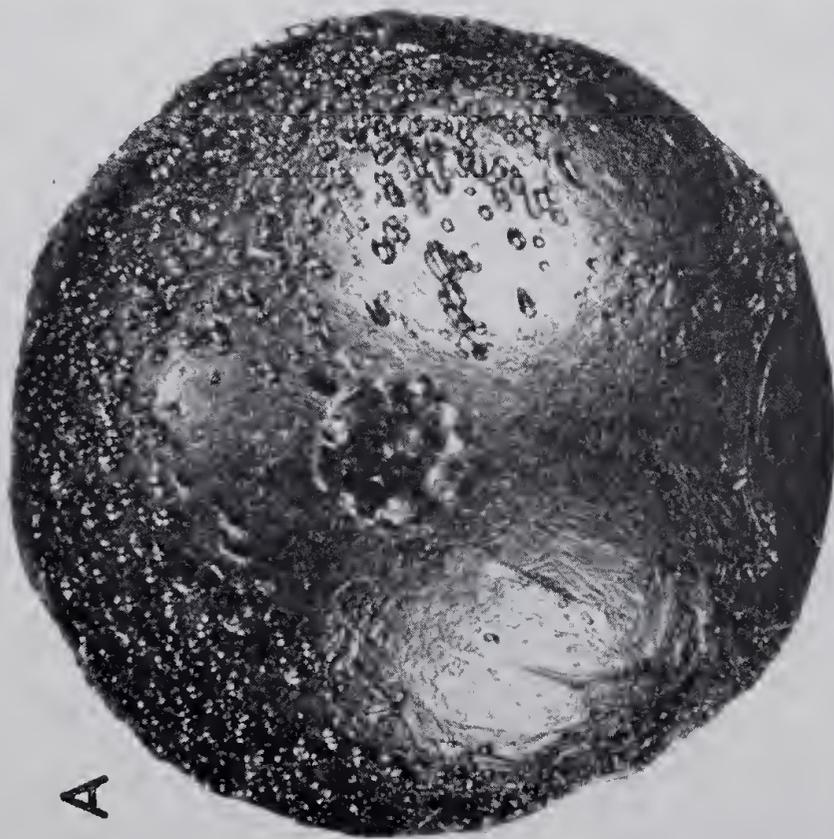


PLATE I

Round australite core from Graball, Western Australia.

A—posterior surface showing bubble pits and flow swirls (darker area in centre of photograph is a fracture surface).

B—anterior surface showing crater-like depressions and meandrine grooves (the surface flattens somewhat from the centre to the top of the photograph).

Scale is in centimetres and millimetres. Photographs by Alfred A. Baker.

posterior surface (uppermost in Plate II) is sharply defined, but the anterior surface (lowermost in Plate II) and the flaked equatorial zone merge more gradually into one another.

Vertical, oblique, and less commonly meandrine short grooves 2 mm long and 1 mm wide, and longer straight grooves up to 10 mm long and 1 mm wide, cut across the flaked equatorial zone, and mainly trend parallel with the breadth. Like the pits on the posterior surface, these grooves occasionally reveal fine schlieren crossing their walls at various angles.

*Anterior surface.*—The anterior surface (Plate I, B), which was fully exposed to aerodynamical forces during high-speed flight through the earth's atmosphere, remained directed forward down the flight path as long as the specimen was maintained in aerodynamic stability at the high entry velocities.

Meandrine (some "vermicular"), straight, and curved grooves on the anterior surface vary in length and average about 1 mm in width (Plate I, B). Sometimes they are S-shaped in plan (left-hand side, Plate I, B), occasionally J-shaped. In cross sectional aspect they are largely U-shaped. The walls of some plainly reveal a few small etch pits; more frequent are fine flow lines that cross the grooves at right angles, or obliquely, or sometimes trend parallel with their length. Occasional grooves are at a slightly lower level than others, and neighbouring grooves sometimes cross or merge with one another in places.

A few depressions 3 mm across, 0.5 mm deep, and circular in outline (lower central portion, Plate I, B) are crater-like compared with smaller pits (right, central portion, Plate I, B). They sometimes carry smaller pits and occasional fine flow lines that cross their walls in random directions.

The asymmetrical silhouette of the anterior surface observed from one side aspect of the specimen (Plate II, B), evidently has arisen from weathering. This gives a flattening effect which is faintly discernible in plan aspect (top portion of Plate I, B).

### Curvature and Volume

The radii of curvature of the posterior ( $R_B$ ) and of the anterior ( $R_F$ ) surfaces were determined from a silhouette tracing equivalent to a cross section containing the polar axis of the specimen (i.e. equivalent to an enlarged silhouette trace of Plate II, A).

The values so obtained are:

$$R_B = 4.0 \text{ cms (40.25 mm).}$$

$$R_F = 3.7 \text{ cms (36.75 mm).}$$

The posterior surface is evenly curved in all directions radially outwards from the rear pole of the specimen. Its arc of curvature corresponds with that of a constructed circle with radius 4.0 cms, but only about 28 per cent. of the original curved surface remains after ablation, assuming the parent form was a sphere.

The arc of curvature of the anterior surface was not even in all directions outwards from the front pole (cf. Plate II, B), so the radius

of curvature was determined from a silhouette tracing of the most regular curvature shown in one side aspect (cf. Plate II, A).

The area of the front surface ( $2\pi rh$ ), where  $h$  is the height of the anterior cap above the rim of the specimen, was calculated as 58.13 cm<sup>2</sup> assuming that the area of the front surface is equivalent to the area of the cap of a smooth sphere. This represents the frontal area projected in the flight direction during the closing stages of the aerodynamic heating process. The height of the anterior cap is 2.5 cms, and the height of the posterior cap is 0.95 cms; together these constitute the depth or thickness (3.45 cms) of the australite.

The volume of the specimen is 69.1 cm<sup>3</sup>. The volume of a sphere of australite glass with  $R = 4.0$  cms and of specific gravity the same as that (2.434) determined for the residual australite shape (large round core), was calculated as 268.1 cm<sup>3</sup>. This is not quite 2½ times the volume of the largest round core so far recorded from the Port Campbell district some 1,500 miles distant in Victoria (Baker 1962b).

### Loss by Ablation

If the parent form of the large round australite core from Graball, Western Australia was a sphere, or a spheroid close to a sphere then the volume of tektite glass lost (a) during entry at high speed, by ablation, and (b) during the few thousand years that the specimen has lain exposed to weathering on the earth's surface, amounts to 199 cm<sup>3</sup>, this being the difference between the parent sphere volume and the volume of the residual australite round core; it represents a loss of approximately three quarters of the primary form. Thus, as a consequence of aerodynamic heating with attendant ablation and fusion stripping, followed by terrestrial erosion, only 25.8 per cent of the original form remains. Allowing for the small chip lost by artificial fracturing (see central portion of Plate I, A), this value can be rounded-off at 26 per cent.

Although it is impracticable to assign definite proportions to either of these processes causing loss of australite glass since initial entry into the atmosphere, largely because of the unknown loss by erosion, it is expected that the combined effects of ablation and fusion stripping and possibly some stress exfoliation in the subsonic region of the flight path, significantly dominated loss by subsequent terrestrial weathering. Assuming, as a generality, that erosional loss in the Australian strewnfield amounted to at least ten per cent. of the tektite glass that reached the earth's surface, it is apparent that over 70 per cent. of the Graball primary form was consumed by aerodynamic ablation. This is in accord with the calculated ablation losses of other primary spheres from which large round cores were produced (Baker 1962b).

As measured graphically, and calculated from  $2(R_B) - D$  where  $R_B$  is the radius of curvature of the posterior surface, and  $D$  the depth of the specimen measured from the back to the front pole, the depth of ablation from the front pole of the reconstructed primary sphere to the front pole of the remnant australite core, is 45.5 mm.

A



B

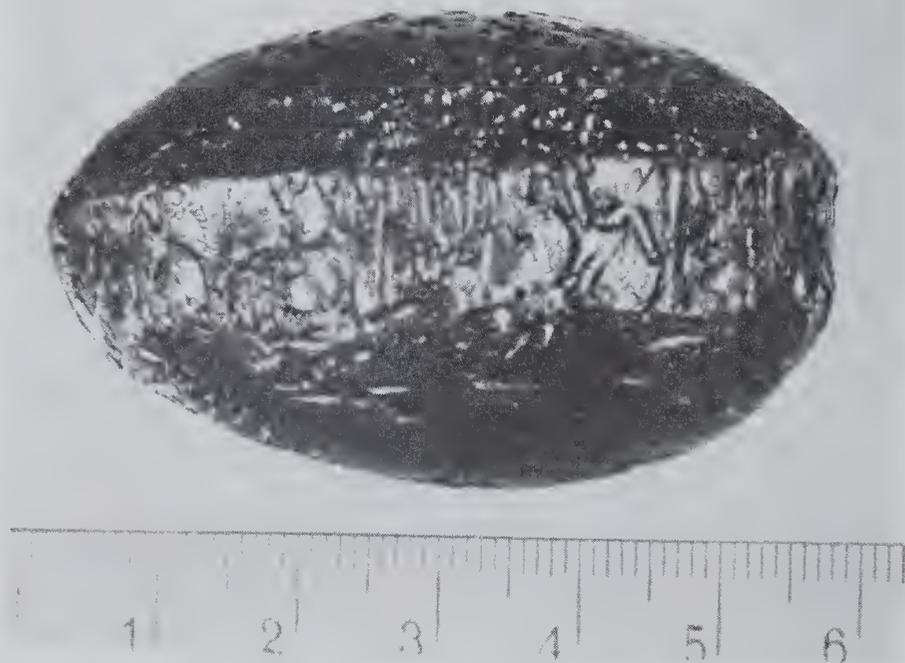


PLATE II

Round australite core from Graball, Western Australia.

A—side aspect showing flaked equatorial zone separating posterior (uppermost) from anterior (lowermost) surfaces.

B—side aspect in a position normal to that of (A) above, showing flattened arc of curvature of anterior surface in lower left portion of the photograph.

Most grooves crossing the flaked equatorial zone trend parallel with the line of flight which was in a direction from top to bottom of the photograph.

Scale is in centimetres and millimetres. Photographs by Alfred A. Baker.

This is 56.9 per cent. of the original sphere diameter, and thus comparable with the average percentage value (56.5 per cent.) for ten round australite cores from Port Campbell, Victoria (Baker 1962b). Among other things, this is proportional to the aerodynamic heating (*vide* Dr. Dean R. Chapman, N.A.S.A., U.S.A.).

Compared with the depth of ablation (7.5 mm) of a hollow australite of comparable diameter containing an eccentrically disposed internal cavity (Baker 1961), the depth of ablation along the polar axis of the solid australite core from Graball has been six times as great. The indication is that the hollow form was therefore a much more effective dissipator of the frictional heat input during aerodynamically stable transit through the earth's atmosphere.

By comparison with the average for perfectly developed, excellently preserved australite buttons having well-formed circumferential flanges (Baker 1962b), and with the value for the hollow australite which is also perfectly developed and very well preserved (Baker 1961), the aerodynamic heating (determined from  $A.H. = k/\sqrt{R_F}$ , where  $R_F$  is the radius of curvature of the anterior surface) for the large, well-developed, reasonably well preserved, round australite core of solid tektite glass from Graball, Western Australia, is 0.520 (see Table I).

TABLE I

Australite Shape Type	Locality	Aerodynamic Heating
Perfect flanged buttons	Port Campbell, Victoria	0.920*
Large round core (solid glass)	Graball, Western Australia	0.520
Large round hollow form	Horsham, Victoria	0.187

\* This is an average value for 23 perfect australite buttons, the range for which was 0.86 to 1.09.

The aerodynamic heating value for the hollow form is lowest, and equal to only one fifth that for the perfect australite buttons. The value for the large solid core is intermediate and its aerodynamic heat input was a little over half that for perfect buttons, approximately two and three quarter times greater than the input for the hollow round australite.

Relative to the perfect flanged buttons, which are smaller, the solid round core from Graball has a larger mass per unit frontal area, hence, during high speed earthward flight, more of the aerodynamic heat received was dissipated, largely by radiation. The amount radiated, however, was considerably less than for the hollow round australite from Horsham.

### Conclusions

The sculpture of the posterior surface of the large, round australite core from Graball, Western Australia is evidently primary and of extra-terrestrial origin; unlike most other large australites from the more westerly parts of the Australian strewnfield, it has been subjected to less severe weathering by terrestrial agents.

The sculpture patterns of the anterior surface and the flaked equatorial zone are secondary. The curvature of the anterior surface was largely determined by aerodynamic sculpturing during frictional heating processes arising from high speed, aerodynamically stable transit through the earth's atmosphere. Evidently all the fused glass from this secondary period of melting was shed almost immediately during flight. There is (i) no evidence on large cores such as this, that ring-wave formations were developed to give flow ridges and flow troughs as on buttons of smaller size (Baker 1962b, Plates XII to XIV), (ii) no evidence of flange glass remaining frozen-in circumferentially as on the flanged buttons, and (iii) no evidence that flange glass was present on landing and was subsequently removed by weathering.

Accepting the parent form as having been a sphere of australite glass of 8.0 cms diameter, then more extensive loss of all the melt glass and vapourised glass during aerodynamic fusion has occurred to produce this large core than in forming flanged button-shaped australites from originally smaller spheres. The depth of ablation in the stagnation point (front polar) regions was proportionally much greater than for flanged buttons where all melt glass was not shed, because some was re-frozen in equatorial regions of the ablated smaller spheres to form circumferential flanges. Depths of ablation in forming perfect flanged australite buttons range from 5.5 mm to 16.5 mm, and average 9.5 mm. This is 47.3 per cent. of the diameters of the originally smaller spheres which ranged from 12.7 mm to 27.1 mm and averaged 20.1 mm in Port Campbell specimens (Baker 1962b). Depth of ablation (45.5 mm) of the sphere from which the large round core from Graball was produced, represents 56.9 per cent. of the original sphere diameter, i.e. approximately 10 per cent. more.

Since not all of the melt glass was shed in forming the australite buttons, and a relatively substantial amount went into the building of the circumferential flanges, there was an increase in the frontal area. This increase was equal to the area of the anterior surface of the newly generated circumferential flange. Consequently, flange formation led to reduced aerodynamic heating (*vide* Dr. Dean R. Chapman) as an outcome of increased amounts of drag arising from increased frontal area. Such a process did not occur in the large core types of australites, so that the aerodynamic heat input was maintained at a steady rate as long as high enough velocities prevailed. This being so, greater aerodynamic heating leading to melting and ablation was experienced than in the phases of button generation when circumferential flanges were formed.

The present sculpture pattern of grooves, craters and pits on the anterior surface, and probably also on the flaked equatorial zone, is fundamentally a result of natural solution-etching developed after landing on earth surface. It is not easy to assess how far a process of exfoliation on cooling may have affected the anterior surface during the final phases of flight, i.e. between the end of the aerodynamic heating stage and the time of impact with the earth.

This may have been interconnected with, or possibly completely superseded by, subsequent spallation from diurnal temperature changes while resting on the earth's surface. After the australite had passed from (1) the phase of flight where ultrasupersonic and then lesser supersonic speeds prevailed, through (2) the transition zone of transonic speeds, and into (3) the subsonic region where much lower speeds supervened for the final few seconds of earthward trajectory, processes of fusion and ablation created by frictional heating had ceased to operate. The last-formed thin skin (1 mm and under) of the forwardly directed surface that was heated and softened at the end of this stage of flight, then cooled rapidly in the lowermost region of the atmosphere. It was not soft on impact with the earth, as deduced from the available evidence, but compared with the underlying glass, it would have been in a relatively highly stressed condition. Such a crust would tend to exfoliate in thin layers from the anterior surface, either before, and/or after landing. This would result in exposure of a sub-surface of the anterior surface to which the secondary process of aerodynamic heating had not penetrated. Gradual chemical attack of this surface by terrestrial agents, mainly etchants in moist soils, further modified the anterior surface to produce its present sculpture pattern. If the nature of the exfoliation determined the initial trends of solution-etching, it is no longer evident because of the degree to which etching has advanced.

The indications on the Graball round australite core are that mechanical agents causing modification by abrasion played no major role in the process of terrestrial erosion, unless the somewhat flatter appearance of the anterior surface as seen in one aspect (Plate II, B, bottom left-hand side) is a faceted area arising from abrasion by wind-driven sand and soil. There is no proof that such faceting occurred, although

the specimen was collected from a region where soil deflation processes operated to a significant degree in recent geological times, and australites are usually discovered with their anterior surfaces uppermost, a position found by experimentation to be their stable position of rest on the earth's surface.

The most dominant cause of weathering was evidently chemical, with soil solutions acting partly differentially to bring about some directionalized and some random natural solution-etching. The meandrine character of certain of the grooves might be indicative of confined biochemical reactions associated with plant rootlets lying in contact with the top of the specimen as it lay embedded in soil. Such reactions are expected to be more prevalent on the uppermost (anterior) than on the lowermost (posterior) surfaces of australites buried in soils, even though, as deflation progressed in some areas, the posterior surface remained longer in contact with soils on exposure.

#### Acknowledgments

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## 8.—A Review of the Gekkonid Lizard Genus *Heteronota* Gray, with a Description of a New Species from Western Australia

By Arnold G. Kluge\*

Manuscript received—21st August, 1962.

A review of the nominal species of the gekkonid lizard genus *Heteronota* reveals that *binoei* has been until present the only recognizable member in the genus. A new species of *Heteronota* is described from the North-West Natural Region of Western Australia. This new species appears to be restricted to subterranean cavities.

### Introduction

Collections of herpetological material from the more isolated regions of Australia have greatly increased within recent years and doubtless will provide the basis for the description of many new species. It must be emphasized, however, in view of the large number of names already applied to various parts of the populations and the almost complete lack of knowledge of relationships, that a generic revision or review of the nominal species should accompany the recognition of these novelties. As an example of the case in point, the extremely variable dorsal body scalation and colour pattern found in the gekkonid lizard genus *Heteronota* has led to considerable confusion, with the description of a large number of species. The following generic diagnosis and review of the nominal species of *Heteronota* is a necessary preliminary to the description of a new species in the genus.

### Diagnosis of the Genus *Heteronota*

*Heteronota* can be distinguished from all other genera of the Gekkonidae by the following combination of characters: terrestrial species with long slender digits; distal phalangeal elements slightly angulate; subdigital lamellae large, rectangular and swollen; a pair of subapical plates; two rows of scales covering sides of digits; subcaudals greatly enlarged transversely; dorsal body scales heterogeneous, consisting of large trihedral tubercles in regular or irregular longitudinal rows and separated by small smooth or keeled conical granules; ventral body scales large, smooth and imbricate; a short angular series of preanal pores in males; cloacal sacs in males and females; a single pair of cloacal bones in males; mental and postmentals large; primary postmentals in contact behind mental; rostral and first supralabial border nostril; pupil with emarginations on both anterior and posterior margins.

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### Nominal Species of *Heteronota*

The present review of nominal species includes all described forms known to be based on examples of *Heteronota* (Group A) and also those which have been erroneously referred to the genus (Group B). Each name is presented in its original form and followed by a citation of the original description and type locality. The present status of the species, where it differs from the original, follows the citation with a reference to the author(s) who made the initial change. If no reference is given the present author assumes the responsibility for the synonymy. The generic name which I regard as being applicable to the genus is placed in square brackets when it differs from that of the author who made the initial change. Following both Groups A and B there is a discussion elucidating some of the synonymy.

#### Group A

- Heteronota binoei* Gray 1845, Cat. Lizards Brit. Mus., p. 174, type locality: Houtman's Abrolhos, Western Australia. Type species of *Heteronota* by elimination.
- Eublepharis derbianus* Gray 1845, Cat. Lizards Brit. Mus., p. 274, type locality: Port Essington, Northern Territory = *Heteronota binoei* Gray *vide* Günther 1867, Ann. Mag. Nat. Hist., ser. 3, vol. 20, p. 50 and Gray 1867, The Lizards of Australia and New Zealand, London, p. 6.
- Hoplodactylus* (*Pentadactylus*) *australis* Steindachner 1867, Reise der Novara (Reptilien), p. 18, type locality: New South Wales = *Heteronota binoei* Gray *vide* Günther 1867, Ann. Mag. Nat. Hist., ser. 3, vol. 20, p. 50 and Gray 1867, The Lizards of Australia and New Zealand, London, p. 6.
- Phyllodactylus anomalus* Peters 1867, Mber, Akad. Wiss. Berlin, p. 14, type locality: Rockhampton, Queensland = *Heteronota derbiana* (Gray) *vide* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 75.

Neither Günther (1867) nor Gray (1867) gave any evidence for synonymizing *Eublepharis derbianus* with *Heteronota binoei* and a number of later workers continued to recognize both species (Boulenger 1885, Oudemans 1894 and Zietz 1920). Lucas and Frost (1896), Procter (1923), Kinghorn (1924), and Loveridge (1934) studied large series of *H. binoei* and supposed *E. derbianus* and have confirmed Günther's and Gray's original action I believe beyond any reasonable doubt.

#### Group B

- Heteronota kendallii* Gray 1845, Cat. Lizards Brit. Mus., p. 174, type locality: Borneo = *Gonatodes* [*Cnemaspis*] *kendalli* (Gray) *vide* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 63.

- Heteronota pelagica* Girard 1857, Proc. Acad. Nat. Sci. Philad., p. 197, type locality: Feejee and Navigator Islands = *Gymnodactylus* [*Cyrtodactylus*] *pelagicus* (Girard) *vide* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 40.
- Gymnodactylus* (*Heteronota*) *arfakianus* Meyer 1874, Mber. Akad. Wiss. Berlin, p. 129, type locality: New Guinea = *Gymnodactylus* [*Cyrtodactylus*] *pelagicus* (Girard) *vide* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 40.
- Heteronota fasciata* Macleay 1877, Proc. Linn. Soc. N.S.W., vol. 2, pt. 1, p. 100, type locality: Hall Sound, New Guinea = *Gymnodactylus* [*Cyrtodactylus*] *heteronotus* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 41.
- Heteronota marmorata* Macleay 1877, Proc. Linn. Soc. N.S.W., vol. 2, pt. 1, p. 100, type locality: Fitzroy Island and Endeavour River, Queensland = *Gymnodactylus* [*Cyrtodactylus*] *cheverti* Boulenger 1885, Cat. Lizards Brit. Mus., vol. 1, p. 41.
- Heteronota eboracensis* Macleay 1877, Proc. Linn. Soc. N.S.W., vol. 2, pt. 1, p. 101, type locality: Cape York, Queensland = *Cyrtodactylus pelagicus* (Girard).
- Heteronota walshi* Kinghorn 1931, Rec. Aust. Mus., vol. 18, no. 5, p. 268, type locality: Boggabri, New South Wales = *Phyllurus walshi* (Kinghorn).

*Heteronota binoci* remained as the only species by Gray's original definition of that genus, when Boulenger (1885) referred *kendalli* to the genus *Gonatodes*. *Heteronota binoci* is therefore considered the type species by elimination (see International Code of Zoological Nomenclature, 1961, Rec. 69B, 3).

Boulenger (1885) referred *Heteronota fasciata* and *H. marmorata* to the genus *Gymnodactylus* (now in part *Cyrtodactylus*, see Underwood 1954) apparently solely on the basis of Macleay's original descriptions. Boulenger was forced to provide new specific names (*heteronotus* and *cheverti*) for both species as Macleay's names

were preoccupied in *Gymnodactylus*. Loveridge (1934) has since synonymized *G. heteronotus* and *G. cheverti* with *C. pelagicus*.

Loveridge (1934) referred *Heteronota eboracensis* to the synonymy of *H. binoci*, however, its affinities appear to lie within the genus *Cyrtodactylus*. Specimens of *Cyrtodactylus pelagicus* from the Cape York Peninsula, Queensland, agree in all respects with the original description of *H. eboracensis*.

The holotype of *Heteronota walshi* has not been examined, but, judging from the original description alone, the species is clearly referable to the genus *Phyllurus*.

From this review of nominal species, *Heteronota binoci* is considered to be the only recognizable species in the genus. While studying the large series of *H. binoci* in the collections of the Western Australian Museum (W.A.M.) and the Department of Zoology of the University of Western Australia, eight specimens from several localities (see Fig. 1) in the North-West Natural Region of Western Australia (Clarke 1926) have proved to be extremely different and are here described as a new species. All of the recently collected material of this species, where accurate locality and habitat information are available, indicates that it is restricted to mines and natural subterranean cavities and it is therefore described as:

#### *Heteronota spelea*, sp. nov.

Holotype; W.A.M. R12638; collected in "Prophecy West" mine at Bamboo Creek, Marble Bar District, Western Australia, by A. M. Douglas and W. D. L. Ride on October 12 or 13, 1957.

Paratypes: W.A.M. R12639-40; also collected in the "Prophecy West" mine and an unnamed adit at Bamboo Creek by A. M. Douglas and W. D. L. Ride on October 12 or 13, 1957.

Diagnosis: *Heteronota spelea* differs from *H. binoci* in possessing regular longitudinal rows of very small trihedral tubercles on the dorsum of the body (see Table 1) and four distinct brown bands on the body and nine to ten on the tail (Fig. 2). In *H. binoci* the tubercles are larger and more randomly scattered and the colour pattern is extremely variable.

Description of holotype: Head somewhat flattened; snout long; rostral rectangular, twice as broad as deep; dorsomedian rostral crease one-half height of rostral; nostril moderately large, directed posterolaterally, surrounded by rostral, first supralabial, one postnasal and two supranasals; anterior supranasal greatly enlarged, meeting counterpart on midline; scales posterior to supranasals greatly enlarged; loreal region strongly concave; 11/12 (right and left sides respectively) scales between postnasal and anterior margin of orbit; dorsal surface of snout slightly concave; supralabials 7/8 (from rostral to immediately below vertical pupil); fourteen scales between centrolateral margins of orbit (excluding supraciliaries and supraocular granules); external ear opening a small obscure slit at level of angle of jaw; mental triangular, much broader than long; primary postmentals meet on midline, greatly enlarged, almost twice as

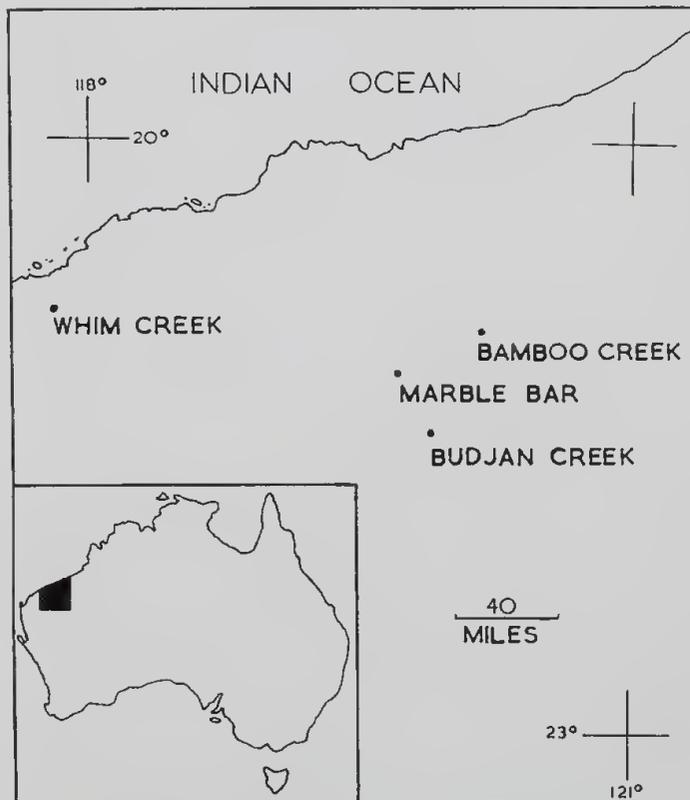


Fig. 1.—The distribution of *Heteronota spelea*.

TABLE I

The range of variation of certain meristic characters of *Heteronota spelea* and *H. binoei* from the zone of sympatry. (\*) indicates the number of specimens examined.

	<i>spelea</i>	<i>binoei</i>	
	(8*)	Mt. Edgar (20*)	Marble Bar (10*)
Number of supralabials	6 to 9 (7.0)	5 to 6 (5.4)	5 to 6 (5.5)
Number of scales between postnasals and preocular granules	10 to 13 (11.2)	8 to 11 (9.6)	8 to 11 (9.3)
Number of keeled scales in primary paravertebral row between axilla and groin	24 to 29 (26.6)	17 to 21 (18.5)	16 to 19 (17.4)
Number of fourth finger subdigital lamellae	13 to 15 (13.6)	8 to 12 (10.7)	10 to 11 (10.6)
Number of fourth toe subdigital lamellae	14 to 18 (16.8)	12 to 14 (13.4)	12 to 14 (13.1)

long as broad, border rostral and first and second infralabials; secondary postmentals enlarged, separated on midline by three small scales; infralabials 8/9; throat region covered with small imbricating cycloid scales; supraocular, interorbital and occipital regions covered with keeled scales, temporal region with irregularly scattered trihedral tubercles and small keeled or smooth granules; dorsum of body covered with large trihedral tubercles in fourteen regular longitudinal rows, twenty-nine tubercles in primary paravertebral row between axilla and groin; longitudinal rows of trihedral tubercles continue on to neck and proximal part of tail; tubercles of longitudinal rows in contact or separated by a small keeled scale or conical granule; two or three conical granules separate primary paravertebral rows of tubercles, adjacent rows in contact or separated by a single conical granule; ventral surface of body covered with imbricating smooth cycloid scales equalling size of dorsal body tubercles; dorsal surface of limbs covered with keeled cycloid scales, those of proximal parts imbricate, distal parts juxtaposed; proximoventral surface of fore limb covered with large conical granules, distal sur-

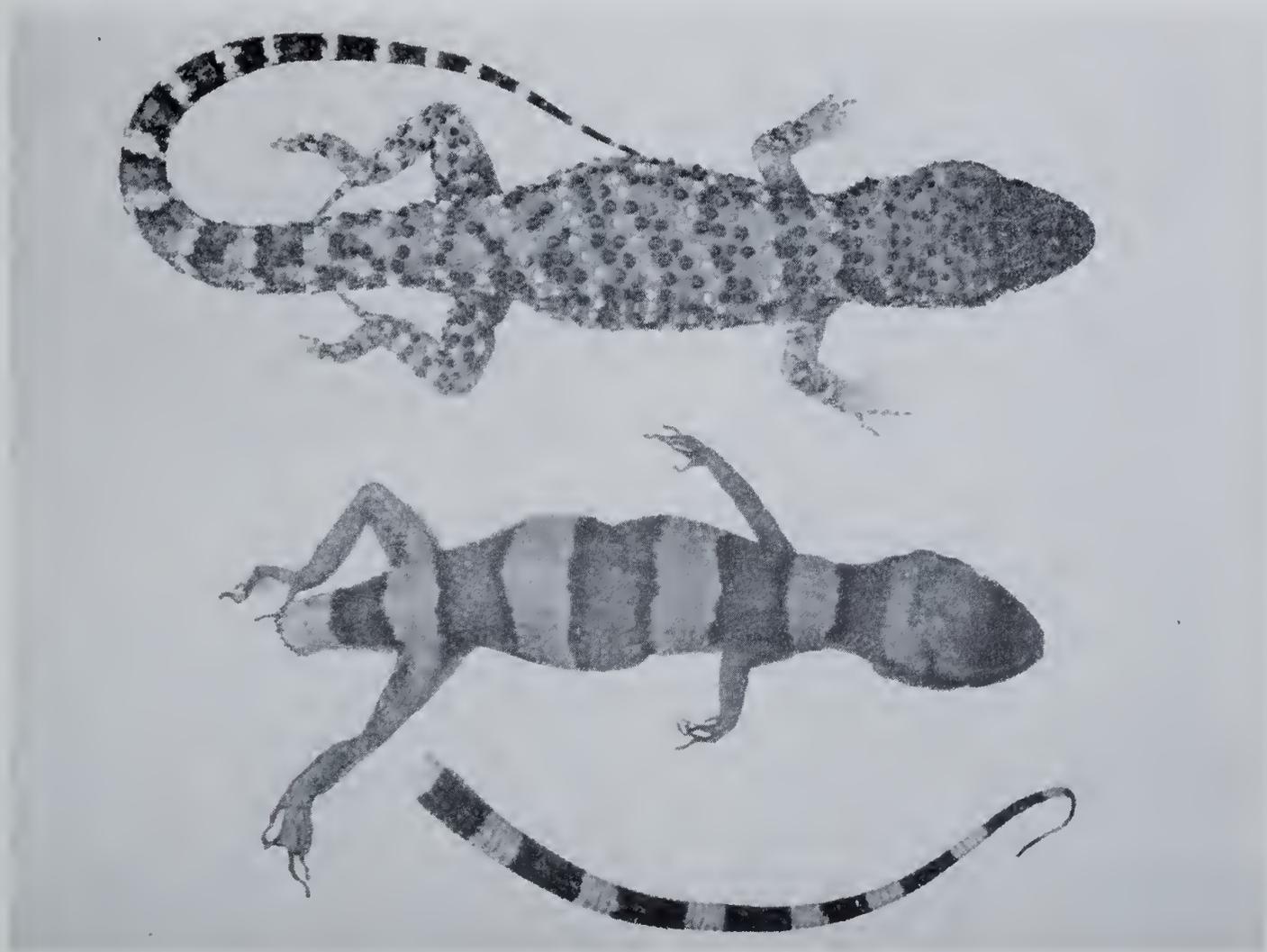


Fig. 2—A dorsal view of *Heteronota binoei* (top) from Marble Bar and the holotype of *H. spelea* (bottom) from Bamboo Creek.

face with large imbricating cycloid scales; ventral surface of hind limb covered with large cycloid scales; posterior surface of thigh covered with small conical granules; dorsal, ventral and posterior regions of thigh sharply defined; digits long, slightly angulate, round in cross section proximally, laterally compressed distally; digits covered inferiorly with enlarged quadrangular subdigital lamellae, those of proximal regions somewhat swollen; claw short, strongly curved, surrounded by a single dorsal and two latero-inferior scales; palmar tubercle greatly enlarged and swollen; fourth finger with 13/14 subdigital lamellae; fourth toe with 17/17 subdigital lamellae; tail long and slender, covered dorsally with strongly keeled imbricating scales forming regular annuli; subcaudals greatly enlarged, bordered laterally by one large or two small scales; female; cloacal spurs indistinct.

Dorsal ground colour yellowish-white; snout covered with sparsely scattered brown chromatophores, heavily concentrated on rostral and labials; faint U-shaped brown mark on occiput; distinct brown postocular eye bar continuous with first brown dorsal band; four wide dark brown bands between nape and sacral region, yellowish-white interspaces equal width of bands (Fig. 2); ten ventrally incomplete dark brown bands on tail; interspaces narrower than bands; all ventral surfaces covered with scattered brown chromatophores, heaviest concentrations on throat region, hands and feet.

Snout-vent length 50.8 (all measurements in millimetres); tail length 75.5; head length 14.9; snout length 6.0; distance from eye to ear 4.8; head width 9.8; distance from axilla to groin 21.0; length of fore limb 17.0; length of fourth finger 3.8; length of hind limb 25.2; length of fourth toe 4.9.

Variation: The following data on external meristic variation are based on (a) paratypes R12639-40 from Bamboo Creek, (b) R12712 from Bamboo Creek, collected by W. D. L. Ride, 1958, (c) R13250 from a natural cave in a low level wash at Budjan Creek, Corunna Downs, collected by A. M. Douglas on May 26, 1959, (d) R14044 from the wall of an adit at approximately the 60 ft. level in the southwest corner of the copper mine at Whim Creek, collected by A. M. Douglas on December 6, 1961, (e) R540 from Marble Bar, collected by A. Brown, and (f) an unlabelled specimen without locality data. All of the above specimens are located in the Western Australian Museum.

Anterior supranasals separated by small granule in R12639; scales posterior to supranasals slightly to greatly enlarged; 10 to 13 (average 11.5) scales between postnasal and anterior margin of orbit; supralabials 6 to 9 (6.8); 15 to 17 (16.1) scales between centro-lateral margins of orbit; external ear opening a small obscure slit or moderately large oval aperture; mental triangular to pentagonal; primary postmentals slightly to moderately enlarged, broader than long to almost twice as long as broad, border mental and first infra-labial or first and second infralabials; secondary postmentals present or absent; infralabials 6 to 8 (6.7); supraocular, interorbital and occipital

regions covered with flattened or elevated keeled scales; trihedral tubercles on body in 12 to 16 (13.6) longitudinal rows; 24 to 29 (26.3) tubercles in primary paravertebral row between axilla and groin; one to four conical granules separating primary paravertebral rows of tubercles, adjacent rows in contact or separated by one to two conical granules; fourth finger with 13 to 15 (13.6) subdigital lamellae; fourth toe with 14 to 18 (16.8) subdigital lamellae; cloacal spurs consist of two to three enlarged fleshy scales in a diagonal row at base of hind limb insertion (apparently no sexual difference in size or number); males, R13250 and unlabelled specimen, with six preanal pores in relatively continuous straight row; U-shaped occipital mark very distinct; nine to ten ventrally incomplete dark brown tail bands.

Discussion: The known geographic range of *Heteronota spelea* is less than 160 miles wide at its extremes (Fig. 1) and is very small when compared to that of the extremely common *H. binoei* which has been recorded from the Shark Bay region of Western Australia to the Cape York Peninsula of Queensland (absent only from the south-western and south-eastern corners of the continent). Apparently *H. binoei* is sympatric over the entire, although limited, range of *H. spelea*. Both species have been collected at Marble Bar and *H. binoei* is very common at Mt. Edgar which is almost equidistant between the Budjan Creek and Bamboo Creek localities of *H. spelea*. Table I shows some of the more obvious morphological differences between the two species in the zone of sympatry.

A large part of the North-West Natural Region is dominated by breakaways which are characterized in part by natural quarries. The region is provided with a still greater number of subterranean cavities as a result of extensive mining in the last 75 years. It is possible that the major reason for the survival of *Heteronota spelea*, in spite of its close association with the apparently highly successful *H. binoei* is that it is restricted to these cavities. *Heteronota binoei* is normally found in open country under natural debris and articles of human habitation. The limited range and peculiar habitat of *H. spelea* suggest that it is a geographical relict. The method and time of speciation will be discussed in a later paper dealing with patterns of speciation in Australian gekkonid lizards.

Although the genus *Heteronota* is endemic to Australia it does not appear to belong to the peculiar diplodactyline group which forms the major portion of the Australian gecko fauna. Based on the general similarity of external meristic and measureable characters *Heteronota* appears to be most closely related to the genus *Cyrtodactylus* which ranges from northeast Africa through southern Asia and Australasia to the Pacific Islands. The only external morphological features that can be used to differentiate between the two genera are associated with the digits. In *Heteronota* the digits are relatively straight, with two rows of lateral scales and with the claw situated between a single dorsal and two lateroinferior plates. In *Cyrtodactylus* the digits are angular, with three or more rows of lateral scales and the claw is

surrounded by single dorsal and ventral plates. In addition to the diagnostic characters listed above, Underwood (1954) stated that the subcaudals in *Cyrtodactylus* are commonly not or but slightly enlarged transversely (in *Heteronota* the subcaudals are greatly enlarged transversely). Underwood's generalization requires qualification as Boulenger (1885) and de Rooij (1915) noted that the subcaudals are greatly enlarged in many species now referred to *Cyrtodactylus*.

Underwood (1957) postulated four gekkotan invasions of Australia. He suggested that *Heteronota* belonged to the third migration which followed the diplodactyline movement, however, distinct from that of the recent expanding modern dominants, i.e. *Gekko* and *Hemidactylus*. The probable time and route of entry into Australia must await a much more complete systematic and zoogeographic study of Australasian geckos.

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**Journal  
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Part 3

**9.—The Plantagenet Beds at Hummocks Beach, Bremer Bay, Western Australia**

By J. G. Kay, J. E. Glover and Rex T. Prider\*

*Manuscript received—11th June, 1963*

A thickness of about 60 feet of the Plantagenet Beds, including a basal conglomerate of gneiss and dolerite, is exposed in a cliff at the northern end of Hummocks Beach, Bremer Bay. The sedimentary sequence nonconformably overlies jointed Precambrian gneisses containing clastic dykes composed partly of gneissic and doleritic fragments. The basal conglomerate of the Plantagenet Beds, which is probably not widespread, was deposited in a shore-line environment very like that in which talus is now accumulating at Hummocks Beach.

**Introduction**

The Plantagenet Beds were named by Jutson and Simpson (1917) but although references were made to the rocks before and after their work, the first comprehensive account of the geology of the sequence was not published until thirty-seven years later (Clarke and Phillipps 1954). Clarke and Phillipps listed all relevant literature, and cited the then generally accepted opinion that the Plantagenet Beds were Miocene, but recent evidence has indicated an Eocene age (see Glaessner 1953, p. 143, 1955, p. 357; Singleton 1954, p. 62; Cookson 1954; Cookson and Pike 1954; McWhae *et al.* 1958; Glenister and Glover 1958; and Quilty *in* Hodgson *et al.* 1962). Quilty (personal communication) now considers that planktonic foraminifera from deposits at Nannarup and Albany indicate an Upper Eocene age correlating with Carter's faunal unit 2 (Carter 1958). However, field observations have not kept pace with palaeontological advances and the work at Cheyne Bay of Hodgson (1962) and Hodgson *et al.* (1962) represents the only significant contribution to our knowledge of the distribution and lithology of the Plantagenet Beds since the investigation of Clarke and Phillipps. There is, therefore, justification for recording here the hitherto undescribed exposures which occur at the north end of a beach known locally as Hummocks Beach, in Bremer Bay. No fossils have been found in these sedimentary rocks, but their stratigraphic position, and the appearance and lithology of the upper part of the sequence, indicate their continuity with the fossiliferous Plantagenet Beds 6 miles to the north on the Gairdner River. This is

borne out by the presence of isolated outcrops in the aeolian sands between Hummocks Beach and the Gairdner River.

The Plantagenet Beds at Hummocks Beach attain a thickness of up to 60 feet and their nonconformity with underlying Precambrian gneisses is clearly exposed in a cliff section. The bottom section, from 5 to 15 feet thick, of the Plantagenet Beds is here made up of a remarkable conglomerate containing boulders of granitic gneiss and highly kaolinized basic rock and the upper section, 45 to 55 feet thick, is composed of claystone. The outcrop of conglomerate extends laterally for about 400 feet and there is no evidence so far to suggest that it has wider extent, or that it occurs elsewhere.

**Access**

Hummocks Beach (sometimes also called Peppermint Beach) is most easily approached from Bremer Bay township by crossing the semi-permanent sand bar at the mouth of the Bremer River and following the northerly track that leads to the Gairdner River. This track follows an abandoned telegraph line. Approximately five miles north of the Bremer River bar, an easterly track that leads to Doubtful Island Bay, Point Hood and Hummocks Beach, should be taken. The latter track is sandy in places but is passable by two-wheel drive vehicles driven with care. The tracks are shown on Fig. 1.

**Geology**

*Regional Geology*

Basement rocks in the area are Precambrian gneisses and granulites of high metamorphic grade. The gneissic foliation trends in the direction 250° and dips steeply south. A dolerite dyke which is about 20 yards wide and trends 330° crops out about 3½ miles east-south-east of the conglomerate location. Basement rocks are overlain in places by the Plantagenet Beds, and elsewhere by aeolian, quartz-rich sand.

*The Hummocks Beach Section*

The cliff section at Hummocks Beach exposes up to 12 feet of Precambrian gneiss which is overlain nonconformably by up to 60 feet of

\* All of the Department of Geology, University of Western Australia, Nedlands, Western Australia.

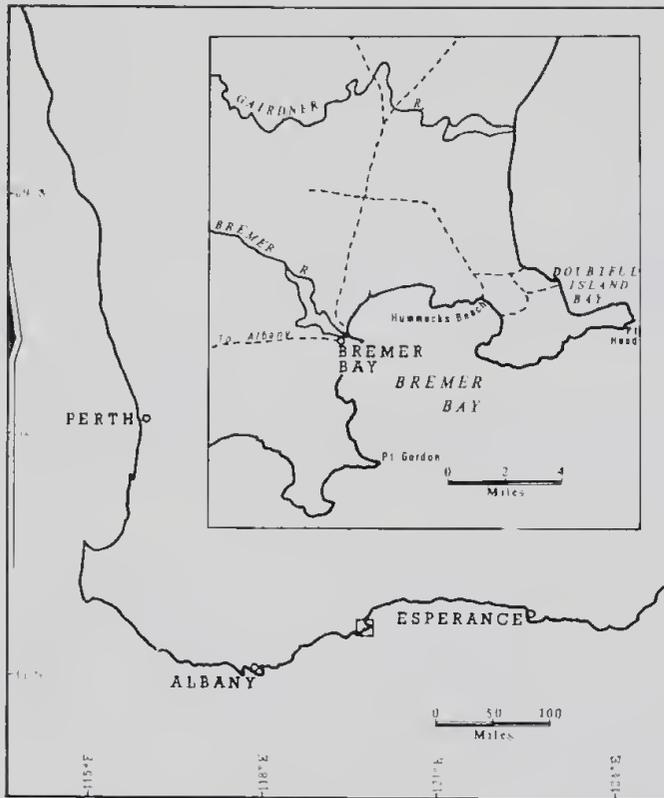


Fig. 1.—Locality map.

the Plantagenet Beds. The original thickness of the Eocene sequence in this area is unknown, but thicknesses of 300 feet (Clarke and Phillipps 1954, p. 4) and 250 feet (Hodgson *et al.* 1962, p. 48) preserved elsewhere indicate that several hundred feet may have been eroded.

*Precambrian Rocks.*—The Precambrian rocks immediately underlying the Plantagenet Beds are poorly banded acid gneisses containing thin bands of basic granulite. Specimen 44811\* which is representative of the gneiss, is a grey, greasy looking, medium-grained, poorly banded rock. In thin section it is seen to be a granoblastic aggregate of antiperthitic oligoclase (60%), perthitic microcline (20%), quartz (12%), hypersthene (4%) and augite (3%), with accessory granules of magnetite, apatite and zircon. The pyroxene grains are dispersed throughout the rock, but a tendency for their concentration into bands has resulted in the poorly developed gneissic structure seen in hand specimen. There is evidence of crushing in the rock for the margins of many quartz and feldspar grains are finely granulated.

*Plantagenet Beds.*—The lowermost 5 to 15 feet of the Plantagenet Beds consist of boulder, cobble and pebble conglomerate and the rest is mainly claystone. The largest boulders in the conglomerate are subrounded with diameters of up to 15 feet, and consist of grey, granitic

\* Specimen numbers are those of the Department of Geology, University of Western Australia.



Fig. 2.—Basal conglomerate in the Plantagenet Beds showing two large boulders of gneiss with fresh cores and strongly weathered rims.



Fig. 3.—The large light grey boulders, one of which contains darker, unweathered patches, are granitic gneiss. Smaller light grey boulders and cobbles packed between the large boulders consist of kaolinized basic rock.

gneiss. Many of the large boulders of gneiss are weathered marginally to a depth of about one foot (Fig. 2) and smaller fragments are kaolinized throughout. Between the large boulders there is commonly an assemblage of smaller boulders, cobbles and pebbles of soft, highly kaolinized, light grey, basic rock (Fig. 3). In some places the basic fragments are so tightly packed that only about 10 per cent. of the resultant conglomerate is composed of white interstitial cement (Fig. 4). The cement is mainly argillaceous but is locally sandy.

Microscopic examination of crushed fragments of the basic rock reveals cloudy argillaceous material from which quartz is absent or present only sparingly. The texture of selected fragments was made clearer by staining flat surfaces with "malachite green" which colours some clay minerals more deeply than others. Strong indications of porphyritic and ophitic textures are visible when stained surfaces are varnished and examined with a hand lens. In one fragment which probably came from the chilled margin of an intrusion, the relict texture ranges from aphanitic to fine-grained ophitic. These observations leave no doubt that the kaolinized material is dolerite. Soft, white veins which cut some dolerite fragments were probably originally end-stage veinlets.

The conglomerate passes upward into bedded, slightly iron-stained, white, poorly consolidated, sandy claystone (Fig. 5). A thin section of claystone (No. 49917, from 8 feet above the top of the conglomerate) reveals that the specimen consists of finely divided argillaceous material (88%), angular quartz grains, most of which are about 0.2 mm in diameter (7%), and biotite, chlorite and muscovite (4%). Glauconite has not been positively identified but may be present. Other minerals include feldspar, black iron ore and zircon. The claystone is draped irregularly over the large boulders near the top of the conglomerate, but higher in the sequence the bedding is regular and practically horizontal.

Some of the weathered gneiss which is *in situ* beneath the nonconformity contains clastic dykes which extend for several feet and are up to three or four inches wide (Figs. 6, 7). These dykes contain fragments of kaolinized dolerite up to  $\frac{1}{2}$ -inch in diameter, quartz grains and rare fragments of gneiss, in an argillaceous matrix. Some of the dykes are parallel to joints in the fresh gneiss forming part of the same outcrop and it is clear that these dykes result from the infilling of fissures weathered out along such joints. Some clastic dykes (Fig. 7) branch and



Fig. 4.—This photograph reveals in greater detail the kaolinized basic fragments shown near the centre of Fig. 3. Note the close packing of the fragments, and the white veinlets that transect some of them. The basic fragments are dolerite, and the veinlets are probably end-stage injections (see text).



Fig. 5.—The basal conglomerate is overlain, toward the top of the photograph, by horizontally bedded claystone. Basement gneiss is shown at the bottom of the photograph.

wedge out downward indicating infilling from above of fissures developed along irregular cracks. It is evident that most of the kaolinization of the dolerite took place after the fragments were incorporated in the conglomerate and clastic dykes, for in their present completely kaolinized state the fragments crumble easily and would not survive much movement. It is most likely also that the friable weathered shells around boulders of gneiss formed after their incorporation in the conglomerate. The intense weathering of the conglomerate was most probably effected before its exposure in the present cycle.

#### Environment of Deposition of the Plantagenet Beds

The lithology and texture of the basal conglomerate of the Plantagenet Beds is best explained by assuming that it formed along a shore-line and its environment of deposition in the Hummocks Beach area was probably very like the present environment. At present boulders of gneiss comparable in size and shape to those in the basal conglomerate of the Plantagenet Beds are scattered along the base

of the cliff (Fig. 8) and although some have weathered out of the conglomerate, others are clearly forming from the exposed basement rocks. Jointed gneisses are partly exposed and partly covered by sand that doubtless fills many concealed fissures to form embryonic clastic dykes. There were, however, some differences during the deposition of the basal Plantagenet Beds. For example, the gneiss, before its partial erosion to yield boulders for the conglomerate, must have been more strongly outcropping than now and there must have been dolerite outcrop nearby. Furthermore, sea-level relative to the base of the conglomerate was probably 10 or 15 feet higher than at present. Nevertheless, there is little doubt that during the time represented by the conglomerate, waves of the South-



Fig. 6.—Clastic dyke in gneiss near the bottom of the cliff on Hummocks Beach.



Fig. 7.—A clastic dyke in the basement gneiss branches and wedges out downward.



Fig. 8.—A general view of the cliff at Hummocks Beach, with shallow water in the foreground. Note the exposed basement gneiss, the basal conglomerate and the overlying claystone. Boulders of gneiss at the foot of the cliff have come from weathering of the basement rocks and the conglomerate.

ern Ocean beat against the coast in much the same place as they do now at the north end of Hummocks Beach. The change from conglomerate to claystone without an intervening transgressive sandstone phase may be the result of sudden incoming of the sea, rather than gentle eustatic movement. In any case, the sea eventually transgressed large areas of the continent. At first the fine sediments were draped over large boulders at Hummocks Beach, but as irregularities were smoothed out the deposits became essentially horizontal.

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## Memorial

### Enid Isabel Allum

In an association of over 40 years with the Royal Society of Western Australia, Miss Allum must be remembered as a most faithful member. Miss Allum's enthusiasm and interest have encouraged members in their scientific endeavours, while her cheerfulness in the face of suffering and disability has inspired them personally.

Miss Allum served the Society as Treasurer from 1920 to 1927 and as Council Member from

1931 to 1936 and in 1952 was elected to Honorary Associate Membership.

A teacher of pianoforte by profession, Miss Allum was also an artist of note, being responsible for the prize-winning design for the Kelvin Medal of the Society.

Miss Allum is remembered in the Society with affection and respect and expressions of sympathy are extended to her relatives and friends.

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## Memorial

### Ludwig Glauert

Mr. Ludwig Glauert, one of Western Australia's best known naturalists, passed away on February 8th, 1963, at the age of 84. Ludwig Glauert was born on May 5th, 1879, at Sheffield, England. He arrived in Western Australia in 1908 and commenced work as a field geologist in the Geological Survey, transferring to the Western Australian Museum in 1910 where he served for 46 years. He occupied positions as scientific assistant, keeper of ethnology and geology, Curator and finally Director, working assiduously to overcome administrative and financial difficulties whilst researching into natural history. He carried the Museum to the public by means of contributions to local magazines and newspapers, and introduced Museum classes for schoolchildren, an innovation in Australia at that time.

On his arrival in Western Australia, he joined the Natural History and Science Society of Western Australia, serving as its Secretary in 1908-9 and as Councillor in 1911-12. On his return from military service he joined the Royal Society and the following year was elected to Council and served the Society for many ensuing years as Librarian from 1925-40 and President in 1933-35 and 1947-48. He took a prominent part in the foundation of the Western Australian Naturalists' Club in 1924 and maintained a strong interest in its activities throughout his life.

He was awarded the Australian Natural History Medal in 1948, the Kelvin Medal for his contribution to science in 1954, the Carnegie Award in 1954 and received the M.B.E. in 1960. In 1953, he was made an Honorary Life Member of the Royal Society of Western Australia.

# 10.—Vertebrate Remains from the Nullarbor Caves, Western Australia

By Ernest L. Lundelius, Jr.\*

Manuscript received—20th March, 1963

Six caves, Cocklebiddy Cave, Murraelleleuan Cave, Madura Cave, Webb's Cave, Snake Pit and Abrakurrie Cave, located along the southern edge of the Nullarbor Plain, have yielded the remains of Pleistocene and Recent vertebrates. The Recent material extends the known range of one species, *Pseudomys (Thetomys) occidentalis*, 600 miles eastward. Remains of *Potorous* from Webb's Cave are intermediate morphologically between *Potorous platyops* from Western Australia and *Potorous morgani* from Kangaroo Island, South Australia. Webb's Cave also contains remains of *Sarcophilus harrisi* in association with recently introduced species. In the lower, red soil unit of Madura Cave a  $P_3$  of *Sthenurus* and a wombat tooth similar in size to *Phascologomys parvus* have been found. The presence of *Sthenurus* in Pleistocene deposits in this area suggests a more humid climate at that time.

## Introduction

Numerous caves have been known in the Cretaceous and Tertiary limestones along the southern edge of the Nullarbor Plain since Tate reported them in 1879. The isolated and desolate nature of this region, however, has delayed the study of the caves and their deposits.

The present study was undertaken to locate caves which contain fossiliferous deposits which could be used to reconstruct the faunal and climatic history of the area.

The caves considered here extend from the vicinity of Cocklebiddy Tank, 140 miles east of Balladonia, to the South Australian boundary (Fig. 1). Additional caves are known from the Nullarbor Plain in South Australia but have not been investigated by the author.

This report is based on a three-week reconnaissance trip along the Eyre Highway during August, 1955.

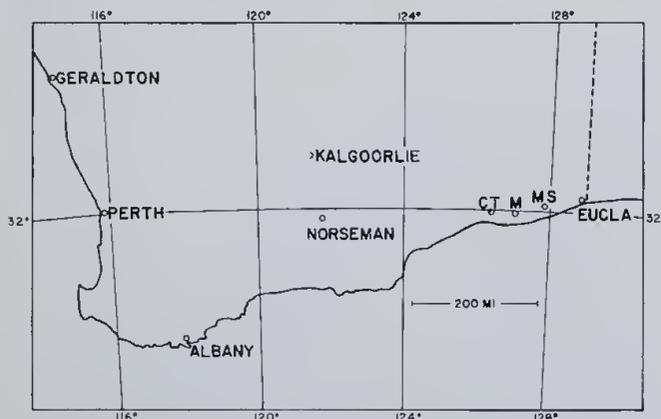


Fig. 1.—Map of southern Western Australia. CT Cocklebiddy Tank, M Madura, MS Mundrabilla Station.

\* Department of Geology, The University of Texas, Austin 12, Texas.

Vertebrate remains were found in six caves. A Recent age for most of the deposits is indicated by the remains of the house mouse, *Mus musculus*, and the European rabbit, *Oryctolagus cuniculus*. Other deposits are older and one goes back as far as the Pleistocene although no precise dates are available at the present time. Brief descriptions of the caves and faunal lists are presented here in the belief that the information will be useful to studies of the recent fauna, and to call attention to the possibility of studying the faunal history of this region.

The author (Lundelius 1957) has previously reported range extensions of a number of species of mammals based on remains from Recent deposits of these caves. These species are listed here along with two species, *Pseudomys (Gymys) occidentalis* and *Lasiorhinus latifrons* which were identified after publication of the 1957 paper.

The faunal lists contain only the mammals. The identification of the avian and reptilian material proved impossible because of lack of adequate comparative material.

## Cocklebiddy Cave

Cocklebiddy Cave is a large cave located about five miles north of the Eyre Highway, 135 miles east of Balladonia. The only deposits in the cave are composed of large boulders of limestone derived from the roof collapse which formed the opening. Bones are sparsely distributed on the surfaces of the boulders. The material consists of well-preserved bones of small reptiles, birds and mammals (Table I). The material was probably brought into the cave by owls. The mammals have been previously known from the Nullarbor Plains area.

## Murraelleleuan Cave

Murraelleleuan Cave is located four and one half miles west of Cocklebiddy Tank. The opening has been formed by roof collapse. A vertical walled pit with a sloping floor of rock debris leads to a large underground chamber on the east side. The remains of animals were collected from a limited area under the overhanging roof, most of which represent material from the regurgitated pellets of owls. Many of the pellets were not completely broken down and still retained some of their original form. A few kangaroo bones were also found.

All but one of the species found in this cave have been recorded previously from this area. The exception is *Pseudomys (Gymys) occidentalis* Tate which is rare in the deposit. It has been known previously from the southwestern part of Western Australia (Tate 1951).

**TABLE I**

*Faunal List from Cocklebiddy, Murraellevean, Webb's, and Snake Pit Caves*

	Cockle-biddy Cave	Murraellevean Cave	Webb's Cave and Snake Pit Cave
Order Marsupialia			
Family Dasyuridae			
<i>Dasyurus geoffroyi</i> (Gould) ...	..	+	+
<i>Dasygaleus cristicauda</i> Krefft ...	+	+	+
<i>Phascogale calura</i> Gould ...	..	+	+
<i>Sminthopsis crassicaudata</i> (Gould) ...	+	+	..
<i>Antechinomys</i> sp. ...	+	+	..
<i>Sarcophilus harrisi</i> (Boitard) ...	..	..	+
Family Peramelidae			
<i>Macrotis lagotis</i> (Reid) ...	+	+	+
<i>Perameles bougainvillei</i> Quoy and Gaimard ...	..	+	..
Family Phalangeridae			
<i>Trichosurus vulpecula</i> Kerr ...	..	+	..
<i>Cercartetus concinnus</i> ...	..	+	..
<i>Pseudocheirus occidentalis</i> (Thomas) ...	..	..	+
Family Macropodidae			
<i>Bettongia lesueuri</i> (Quoy and Gaimard) ...	..	..	+
<i>Bettongia penicillata</i> Gray ...	..	..	+
<i>Lagorchestes hirsutus</i> Gould ...	..	+	..
<i>Macropus</i> sp. ...	..	+	..
<i>Potorous platypus</i> (Gould) ...	..	..	+
<i>Caloprymnus campestris</i> (Gould) ...	..	..	+
Order Rodentia			
Family Muridae			
<i>Leporillus conditor</i> (Sturt) ...	+	+	..
<i>Leporillus apicalis</i> (Gould) ...	..	+	..
<i>Notomys mitchelli</i> (Ogilby) ...	+	+	+
<i>Pseudomys rawnianae</i> Troughton ...	+	..	+
<i>Pseudomys (Gyomys) occidentalis</i> Tate ...	..	+	..
<i>Leggadina hermannsburgensis</i> (Walte) ...	..	+	+
<i>Mus musculus</i> Linnaeus ...	..	+	..
Order Chiroptera			
<i>Myotis geoffroyi</i> Leach ...	..	..	..
Order Lagomorpha			
<i>Oryzolagus cuniculus</i> (Linnaeus) ...	..	+	..

Its presence in these surface deposits indicates that it is a part of the Recent fauna of the Nullarbor Plain and extends its range 600 miles eastward. The Nullarbor specimens show some minor differences from those from farther west. These differences will be reported in detail in a later study.

**Madura Cave**

Madura Cave is located six miles south of Madura on the road from Madura to the coast. It is a small cave whose entrance has been formed by collapse of the roof. Two passages lead from the collapsed area, one to the south-west for approximately one hundred feet where it ends, the other extends north-west for approximately 275 feet where it divides into two passages which extend on for an additional 200 feet before becoming too small to enter. Frost (1958) has published a sketch map of the cave.

The NW-SE passage is partly filled with sediment from which the bones were collected. Some of the fill is now being removed by channelling.

Two test trenches were dug. Trench 1 was sunk near the opening. It was excavated to a total depth of 3 feet without reaching the bed rock floor of the cave. The upper 2½ feet of fill consists of fine, light brown silt with abundant bones in the top six inches. The lower six inches consists of red earth with limestone

fragments up to eight inches in diameter. The bone in this lower layer is scarce and badly broken.

Trench 2 was sunk at the point at which the cave divides into two passages. The upper layer of brown silt is absent. The fill at this point consists of one foot of red soil with rocks up to six inches in diameter underlain by 14 inches of alternating, crossbedded layers of white sand and dark silt which rests on the limestone floor of the cave. The bone in both layers is badly broken.

With the exception of the wombat, all the species obtained from the upper brown silt in Trench 1 have been known previously from the area. *Lasiorchinus latifrons* occurs today in the Nullarbor Plain of South Australia almost to the boundary of Western Australia. Its presence in Madura Cave is approximately 110 miles west of its present known occurrence, but within the range accorded it in old reports of an anecdotal kind (Jenkins 1962).

The exact age of the brown unit is not known. The fact that the present drainage in the cave is entrenched in the fill indicates that erosion is the dominant process in the cave today. Thus the deposition of the brown unit and the bones predates the present entrenching but not necessarily by a very long time.

The material from the lower red soil unit is too sparse to give any real idea of the fauna at the time of its deposition. As in the upper unit the only species which is not known from the area at present is the wombat. This species is represented by one tooth which is inadequate for an accurate specific identification. The size of the tooth is within the range of *Phascolomys parvus*, a Pleistocene species, but it could equally well represent a juvenile individual of *L. latifrons*.

**TABLE II**

*Faunal List from Madura Cave*

	Trench 1		Trench 2
	Top 1 foot	2½ feet below surface	2½ feet below surface
Order Marsupialia			
Family Dasyuridae			
<i>Sminthopsis crassicaudata</i> (Gould) ...	+	..	..
<i>Antechinomys</i> sp. ...	+	..	..
<i>Dasygaleus cristicauda</i> Krefft ...	..	+	..
<i>Phascogale calura</i> Gould ...	+	..	..
Family Peramelidae			
<i>Macrotis lagotis</i> (Reid) ...	+	..	..
<i>Perameles bougainvillei</i> Quoy and Gaimard ...	..	..	..
Family Macropodidae			
<i>Macropus</i> sp. ...	..	..	..
<i>Sthenurus</i> sp. ...	..	..	..
<i>Bettongia lesueuri</i> (Quoy and Gaimard) ...	..	..	..
<i>Lagorchestes hirsutus</i> Gould ...	..	..	..
Family Phascologyidae			
<i>Phascolomys</i> sp. ...	..	..	..
Order Rodentia			
Family Muridae			
<i>Notomys mitchelli</i> (Ogilby) ...	..	..	..
<i>Leporillus conditor</i> (Sturt) ...	+	+	..
<i>Leporillus apicalis</i> (Gould) ...	+	+	..
<i>Leggadina hermannsburgensis</i> (Walte) ...	..	..	..
<i>Pseudomys rawnianae</i> Troughton ...	+	..	..

The material from the red soil zone of Trench 2 contains remains of Recent species, with the addition of a lower third premolar of the extinct *Sthenurus* (Fig. 2). *Sthenurus* has been recorded in Western Australia from Mammoth Cave (*S. occidentalis*—Glauert 1910) and from Balladonia (*S. atlas*\*—Glauert 1912).

The new material cannot be assigned to either of these species. The presence of *Sthenurus* probably indicates a late Pleistocene or early Recent age for this unit. Gill (1955) reports the most recent  $C^{14}$  date for *Sthenurus* in eastern Australia as 13,000 years and Tedford (1955) assigns a late Pleistocene or early Recent date on *Sthenurus* from Lake Menindee in New South Wales.†

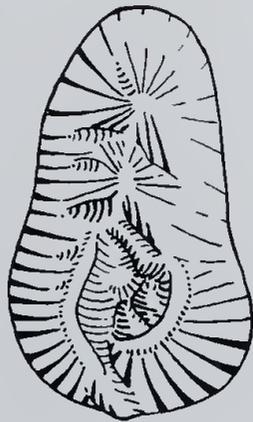


Fig. 2.— $P_3$  of *Sthenurus* sp. from Madura Cave. (CNHM PM4356). (X3.)

*Macropus* is represented by a portion of a right mandible with  $M_4$  intact. The mandible and the proportions of the  $M_4$  closely resemble those of *M. rufus* but are slightly larger than any the writer has seen. The difference is not great and probably does not justify separating it from *M. rufus*.

#### Webb's Cave and Snake Pit Cave

Webb's Cave and Snake Pit Cave are located just north of the Hampton Scarp at Mundrabilla Station homestead. Both caves are small and are located within a mile of one another. The floors of both caves are formed of large blocks of limestone which have fallen from the roof. Most of the bones occur in a very thin layer of silt and dust (rarely exceeding one foot) on the surface of the larger blocks. Remains of *Mus musculus* and rabbits, both European imports, indicate that the deposit is of very recent age.

The bones in Snake Pit Cave appear to be derived from animals which fell in and died. The opening is a sinkhole which would be a natural trap for animals.

The bones in Webb's Cave appear to have been brought in by owls and predators. The small animals are represented by unbroken

\* The paper by Marcus (1962), in which doubt is cast on the identification of Balladonia material as *Sthenurus atlas*, was received too late for consideration.

† It appears now that the latter dates are in error (Tedford, pers. comm.); efforts are being made to obtain an accurate date.

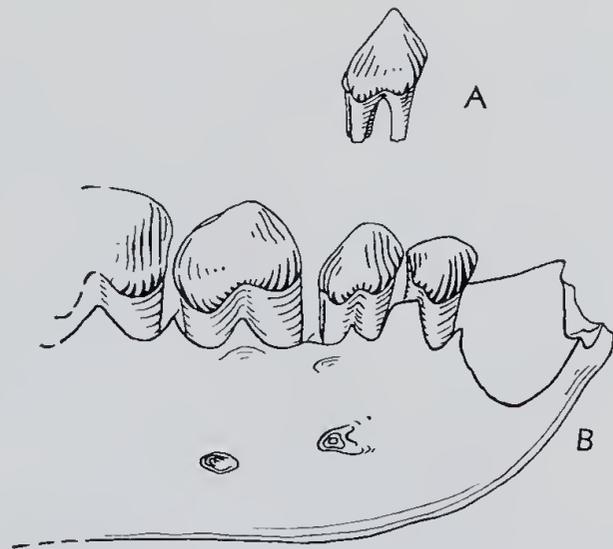


Fig. 3.—Labial view of (A) right  $P_2$  of *Sarcophilus harrisi* (CNHM PM4354) from Webb's Cave, (B) mandible (CNHM PM4353) from Wedge's Cave, Western Australia. (X2.5 approximately.)

mandibles, limb bones, and skulls. The bones of larger species are usually badly broken, probably by predators.

All of the species except *Sarcophilus harrisi*, which is indicated by one lower premolar (Figs. 3 and 4), have been reported previously from the Nullarbor Plains. The specimen is almost identical with a lower premolar of a specimen from Wedge's Cave at Mimegara, Western Australia. In addition, the broken condition of most of the larger bones indicates the presence

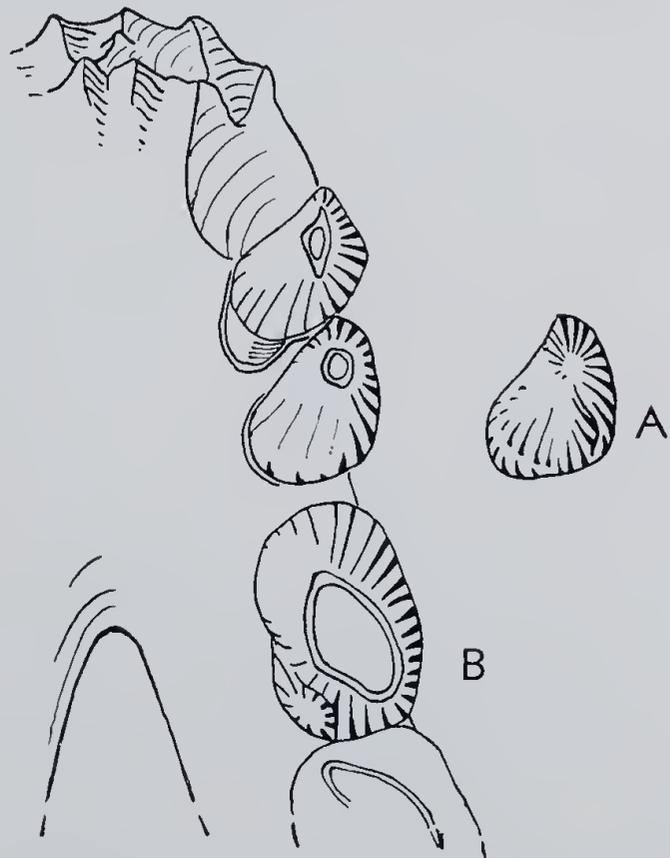


Fig. 4.—Occlusal view of (A) right  $P_2$  of *Sarcophilus harrisi* from Webb's Cave, (B) mandible from Wedge's Cave, Western Australia. (X3 approximately.)

of a relatively large carnivore. This association of broken bones and the remains of *Sarcophilus* has been reported by the author (Lundelius 1960) in two other Western Australian caves. The presence of *Sarcophilus* in very recent deposits is extremely interesting but not wholly unexpected in the light of reports of its occurrence in Australia (Jones 1923) and a record of it in Victoria dated at 500 years (Gill 1955). This indicates a very recent disappearance of this animal from the Australian mainland.

Another very interesting occurrence in Webb's Cave is *Potorous platyops*. The material consists of one immature skull with the right and left deciduous P<sup>2</sup> and the left deciduous P<sup>3</sup>. The right side of the palate is completely preserved and shows an unerupted M<sup>4</sup>.

Although the comparison of immature and mature individuals is often hazardous this occurrence is of sufficient importance to warrant the comparison of this specimen with *P. platyops* and *P. morgani*. The comparisons are based on description and figures in Finlayson (1938) and some fragmentary material from cave deposits along the west coast of Australia.

The Nullarbor specimen agrees with *P. platyops* and differs from *P. morgani* in having a definite restriction of the interorbital area. *P. morgani* has a parallel sided interorbital area. On the other hand it differs from *P. platyops* in having the posterior part of the nasals less expanded.

The deciduous P<sup>2-3</sup> present in the Nullarbor specimen have not been described in either *P. platyops* or *P. morgani* so no comparisons can be made of the dentitions. The deciduous P<sup>2</sup> is

a simple blade composed of two cusps of which the anterior is the larger. The two cusps are connected by a thin ridge which bears two very shallow grooves on its inner and outer surfaces. The anterior cusp bears a tiny tubercle on its anterior edge. The inner basal surface is strongly convex.

The deciduous P<sup>3</sup> is subquadrangular in outline with the greatest length along the outside edge. The two outer cusps are of the same size and stand higher than the two inner cusps. They are connected by a low ridge. The antero-external cusp has an anterior blade like extension which is responsible for the long outer edge. The two lingual cusps are equal in size. The two anterior and posterior cusps are connected by low ridges. A posterior cingular ridge is present.

The only molar present is the right M<sup>1</sup> which is unerupted. The alveoli of the other molars indicate that their relative sizes are M<sup>2</sup> < M<sup>1</sup> < M<sup>3</sup>.

This occurrence of *P. platyops* in the Nullarbor area is geographically intermediate between the type locality of *P. platyops* in Western Australia and that of *P. morgani* on Kangaroo Island, and might be expected to shed some light on the relationship between *P. platyops* and *P. morgani*. As noted above, the Nullarbor specimen is morphologically intermediate but the nature of the material prevents a comprehensive comparison.

In any consideration of the relationship of the two species it should be kept in mind that Kangaroo Island is very close to the mainland and the maximum depth of water between them is 120 feet (British Admiralty Chart; Australia,

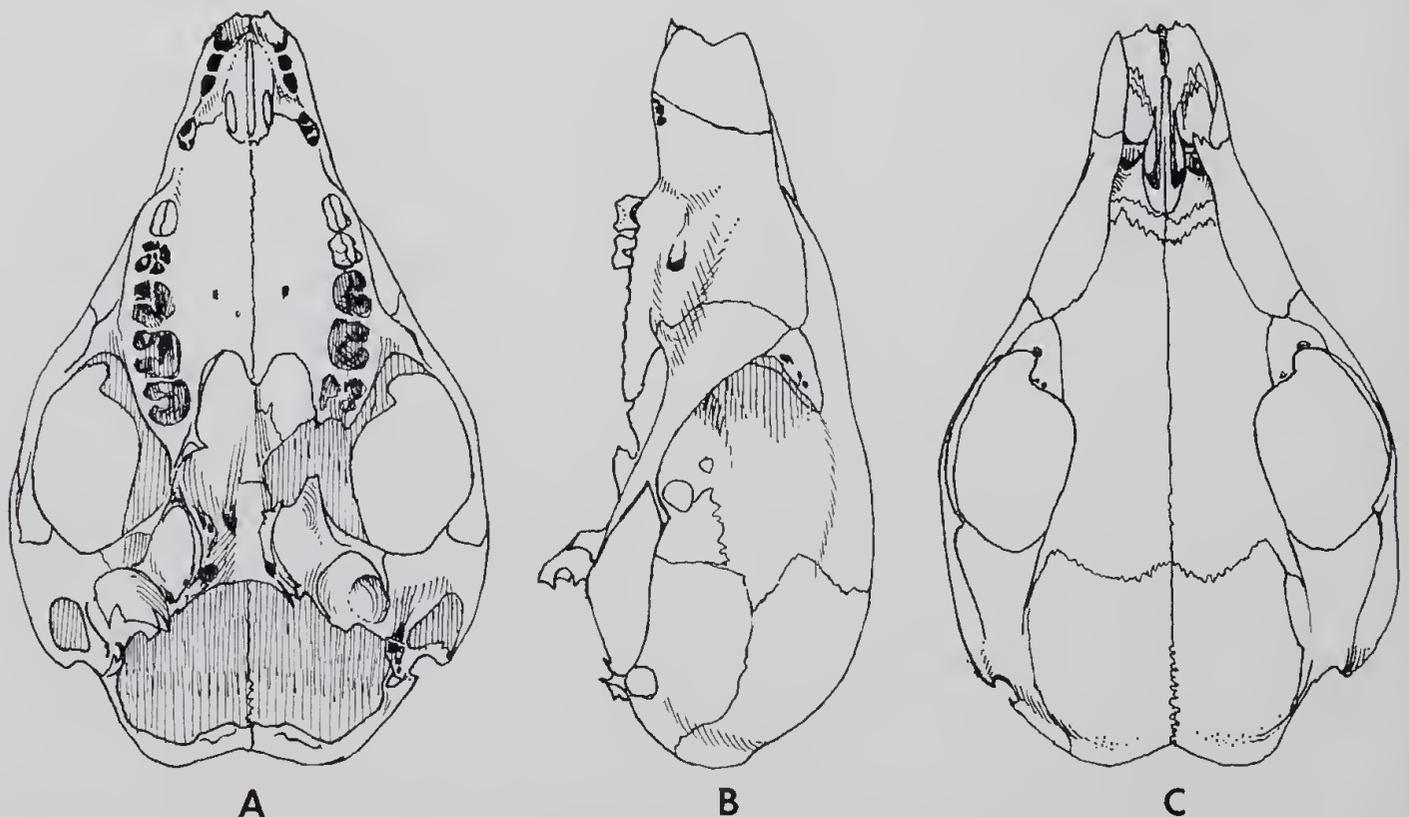


Fig. 5.—Ventral view (A), lateral view (B), and dorsal view (C) of *Potorous platyops* (CNHM PM4355) from Webb's Cave. (X1.5 approximately.)



Fig. 6.—Occlusal view of P<sup>2-3</sup> of *Potorous platyops* (CNHM PM4355).

Southern Portion). This indicates that its separation from the mainland is probably a result of the post glacial sea level rise (Godwin *et al.* 1958). Thus it is quite possible that the two species of *Potorous* under discussion actually represent different populations of the same species which was widespread along the south coast of Australia. More complete material from the Nullarbor Plain is needed to settle this question.

**Abrakurrie Cave**

Abrakurrie Cave is located 25 miles north of Eucla. It is a large cave with a high arched roof. The entrance was formed by roof collapse. The fill consists of red silt with some limestone gravel near the entrance. The profile of the walls and roof of the cave suggest that the fill may be quite deep. Test trenches were dug to a depth of 2½ feet without encountering the bed rock floor of the cave. Almost all the vertebrate remains were collected from the upper one foot of fill near the entrance. Table III shows the distribution of the species by levels in the cave. All of these have been reported previously from this area.

Six of the seven caves investigated by the author contained the remains of vertebrates. This indicates that there is a good chance of obtaining cave deposits which will yield a faunal sequence. From this can be inferred the climatic history.

**TABLE III**  
Faunal List from Abrakurrie Cave

	Surface	2 feet below surface
Order Marsupialia		
Family Dasyuridae		
<i>Dasyurus geoffroyi</i> (Gould)	+	..
<i>Dasyurus cristicauda</i> Kreffl	+	+
<i>Antechinus</i> sp.	+	+
<i>Sminthopsis crassicaudata</i> (Gould)	+	..
Family Peramelidae		
<i>Macrotis lagotis</i> (Reid)	+	..
<i>Perameles bougainvillei</i> Quoy and Gaimard	+	..
Family Macropodidae		
<i>Bettongia lesueuri</i> (Quoy and Gaimard)	+	..
<i>Bettongia penicillata</i> Gray	+	..
<i>Macropus</i> sp.	..	+
Order Rodentia		
Family Muridae		
<i>Natamys mitchelli</i> (Ogilby)	+	+
<i>Pseudomys rufinus</i> Troughton	+	..
<i>Leggadina hermannsburgensis</i> (Waite)	+	..
<i>Leporillus conditor</i> (Sturt)	+	..
<i>Leporillus apicalis</i> (Gould)	+	..

A knowledge of the faunal and climatic history of the Nullarbor Plain would be very useful in checking ideas concerning the speciation patterns in some Western Australian animals. Main, Lee and Littlejohn (1958) and Serventy (1951) have explained the existence of several closely related species of frogs and birds in Western Australia as the result of successive faunal movements from eastern Australia to

Western Australia during humid periods of the Pleistocene. Intervening arid periods are postulated as periods of isolation of the eastern and western faunas. The humid periods are believed to be correlated with the glacial stages of the Pleistocene, the arid periods with the interglacial stages. The southern part of the Nullarbor Plain is the most likely route of these faunal movements.

The only data concerning the faunal history of the Nullarbor Plain come from a fossil fauna reported by Glauert (1912) from a swamp deposit at Balladonia. This fauna is of Pleistocene age and indicates a more moist climate than the present. Unfortunately only the remains of the larger animals were recovered. Cave deposits usually contain abundant remains of small animals which allow a more precise interpretation of the climate. It should also be possible to recover material for  $C^{14}$  dates which will be useful in checking the correlation of the humid periods with glacial stages.

The most promising of the caves described here is Madura Cave, as the presence of *Sthenurus* in the lower unit indicates a Pleistocene age. Very little of the fill was removed by the author thus leaving a large quantity for future excavation. Future investigations should bring to light additional caves with fossiliferous deposits.

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# 11.—Some New Western Australian Sawflies of the Euryinae and Phylacteophaginae (Hymenoptera, Pergidae)

By Robert B. Benson\*

Manuscript received—19th February, 1963

Three out of the four species of Western Australian sawflies studied biologically by Mr. Athol M. Douglas proved to belong to previously unknown species or subspecies of *Eurys*, *Clarissa* and *Phylacteophaga*, three endemic Australian genera not previously found in Western Australia.

A new key is given to the genera of Euryinae. The new species *Eurys aglaia* and *Clarissa hebe* are described and compared with their nearest known relatives in the previous keys to species. To the three forms of two described species of *Phylacteophaga* is added a fourth form and all four are treated as geographical subspecies of a single species.

## Introduction.

The sawfly fauna of Western Australia, so far as it is yet known, is almost entirely endemic. Mr. Athol M. Douglas of Perth, who has been studying the biology of four local species, has sent samples to me for naming. Three of these are undescribed species, or subspecies, and the fourth one is the endemic *Neoeurys turneri* (see Benson 1938b). The genera *Eurys*, *Clarissa* and *Phylacteophaga* to which the three new forms belong, have not previously been recorded from Western Australia. This suggests that many more interesting sawflies await discovery in Western Australia.

The holotypes and most of the paratypes are being deposited in the Western Australian Museum at Perth, but duplicate paratypes are being retained for the British Museum. I am indebted to Mr. Douglas for allowing me to examine his material.

## Key to Genera of Euryinae.

This subfamily as defined by Benson (1935, 1938a) is restricted to the Australian and New Guinea regions. The following key to genera is intended to supersede the one published by Benson (1934).

1. Anal cell of forewing petiolate and closed apically (Fig. 9). Cell Rs of hindwing with base closed (cross-vein 1r-m complete) (Figs. 5-8). Hind basitarsus shorter than three following tarsomeres together. Maxillary palp shorter than greatest measure of eye (except in *Diphamorphos*). Confined to Australian region .... 2
- Anal cell of forewing open apically (Fig. 10). Cell Rs of hindwing usually open at base (cross-vein 1r-m does not extend from M beyond Remigial Fold) (Fig. 4). Hind basitarsus en-

larged and as long as 3 or 4 following tarsomeres together. Maxillary palp much longer than greatest measure of eye. Confined to New Guinea region. [Antennae filiform and set well below level of middle of eyes. Labium not elongate. Hindwing with large apical cell and cell Rs close to M+Cu. Inner hind tibial spur as long or longer than apical width of tibia. 5 spp. Key in Benson (1958). Type: *Ancyloneura varipes* Cameron.] ....

*Ancyloneura*  
Cameron

2. (1) Flagellar segments of antennae simple (neither pectinnate nor serrate) .... 3

— Flagellar segments pectinnate in ♂ and serrate in ♀ (middle segments in ♂ with a ventral branch about X10 times width of segment; and in ♀ with a ventral tooth about as long as width of segment). [Antenna set well below level of middle of eyes. Labium not elongate. Hindwing with apical cell obsolete and cell Rs closer to M+Cu. than the length of its base (1 r-m) (Fig. 7). Inner hind tibial spur not longer than apical width of tibia. 1 sp. Type: *Polyclonus atratus* Kirby.] ....

*Polyclonus*  
Kirby

3. (2) Tongue not or only slightly elongate (ligula and mentum together shorter than front tibia). Usually black or brown species, without metallic lustre .... 4

— Tongue strongly elongate (ligula and mentum together longer than front tibia) (Figs. 1-3). Metallic green, blue, violaceous or cupreous. [Antennae subclavate and sockets touching level of middle of eyes. Hindwing with large apical cell. Cell Rs of hindwing about as far from cell M+Cu. as the length of its own base (1 r-m) (Fig. 5). Inner hind tibial spur longer than apical breadth of hind tibia. 9 spp. Key in Benson (1934) with 2 additional species in Benson (1938b) and one in this paper. Type: *Eurys aeratus* Newman.]

*Eurys* New-  
man

4. (3) Hind wing with apical cell large (Fig. 6) .... 5

— Hindwing with apical cell small (Figs 7 and 8). [Inner hind tibial spur much longer than apical width of tibia] .. ... 6

5. (4) Antennae filiform with flagellum longer than breadth of head. Inner hind spur longer than apical

\* British Museum (Natural History), London S.W.7.

width of tibia and hind tarsus usually as long as tibia. Hindwing with cells Rs about as close to cell M+Cu. as half the length of its own base (i.e., half length of cross-vein 1 r-m).

[Antennae set well below level of middle of eyes. 20 spp. Key to 13♀ in Benson (1934), 2 additional species in Benson (1935) and 5 in Benson (1938b). Type: *Neoeurys metallica* Rohwer.]

*Neoeurys*  
Rohwer

Antennae subclavate with flagellum only about as long as width of head. Inner apical tibial spur not longer than apical width of tibia and hind tarsus much shorter than tibia. Hindwing with cell Rs further from cell M+Cu. than half the length of its own base.

[Antennae set well below level of middle of eyes. 2 spp. N.S. Wales. Key in Benson (1934). Type: *Clarissa froggatti* Rohwer.]

*Warra*  
Benson

6. (4) Hind wing with cell Rs further from cell M+Cu. than the length of its own base (i.e., the cross-vein 1 r-m) (Fig. 8). Maxillary palp shorter than the greatest eye-length. Antennae

filiform and set with upper edge of socket near level of middle of eyes.

[12 spp. Key to 5♀ in Benson (1934) with 3 more in Benson (1955, 1938b) and in the present paper; in Benson (1955) there is also a key to 6♂, 4 of which are treated as spp. nov. of which the ♀ is unknown.

Type: *Clarissa divergens* Kirby.] *Clarissa*  
Kirby

Hindwing with cell Rs much closer to Cell M+Cu. than the length of its own base (i.e., little more than half the cross-vein 1r-m) (Fig. 7). Maxillary palp longer than the greatest eye-length. Antenna filiform, set well below the level of the middle of the eyes.

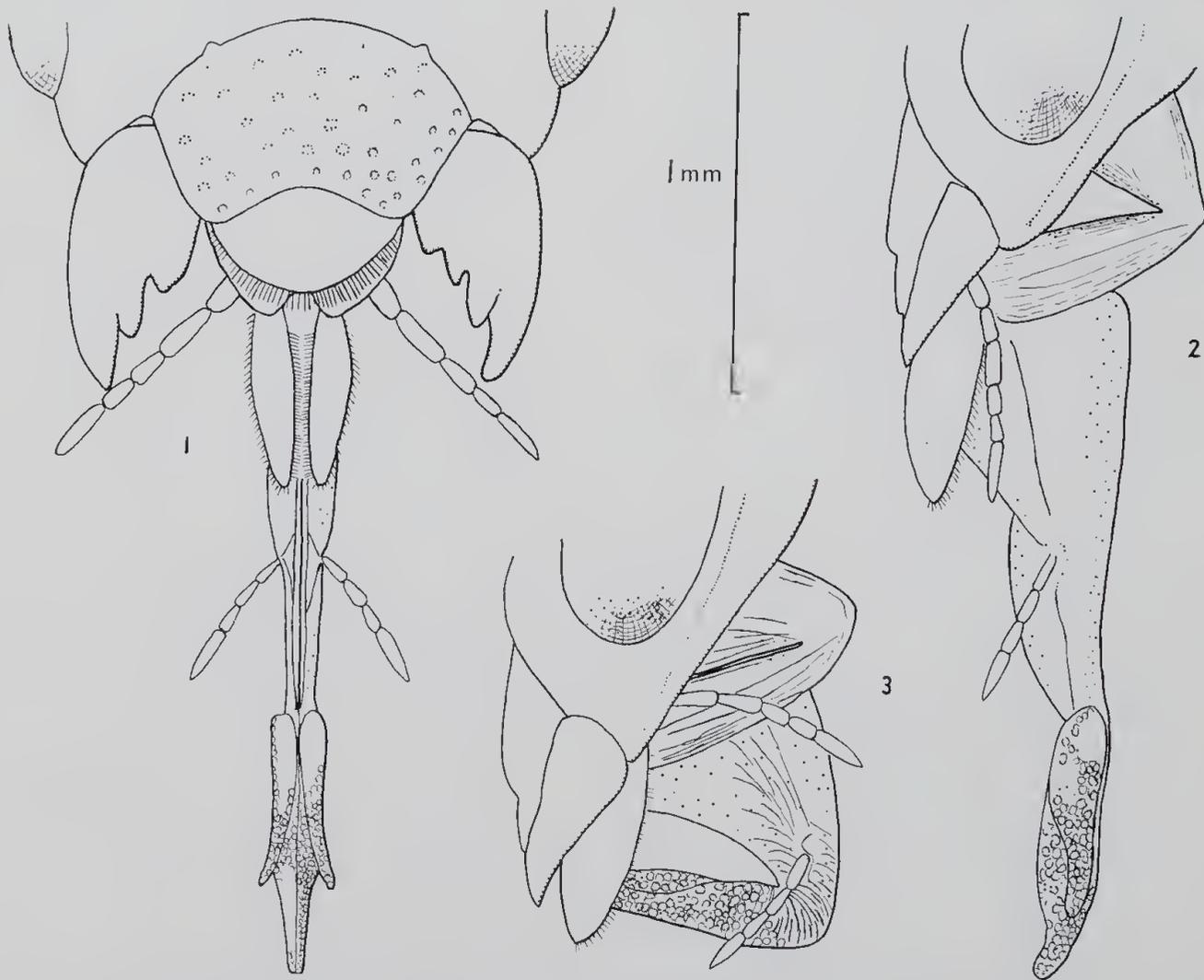
[4 spp. Key in Benson, (1934) and one additional species in Benson (1935).

Type: *Diphamorphus nigrescens* Rohwer.]

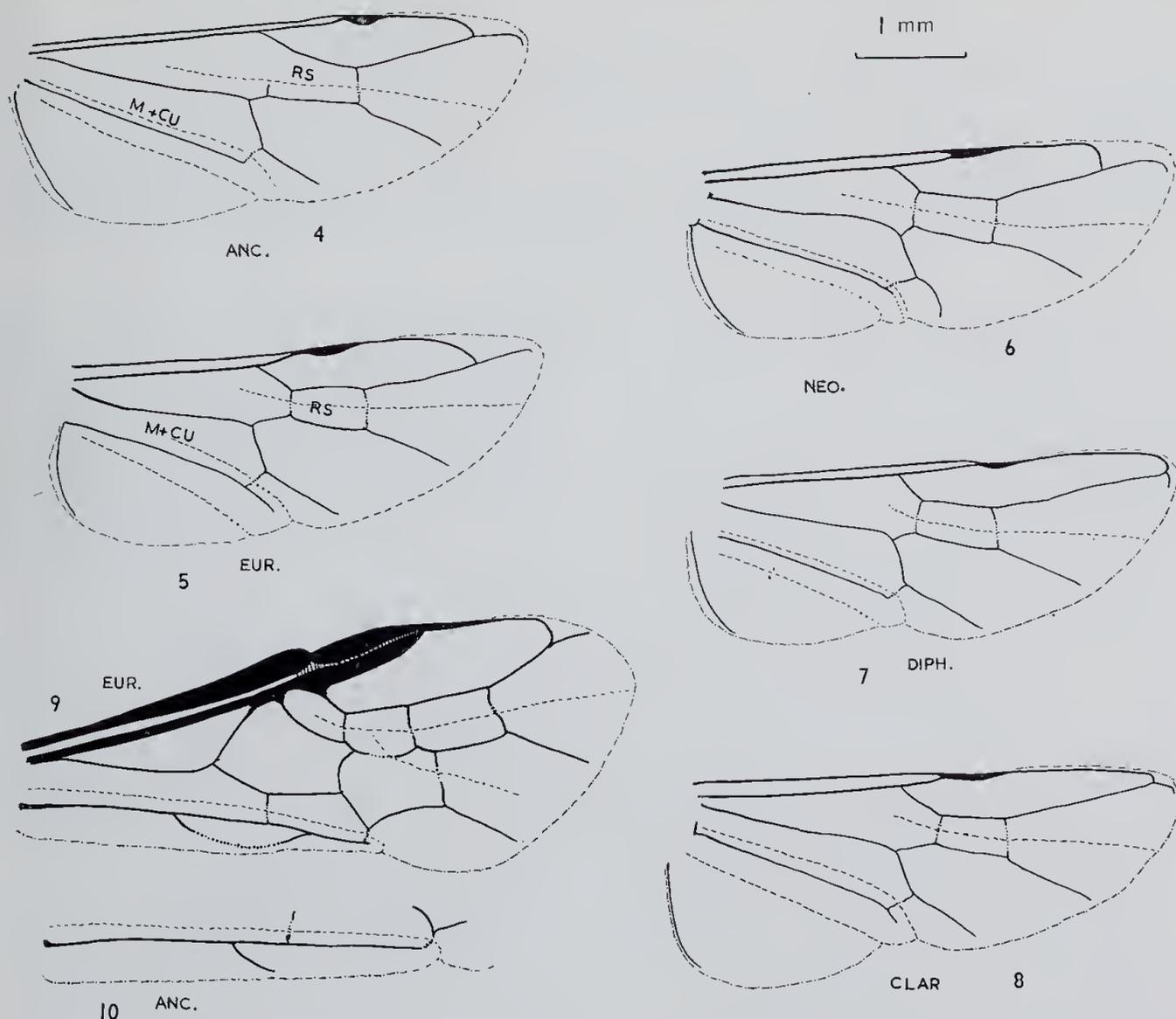
*Diphamorphus*  
Rohwer.

### *Eurys aglaia*, sp. nov.

♀ Colour: cupreous with violaceous reflections on head and mesonotum; infuscate on the front of the clypeus, base of mandible, antenna and concavities of thorax; apices of mandibles and legs brown, infuscate on trochanters, femora



Figs. 1-3.—Tongue of *Eurys laetus* (Westwood): 1, front view extended; 2, lateral view extended; 3, lateral view folded.



Figs. 4-8.—Hindwings of Euryinae: 4, *Ancyloneura*; 5, *Eurys*; 6, *Neoeurys*; 7, *Diphamorphos*; and 8, *Clarissa*.  
Fig. 9.—Forewing of *Eurys*. Fig. 10.—Anal region of forewing of *Ancyloneura*.

(except apices) and apices of tarsomeres; ivory white is the labrum and a line along the lateral margin of the 2nd to 7th tergites. Wings hyaline; stigma and costa pale brown, rest of venation brown to piceous. Length 5 mm.

Head: with mouthparts as in Figs. 1-3. Antenna 10-segmented, subclavate, longer than breadth of head (as 1.2:1.0), with only 9th segment broader than long. Malar space X 0.3 distance between antennal sockets. Hind ocelli about as far apart as from hind margin of head.

Thorax: normal; inner hind tibial spur more than half as long as basitarsus.

Abdomen: normal; sheath and saw as in Benson (1934, Figs. 5b and 5a).

Surface sculpture: head and thorax dull with microsculpture between dense punctures; abdomen with dense transverse striae.

Pubescence: head, thorax and underside of abdomen clothed with dense fine pubescence.

WESTERN AUSTRALIA. Yanchep, 4♀ (including holotype) 5.ix.1962 (A. Douglas).

This species in Benson's key (1934) would run to *E. pulcher* Benson (New South Wales) which differs however, in its sparser punctures on head above and mesonotum with shining interspaces, in its longer 11-segmented antenna with no segment broader than long, and longer malar space, X 0.5 distance between antennal sockets.

***Clarissa hebe*, sp. nov.**

♀ Colour: bronze with violaceous and blue metallic reflections; there is a lateral abdominal stripe of ivory white made up of L-shaped flecks covering the lateral margin and posterior margin at the corner of each of the 2nd to 8th tergites; yellowish-white to brown are the mandibles (except their infusate apices), the labrum, the legs (except the infusate bases of coxae and ± apical tarsomere) and sometimes a ± obscure medial fleck on the apical tergites. Wings hyaline to slightly infusate: basal half of costa and anal vein yellow; stigma and rest of venation black to piceous. Length 6 mm.

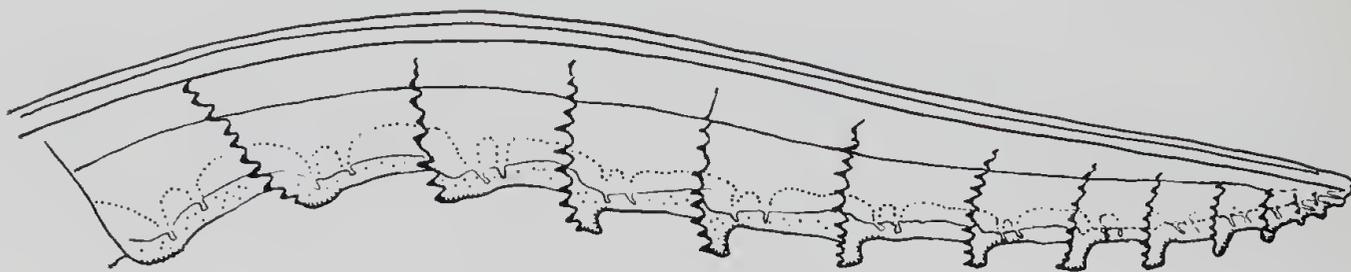


Fig. 11.—Saw of *Clarissa hebe* sp. nov.

Head: with clypeus subtruncate in front, slightly emarginate and about one quarter as long as broad. Malar space short (about as long as two compound-eye facets). Distance between antennal sockets about X2 distance from socket to anterior tentorial pit. Antenna about as long as breadth of head, 8-segmented and sub-clavate, with 7th segment broader than long. Hind ocelli further apart than from hind margin of head (1.0: 0.8).

Thorax: normal; inner hind tibial spur more than half basitarsus; hind basitarsus a little longer than two following tarsomeres together.

Abdomen: with sawsheath, scarcely as long as hind femur, and narrowly truncate at apex, where it is only about half as wide as apex of hind femur, with straight lateral hairs set at an acute angle between those on one side with those on other; saw (Fig. 11) with well-developed marginal and lateral teeth.

Surface sculpture: minute punctures very dense on head, becoming sparser with shining interspaces on vertex; underthorax shining with very minute evenly spaced punctures; on mesonotum the punctures are widely spaced and shallow, obsolescent in the middle of the lobes, and the whole surface shining. Abdomen above with dense transverse striae.

Pubescence: head, thorax and abdomen below clothed in short, fine, pale pubescence.

♂ and ♀ except for sexual character; apical abdominal sternite yellow; length 5.5 mm.

WESTERN AUSTRALIA, Tambrey, 9 ♀ (including holotype) and 4 ♂, 29 vii 1958 (A. Douglas).

In the key to *Clarissa* in Benson (1934) this species does not pass the first couplet, because, though the pedicel is longer than broad, the clypeus is only about one quarter as long as broad, and the hind basitarsus a little longer than the two following tarsomeres. In the position of the antennae (ratio of distance between antennal sockets and distance of antennal socket from anterior tentorial pit) it agrees with *C. ruficollis*, etc., (2 : 1), and disagrees with *C. divergens* and *C. atrata* (1.3:1). The saw is most like that of *C. flammea* Benson (1935, p. 214, Fig. 3), but with much more clearly marked lateral and ventral teeth.

#### Key to subspecies of *Phylacteophaga eucalypti* Froggatt.

*Phylacteophaga* Froggatt is the only described genus in the Phylacteophaginae and was supposed to contain only one species till Riek (1955) drew attention to the existence in eastern Australia of three allopatric colour forms, which he treated as two species, one of them in two subspecies. These forms are distinguished at

present only on the amount of infuscation on the basic reddish-brown colour in three different regions—the amount increasing progressively southwards. The Western Australian form is somewhat intermediate between the Queensland-New South Wales and the Victorian form. The true status of these four forms is not known; and the degree of infuscation may depend on temperature. The possible existence of a continuous cline from Queensland to Victoria needs to be investigated. In the key below the four forms are treated as subspecies of one species.

- |    |   |                                   |
|----|---|-----------------------------------|
| 1. | Scape and pedicel of antenna mostly infuscate. Scutellum at least partly infuscate behind   | 2                                 |
| —  | Scape and pedicel pale. Scutellum entirely pale. [Legs pale except apex of tarsus in ♀ and in ♂ tarsus and apex of tibia: Queensland and New South Wales]   | <i>froggatti</i> Riek, stat. nov. |
| 2. | (1) Hind femur ± infuscate  | 3                                 |
| —  | Hind femur entirely pale. [Western Australia: Nollamara, 1♀ (holotype) emerged 20.ix.1962 ex mines in leaves of <i>Eucalyptus marginata</i> Sm. collected ix.1962 (A. M. Douglas), and 5 ♂, 8 ♀ em. 18-22 ix.1962 likewise; Tuart Hill, 6 ♀. em. 5-17.ix.1962.] | <i>occidens</i> subsp. nov.       |
| 3. | (2) At least middle tibia pale below; middle tarsus pale; foreleg entirely pale in ♀ (♂ not described). Victoria and A.C.T.   | <i>eucalypti</i> Froggatt         |
| —  | Middle and hind legs all dark; foreleg with tibia and tarsus slightly darkened. Tasmania  | <i>tasmanica</i> Riek             |

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## 12.—The gekkonid genus *Nephrurus* in Western Australia, including a new species and three new subspecies

By G. M. Storr\*

*Manuscript received—21st May, 1963*

The eight forms of the genus *Nephrurus* known to inhabit Western Australia are described, including a new species (*vertebralis*) and three new subspecies (*wheeleri cinctus*, *levis occidentalis*, and *levis pilbarensis*). Tables of measurements illustrate a tendency for certain characters to vary clinally from north to south; these trends operate in the genus as a whole and regardless of the boundaries of species, which are still largely allopatric.

### Introduction

The various species of *Nephrurus* mainly inhabit the arid interior of the continent and so were missed by the early collectors, whose activities were generally restricted to coastal areas. Indeed, it is only recently that sufficient material has accumulated in the Western Australian Museum for even a preliminary survey of the genus within this state. Most of the specimens received up to about five years ago were donated by pastoralists and miners. Since then material has largely come from naturalists, who are increasingly exploring the remoter parts of the State. We are especially indebted to Messrs W. H. Butler and M. de Graaf for collections from respectively the southern and northern fringes of the Great Victoria Desert.

In the following descriptions the term "tubercle" includes the rosette of small scales that usually surrounds each large conical scale (elsewhere the latter alone is often referred to as a tubercle). There are no diagnoses apart from descriptions; important characters, however, have been printed in bold type. Unless stated to the contrary, all material examined is lodged in the Western Australian Museum, and all localities are in this State.

### Genus *Nephrurus* Günther

Type (by monotypy): *N. asper* Günther, 1876, J. Mus. Godeffroy 5: 46.

**Description:** Terrestrial geckoes with large subtriangular bony head strongly marked off from the trunk by a slender neck. Limbs moderately long and slender. Digits short, straight, undilated and bearing claws; **the fifth toe (but not the fifth finger) being widely separated from the fourth.** Tail moderately to very short, more or less depressed, annulated (indistinctly in flat-tailed forms), **terminating in a subglobular knob**, and narrowly articulate with swollen post-pygum (it is only at this constriction that the tail breaks). Upper eyelid large and thick. Eye large, the pupil vertical. Nostril opens upwards and backwards. External ear orifice large and narrow vertical. Only enlarged

head scales are rostral, mental, and labials (15-22 upper, 13-21 lower). Head, body and appendages covered with small juxtaposed or granular scales, intermixed with larger ones which may be tuberculate. Supradigital scales become increasingly keeled and imbricate towards end of toe. Subdigital scales granular.

**Distribution:** Endemic to continental Australia: arid and semi-arid regions from the mid-west and north-west coast east through the interior to central Queensland. In Western Australia there are five species, which collectively range from North Kimberley south to the north-eastern Wheat Belt and the Nullarbor Plain.

### Key To Species of *Nephrurus*

- 1.a. Scattered tubercles on flanks .... 2
- b. Flanks smooth .... *laevissimus*
- 2.a. Flank tubercles contain a single conical scale; fewer than 8 inter-orbital scales .... 3
- b. Flank tubercles contain several conical scales; more than 8 inter-orbital scales .... *asper*
- 3.a. 4 or 5 broad dark bands across body and tail .... *wheeleri*
- b. No broad transverse bands .... 4
- 4.a. Prominent pale vertebral line; tail narrow and slightly depressed .... *vertebralis*
- b. No vertebral line; tail broad and flat .... *levis*

### *Nephrurus asper* Günther

*Nephrurus asper* Günther, 1876, J. Mus. Godeffroy 5: 46. Peak Downs, Queensland.

Material examined: R13646 (Kalumburu), R12613 (Calwinyardah), R1340 (Leopold Downs).

**Form:** Head very large and twice (or more) as wide as neck. **Tail extremely short**, not so depressed as is usual in the genus, and terminating in a relatively large knob. There are **fewer (8 or 9) caudal annuli** than in other species (15-21). Snout-vent length of largest specimen (R1340) is 107mm.

**Scalation:** Head covered with round to hexagonal, flat or slightly raised, juxtaposed scales, largest round the orbit, smallest in the loreal concavity. **9-11 inter-orbital scales**, i.e. considerably more than in other species (3-7). Head tubercles (much smaller than those on back etc.) consist of a relatively large and high scale surrounded by a ring of smaller scales; they first appear in the frontal region and become increasingly large and frequent through the occiput to the nape. Three longitudinal lines of tubercles on upper eyelid. Throat may or may not be densely covered with small flattish tubercles, consisting of rosettes of scales very little larger and higher than ordinary scales.

\*The Western Australia Museum, Perth, Western Australia.

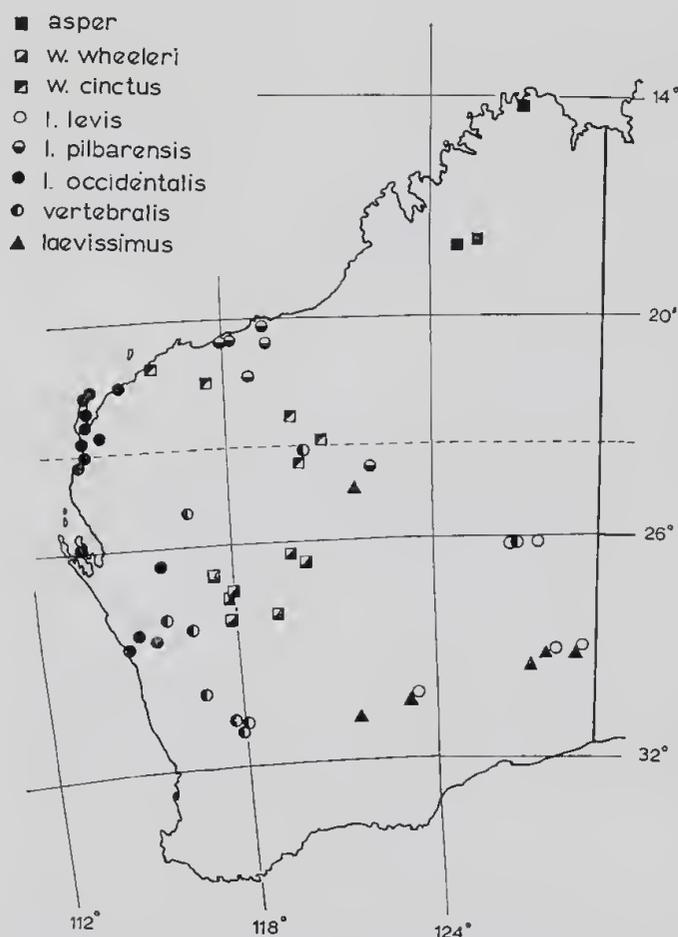


Fig. 1.—Map of Western Australia showing location of specimens of *Nephurus*.

Back, flanks and upper surface of limbs and tail covered with small flat juxtaposed scales through which tubercles are thickly scattered. Tubercles are smallest on the arms and anteriorly on the mid-dorsum where they usually consist of a single conical scale surrounded by a ring of smaller and lower scales which are clearly larger than the ordinary scales between tubercles. On the neck, flanks, thighs and tail the tubercles are larger and comprise a cluster of acutely conical scales within a ring of smaller scales.

Ventral scales uniformly small and juxtaposed. Scales under tail similar in size but higher and tending to become conical.

Coloration: In juveniles the dorsal and lateral ground colour is pinkish grey. A fine blackish brown reticulation on the head and sides of jaw. There are 13 fine blackish bands across the body and tail, the first and widest on the nape. Between these black bands are lines of white spots, each co-existent with a tubercle. Limbs darker, narrowly and indistinctly banded with white, the bands becoming more distinct on the digits. With increasing size many details of coloration disappear.

Distribution: Confined in Western Australia to the Kimberley Division. East and south-east the species extends through the Northern Territory to Queensland.

Comments: Specimens from Kimberley have a much shorter tail (16% of the head plus body) than those from Queensland (24% in both the

type and the MCZ specimen measured by Loveridge, in 1934). The central Australian specimen measured by Lucas and Frost (1896) is exactly intermediate (20%).

#### *Nephurus wheeleri wheeleri* Loveridge

*Nephurus wheeleri* Loveridge, 1932, Proc. New England Zool. Club 13: 31. Yandil, Western Australia.

Material examined: R4719 (Wiluna); R4459 (a paratype), R2224, R2225, (Yandil); R19092 (Wilgie Mia); R733, R1168, R1396 (Cue); R16528 (Day Dawn); R6417 ("Narudie via Mt. Magnet"); R8942 (Sandstone).

Form: Head longer and narrower than in *asper*. Tail much longer than in *asper*, the proximal two-thirds being wide, depressed, and sharply marked off from the distal third. Terminal knob relatively small. Snout-vent length of largest specimen (R4719) is 90 mm.

Scalation: Head covered with flat, hexagonal, juxtaposed scales, smallest in the loreal concavity. These are replaced by larger, conical scales on and immediately below the canthus rostralis, round the orbit, and scattered over the occiput. Throat covered with minute granules, densely interspersed with conical scales much smaller than those on top of head. Subconical scales on sides of lower jaw are only slightly smaller than labials; the transition to the minute gular scales being very rapid on the ventro-lateral angle of the jaw.

Nape, back, flanks and upper surface of tail densely covered with tubercles, each consisting of a large conical scale surrounded by a ring of raised striate scales which are clearly larger than the small granules between tubercles. The conical scales on the upper surface of limbs are surrounded by scales that are not appreciably larger than the inter-tubercular scales.

Coloration: Dorsal ground colour vinaceous pink in life (Glauert 1961). **Four dark-brown bands across body and tail**; the first and broadest across the neck and upper back; the others respectively across the lower back, base of tail, and narrow distal portion of tail. A brown reticulation on snout and side of head.

Distribution: Murchison Goldfield, Western Australia.

#### *Nephurus wheeleri cinctus* subsp. nov.

Holotype: R4284 (in Western Australian Museum), collected at Tambrey, Western Australia, (21° 38' S, 117° 37' E), by Mrs O. Cusack in 1931.

Paratypes: R13114, R14600 (Mardie); R2714, R2715, R2716, R4285, R5271, R8099 (Tambrey); R13840 (Roy Hill); R1009 (Jigalong); R12275, R12276, R12283, R12284, R12285, R12286, (Mundiwindi); R14831, R14832 (14 miles SW of Mundiwindi).

Form: As in nominate race, except for slightly smaller head and considerably smaller orbit. Snout-vent length of largest specimen (R13840) is 100.5 mm.

Scalation: Differs from nominate race in having larger tubercles, especially on the throat where they are also more numerous. The conical scales on legs are surrounded by scales that are distinctly larger than their neighbours.



Fig. 2.—Left (top to bottom): *Nephrorus w. wheeleri*, *N. w. cinctus*, and *N. asper*. Right (top to bottom): *N. vertebralis*, *N. levis* and *N. laevissimus*.

Coloration: As in nominate race except that there are 5 (not 4) dark bands across body and tail. The additional band is due to the splitting of the first broad band (in *w. wheeleri*) into two equal bands separated by a pale space of similar width.

Distribution: Western Australia, principally in the valley of the Fortescue River, from Mardie in the north-west to Jigalong in the south-east, with a slight southward extension to Mundiwindi.

#### *Nephrorus levis levis* De Vis

*Nephrorus levis* De Vis, 1886, Proc. Linn. Soc. N.S.W. (2) 1: 163. Queensland.

*N. platyurus* Boulenger, 1886, Ann. Mag. Nat. Hist. (5) 18:91. Adelaide, South Australia.

Material examined: R14836 (Boorabbie, i.e. 150 miles NE of Loongana); R14837, R14838 (Iltoon, i.e. near Lake Eil); R14839 (Queen Victoria Spring); R17111 (Warburton Range Mission); R14840 (38 miles E of Warburton Range Mission); A. Kluge no. 1344 (Hammond Downs, i.e. near Windorah, Queensland).

Form: Generally similar to that of *N. wheeleri*. Snout-vent length of largest specimen (R14836) is 88 mm.

Scalation: Head covered with rounded to hexagonal, juxtaposed, striate scales, largest and highest on the occiput, above the temples and round the orbit; smallest below and behind nostril. Throat covered with uniformly small

granules. Rostral about as wide and deep as mental. First upper labial usually higher than second.

Neck, back and upper surface of limbs covered with striate, juxtaposed granules, smaller than those on head, and uniformly intermixed with tubercles, each of which consists of a striate conical scale surrounded by a ring of smaller scales, not differing in size and shape from those between tubercles. White tubercles tend to be higher than dark ones.

Caudal tubercles consist of a mucronate conical scale (much larger than those on dorsum and usually pointed backwards) surrounded by a ring of scales somewhat larger than those between tubercles. Caudal tubercles are arranged in 8-12 irregularly longitudinal rows.

Entire ventral surface of body and limbs covered with small, juxtaposed non-striate scales.

Coloration: Dorsal ground colour more or less dark purplish brown (becoming paler with age). The pattern consists of various white spots, blotches and lines. The most prominent and consistent features are three white lines in the region of the neck and shoulder; the first runs straight across the occiput; the second is across the neck and slightly curved backwards; the third is V-shaped and originates on the shoulders above the insertion of the arm and extends diagonally back to the mid-line. On the back there are several more white lines; these are

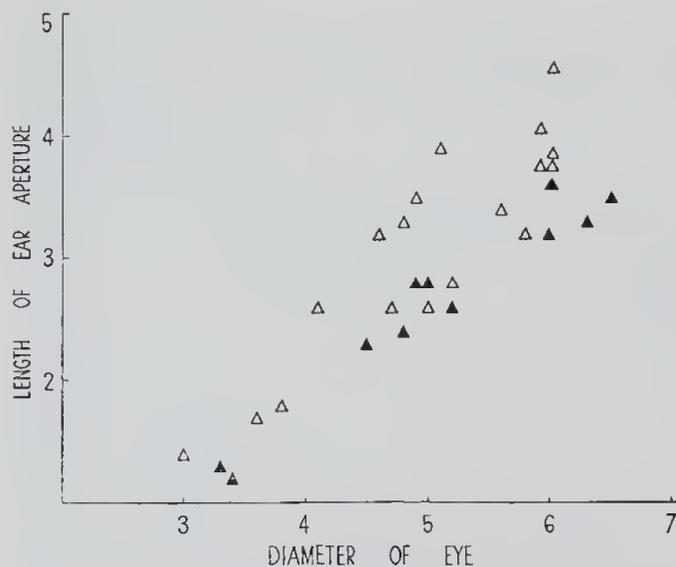


Fig. 3.—Graph showing relation between length of ear aperture and horizontal diameter of eye in *N. wheeleri wheeleri* (solid triangles) and *N. wheeleri cinctus* (hollow triangles).

considerably less distinct than the three described above and are actually irregularly transverse lines of white dots, each coincident with a tubercle.

**Distribution:** Eastern interior of Western Australia, north to the Warburton Range and west to Queen Victoria Spring. Eastwards it extends through central Australia to western Queensland.

**Comment:** Figured in colour by Lucas and Frost (1896).

***Nephurus levis occidentalis* subsp. nov.**

**Holotype:** R13918 (in Western Australian Museum), collected at Narryer, Western Australia, (26°34' S, 115°56' E), by N Armstrong in 1961.

**Paratypes:** R8708 (Onslow); R5323 (Marilla); A. Kluge no. 371 (7 miles SSW of Learmonth); R14027 (North-West Cape); R13113 (Yardie Creek); R16864 (8 miles SW of Bullara); R9007 (Cardabia); R8210 (Warroora); R9165 (Gnaraloo); R19643 (Denham); R13917 (Narryer); R61, R7249, R10296 (Mullewa); R1904 (Yuna); R2255 (Waggrakine); R5353 (Geraldton).

**Form:** As in nominate race, except for considerably longer, wider and more depressed tail. Snout-vent length of largest specimen (R61) is 91 mm.

**Scalation:** Differs from nominate *levis* in that most specimens have the rostral narrower than the mental, the first upper labial lower than the second, and the mid-posterior edge of mental with a lip-like projection. Caudal tubercles are arranged in 10-12 highly irregular series.

**Coloration:** Differs from nominate *levis* mainly in being a little paler.

**Distribution:** Restricted to Western Australia from Onslow south along the coast to Geraldton and inland to Marilla, Narryer and Mullewa.

***Nephurus levis pilbarensis* subsp. nov.**

**Holotype:** R14835 (in Western Australian Museum), collected 12 miles east of Mundabullangana, Western Australia, (20°31' S, 118°13' E), by G. M. Storr and B. T. Clay on February 23, 1962.

**Paratypes:** R14833, R14834 (Mundabullangana); R1640 (De Grey); R8520 (Shaw River Tank); R11330 (Shaw River); R13061, R13062, R13325 (Woodstock); R3890 (Well 15, Canning Stock Route).

**Form:** As in *l. occidentalis*, i.e. tail is larger and flatter than in *l. levis*.

**Scalation:** As in other forms of *levis*, except that in this race alone larger granules are scattered among the smaller granules of the throat. From *occidentalis* to which it is most similar, it also differs in that nearly all specimens have the rostral about as wide as the mental, and the first upper labial as high as the second (in this respect it agrees with nominate *levis*). It shares with *occidentalis* a tendency to have the mental "lipped".

**Coloration:** The dorsal ground colour is paler than in other races, viz. pale purplish grey; hence the white occipito-scapular lines, characteristic of other races, are not so prominent here as the dark purplish brown lines that parallel them. In addition to these there is an irregular network of dark blotches and lines on the back.

**Distribution:** Restricted to the Pilbara region of Western Australia from the Yule and De Grey River drainages south-east to the vicinity of Lake Disappointment.

***Nephurus vertebralis* sp. nov.**

**Holotype:** R5231 (in Western Australian Museum), collected at Jibberding, Western Australia, (29°58' S, 116°51' E), by E. W. Pendavey in 1935.

**Paratypes:** A. Kluge no. 892 (10 miles N of Mundiwindi); R1899 (Landor); R13112 (Yuin); R5300 (Wadgingarra); R2490 (Jibberding);

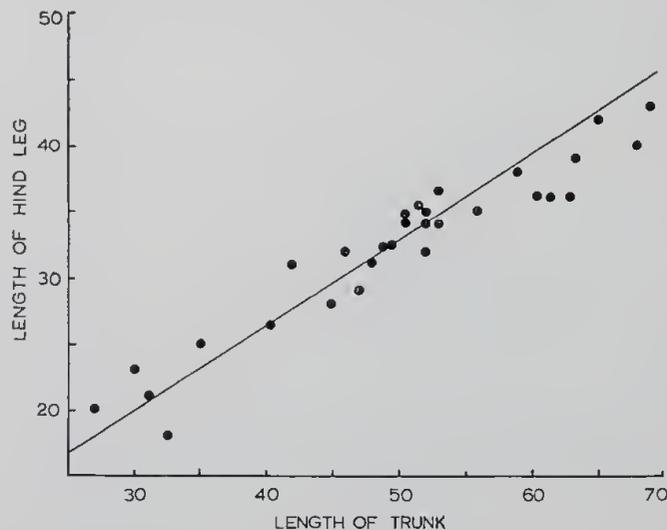


Fig. 4.—Graph showing changing relation between length of hind-leg and length of trunk (mm) in *Nephurus levis*. The straight line has a slope of 0.67, i.e. the mean ratio hind-leg to trunk in animals with a trunk length of less than 55 mm.

R1392 (Bencubbin); R6191 (Mukinbudin); R13415 (Kununoppin); R17110 (Warburton Range Mission).

Form: As in *levis*, except for narrower and less depressed tail and longer ear-slit. Snout-vent length of largest specimen (R1392) is 92 mm.

Scalation: As in *levis*, except that the caudal tubercles are arranged in more regular but fewer longitudinal rows, and tend to be surrounded by higher and more acute scales.

Coloration: Ground colour of head, neck, shoulders, sacrum and tail, dark purplish brown; of back and upper surface of limbs, pale purplish brown. Across the occiput, neck and shoulders are three pale lines as in *levis*, but differing slightly as follows: the first is bowed back slightly (not straight) and laterally continues down and forward over temples to orbit. The second and third, though generally arched backwards, swing forward a little as they approach the mid-line, so that the third line could almost be described as W-shaped. The most prominent feature is a pale vertebral line extending from the occipital transverse line almost to end of tail; such a line is at best only faintly discernible in *levis*.

Distribution: Restricted to Western Australia. Mainly distributed in a long narrow strip of country from Mundiwindi, south through the Upper Gascoyne and Yalgoo districts to the north-eastern Wheat Belt. Also occurs far to the east at Warburton Range.

#### *Nephrurus laevis* Mertens

*Nephrurus laevis* Mertens, 1958, Senck. Biol. 39: 51. Dunes about 2 km north-west of Ayers Rock, Northern Territory.

Material examined: R8416, R8417 (White Lake, i.e. 170 miles NE of Wiluna); R12230 (19 miles W of Randalls); R14844, R14845 (Queen Victoria Spring); R12223, R12226 (10 miles S of Queen Victoria Spring); R14483 (Iltoon, i.e. near Lake Ell); R14842 (Smith's Station, i.e. 90 miles N of Loongana); R14841 (Boorabie, i.e. 150 miles NE of Loongana); R2269 (Ooldea, South Australia).

Form: Similar to *levis*, *vertebralis*, and *wheeleri*, except for somewhat shorter and considerably narrower tail, and for longer and relatively narrower head. Snout-vent length of largest specimen (R12223) is 77mm.

Scalation: Head covered with rounded to hexagonal scales largest and highest in the

parietal region, smallest on the temples and behind nostrils. Posteriorly from the occiput the granules rapidly decrease in size. The neck and greater part of back and flanks are very smooth, there being scarcely any indication of scales or granules, except in the vicinity of the mid-line where there are scattered small conical scales. These become larger and denser on the sacrum and the thighs. On the upper surface of the tail the conical scales are considerably larger and spinier, and are arranged in six fairly regular longitudinal series. Each conical scale is surrounded by a ring of granules not or only slightly larger than the intertubercular granules. The entire under surface is covered with granules, smallest on the throat.

The dorsal skin is so thin in this species that the vertebrae and ribs protrude through it.

Coloration: Dorsal ground colour very pale pinkish grey. There are three blackish brown transverse lines in the region of the neck: the first, beginning immediately behind the eye, goes straight back to level of ear, then turns abruptly to run across extreme back of head; the second runs across the neck and is slightly bowed towards the tail; the third begins above or behind the insertion of the arm and is more strongly bowed towards tail; some or all of these lines are broken in many specimens. There is a dark brown spot behind the nostril and three more on the mid-line of the head, respectively opposite the anterior and posterior ends of the orbit and in the middle of the occiput; the last two may be absent or laterally expanded to form short transverse lines arching backwards. There is a blackish brown longitudinal line on each side of the sacrum and one or more spots towards the mid-line in the lumbo-sacral region. The caudal tubercles, a spot below the orbit, and the entire under-surface is white.

Distribution: Eastern interior of Western Australia, from latitude 24 south to the Nullarbor Plain. Eastwards it extends into south-western Northern Territory and north-western South Australia.

Comments: This distinctive species was long confused with *N. levis*. A specimen collected at Immarna, South Australia, in 1920 was described and figured by Kinghorn (1924) as a new colour variety of *levis*. The species has been represented in the Western Australian Museum since 1942 when K. G. Buller collected two specimens on the Canning Stock Route.

TABLE I

Mean length of head etc. (with standard deviation in brackets) expressed as a percentage of length of trunk. The figure in brackets after number in sample is the number of specimens complete with tail.

	Number in Sample	Head		Tail		Hind Leg	Diameter of Eye	Ear Aperture
		Length	Width	Length	Width			
<i>asper</i>	3 (3)	39.0 (5.7)	41.0 (4.1)	22.0 (0.8)	9.3 (0.5)	62.3 (3.8)	9.0 (2.1)	6.7 (0.3)
<i>w. vinctus</i>	19 (9)	38.4 (2.6)	36.7 (2.6)	57.0 (3.4)	24.1 (3.1)	63.4 (3.6)	9.2 (1.3)	5.6 (0.7)
<i>w. wheeleri</i>	11 (6)	41.2 (3.1)	39.0 (3.2)	61.0 (1.8)	22.0 (3.0)	65.7 (3.4)	11.0 (1.3)	5.5 (0.8)
<i>l. pilbarensis</i>	10 (8)	38.2 (2.9)	37.0 (2.1)	61.6 (4.6)	27.0 (5.1)	63.8 (3.3)	10.3 (1.2)	4.8 (0.7)
<i>l. occidentalis</i>	17 (14)	40.7 (3.5)	38.2 (2.2)	61.0 (4.5)	26.5 (3.9)	66.4 (5.7)	11.4 (1.3)	4.6 (0.7)
<i>l. levis</i>	7 (6)	38.8 (1.6)	36.0 (0.9)	52.6 (4.9)	21.2 (1.5)	63.7 (3.0)	10.7 (1.4)	4.8 (0.6)
<i>vertebralis</i>	10 (9)	39.5 (2.9)	34.6 (2.8)	53.1 (4.5)	16.2 (2.5)	66.6 (4.4)	11.2 (1.3)	5.3 (0.6)
<i>laevis</i>	11 (10)	45.1 (2.4)	38.2 (1.4)	49.1 (2.6)	13.1 (2.2)	67.8 (3.3)	12.5 (0.9)	5.3 (0.8)

## Measurements

The following measurements were made on all specimens: total length, i.e. head plus trunk (including neck) plus tail (measured from the vent, not the post-pygial constriction as was apparently done by De Vis when measuring the type of *levis*) hind leg, and width of head and tail (all to the nearest 0.5 mm); and the length of ear aperture and the horizontal diameter of visible part of eye (both to the nearest 0.1 mm). These data were expressed as ratios; means and standard deviations for each taxon are set out in Tables I and II.

The eight taxa of *Nephrurus* inhabiting Western Australia are listed in the tables in a generally north-south sequence, revealing geographical trends in the ratios which transcend species limits. The ratios, ear aperture to trunk and width of head to its length, decrease as one goes south; whereas diameter of eye and length of hind leg increase. Clinal variation is especially marked in the ratio, length of ear aperture to diameter of eye; this ratio yields a good separation of the northern and southern races of *wheeleri*, as illustrated in Figure 2.

Ideally ratios should remain constant throughout life, a condition that is not always fulfilled in the present genus, where the growth of appendages in adults tends to slow down with respect to the trunk. For example, the ratio hind leg to trunk in *levis* decreases slightly after a trunk length of 55 mm is attained (see Figure 3). The proportions within an appendage, however, seem to be unaffected by age, e.g. width to length of head and tail, and length of ear aperture to diameter of eye.

TABLE II

Mean ratio: width to length of head and tail, and length of ear aperture to horizontal diameter of eye (with standard deviation in brackets).

	Width to Length of Head	Width to Length of Tail	Ear Aperture to Eye
<i>asper</i> ..	1.05	0.42	0.75
<i>n. cinctus</i> ..	0.96 (0.06)	0.43 (0.06)	0.62 (0.10)
<i>n. wheeleri</i> ..	0.95 (0.04)	0.36 (0.06)	0.50 (0.07)
<i>l. pilbarensis</i> ..	0.96 (0.04)	0.44 (0.09)	0.46 (0.09)
<i>l. occidentalis</i> ..	0.93 (0.05)	0.44 (0.07)	0.41 (0.08)
<i>l. levis</i> ...	0.92 (0.05)	0.40 (0.03)	0.45 (0.07)
<i>vertebralis</i> ..	0.87 (0.05)	0.31 (0.04)	0.47 (0.06)
<i>laevissimus</i> ..	0.85 (0.04)	0.27 (0.05)	0.42 (0.08)

## Discussion

To a large extent the various species of *Nephrurus* are still allopatric, so that over much of the State any one region is occupied by a single form of the genus (see map, Fig. 1). In the Kimberleys *asper* alone has been found; in the De Grey drainage, only *levis pilbarensis*; in the Fortescue, *wheeleri cinctus*; in the East

Murchison, nominate *wheeleri*; and in the Carnarvon Basin, *levis occidentalis*. It is only in the Great Victoria Desert that two forms (viz. *levis levis* and *laevissimus*) are widely sympatric. Elsewhere sympatry has been established at Mundiwindi and Warburton Range, between *vertebralis* and respectively *wheeleri cinctus* and *levis levis*.

The status of *vertebralis* has only been recently settled. Glauert (1961) treated it as a colour variant (his No. 2) of *levis*. At first the present writer too was inclined to regard it as no more than a well-marked race of *levis*. The available specimens at that time all came from the country immediately east and south-east of the range of *levis occidentalis*. As nominate *levis* occurred further to the east, *vertebralis* appeared to be not only allopatric to *occidentalis* and nominate *levis* but also geographically intermediate between them. But only in minor ways was *vertebralis* morphologically intermediate between these forms, and the writer began to doubt the propriety of including it in *levis*. These doubts increased when a specimen of *vertebralis* was collected at Yuin, which is only 30 miles east of the straight line between Mullewa and Narryer, at both of which a *levis occidentalis* had been collected, neither specimen showing any intergradation with *vertebralis*. The problem was finally solved last year, when Mr. Mark de Graaf collected a specimen each of *vertebralis* and *levis* near the Warburton Range Mission. This absolute sympatry necessitated the promotion of *vertebralis* to a full species.

*Occidentalis* and the closely related *pilbarensis* are themselves very distinct from nominate *levis*, from which they are geographically separated by a large area of heavy, frequently stony, soils which are dominated by mulga and occupied by *wheeleri*. However, *levis* could well have a continuous distribution in the far interior of the state. Although Well 15 on the Canning Stock Route (a *pilbarensis* locality) is 300 miles WNW of Warburton Range (the nearest locality of nominate *levis*), the intervening desert is almost certainly inhabited by some form of the species.

## References

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### 13.—The Angler-fish *Ceratias holboelli* from Western Australian Waters

By B. K. Bowen\*

*Manuscript received—11th June, 1963*

The first recorded adult specimen of the deep-sea angler-fish *Ceratias holboelli* from Australian water was taken from a whale's stomach at Albany in 1957. The specimen is figured and described.

On August 31st, 1957, a male sperm whale 38.5 ft in length, was caught at 35° 34' S., 117° 36' E. (38 miles south-west of Albany). When the stomach of the whale was opened on the flensing deck at Albany, it was found to contain a specimen of the deep-sea angler-fish *Ceratias holboelli* Kroyer (Fig. 1). The specimen was a fully metamorphosed female without an attached male. Its standard length was 48 cm.

This specimen of *C. holboelli* is the twenty-second adult female recorded throughout the world and the first to be taken in Australian waters. Bertelsen (1951) records all specimens known up to 1951 and more modern records are by Krefft (1954) and Van Utrecht (1957). The only previous record of this species from Aus-

\* Fisheries Department, Perth, Western Australia.

tralia is that of a female larva taken on February 25th, 1929, at Dana Station No. 3665, location 29° 37' 5" S., 156° 46' E., off the east coast of Australia.

The specimen was badly lacerated on the right side in the region of the exhalant aperture and in addition all fin rays were broken and lacked their distal ends. The specimen was otherwise in good condition. The eyes had completely regressed but could be exposed by an incision.

Bertelsen (1951) has suggested that there are two sub-species of *C. holboelli*, *C.h. holboelli* from the northern hemisphere and *C.h. tentaculatus* from the southern hemisphere. *C.h. holboelli* possesses a single escal filament, while *C.h. tentaculatus* possesses two filaments which may be further branched. Unfortunately our specimen (Western Australian Museum No. P4266) has a damaged tip to the escal bulb and does not provide further information in this regard.



Fig. 1.—Female deep-sea angler-fish *Ceratias holboelli* taken from the stomach of a sperm whale at Albany. (Photograph: Government Printer)

The measurements shown in Table I were taken in conformity with those taken by Clarke (1950).

TABLE I

Measurements (in cm) of *Ceratias holboelli* (W.A.M. No. P4266)

Standard length	48.0
Length of illicium	8.8
Height of caruncle, stalk included	1.6
Snout to base of tentacle	9.5
Snout to dorsal fin	35.0
Snout to anal fin	37.3
Snout to base of pectoral fin	17.6
Base of tentacle on back to dorsal fin	5.6
Posterior caruncle to dorsal fin	4.4
Length of lower jaw	7.6
Greatest depth of body	17.2
Depth of caudal peduncle	4.2
Base of tentacle on head to base of tentacle on back	20.0
Dorsal fin to caudal fin	8.1
Anal fin to caudal fin	7.1
Base of anal fin	2.6

All of the measurements with the exception of the height of the caruncles, fit the allometric growth graphs drawn by Clarke (1950). The caruncles measure 1.6 cm in height, whereas in the specimens considered by Clarke (1950) not one of the measurements exceeds 0.75 cm. Clarke has shown that the maximum height of the caruncles is reached when the fish is about 12 cm standard length, after which they regress in absolute size. He suggests that the onset of this enantiometric (i.e. absolute negative) growth is associated with a crisis in the development of the fish, which is probably the attainment of sexual maturity. The caruncles of the new specimen, which is a mature fish, also differ in



Fig. 2.—The caruncles showing a division into a head and stalk region. Diameter of field 4.3 cms. (Del. M. Walsh).

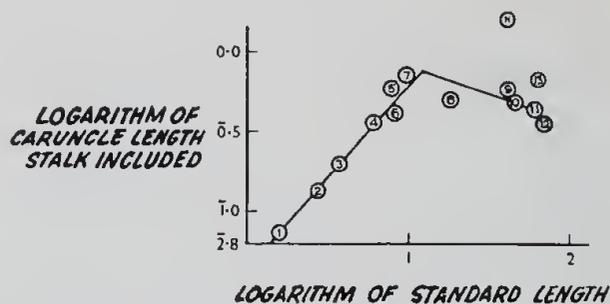


Fig. 3.—Caruncle length plotted against a standard length on a double logarithmic scale. (The numbers of the points are those allocated to specimens by Clarke 1950. The new specimen is designated N.)

shape from other mature fish studied. They are divided into a head and stalk region similar to the juvenile rather than the regressed club-like form of the mature fish (Fig. 2).

If the measurement for the new specimen is incorporated in Clarke's (1950) allometric growth graph for the "length of caruncle", (Fig. 3), it will be seen that it lies to the right of a projection of the line derived from the plotting of the caruncle heights of immature fish and above the line obtained for mature fish. Thus the point can not be definitely associated with either line. Also, it is impossible to state whether or not the absolute size of the caruncles decreased after metamorphosis. However, the fact that the caruncles still resemble the juvenile form points to the probability that growth has been progressive throughout the life of the fish.

It is apparent, therefore, that the growth of the caruncles of the new specimen has differed from those studied by Clarke (1950) and confuses his hypothesis that they reach maximum size at sexual maturity.

It could be argued that the females mature over a length range and that on maturity the caruncles cease to grow in length but gradually thicken to the club-like form. This would explain the differences in caruncle lengths and shapes. However, for such an explanation to hold true the range of maturity would have to be approximately 6 to 19 cm. This seems unlikely and, therefore, the growth of the caruncles of *Ceratias holboelli* remains an interesting problem.

#### References

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## 14.—The Callionymidae of Western Australia (Pisces)

By G. F. Mees \*

Manuscript received—19th March, 1963

In Western Australian waters the Callionymidae are represented by two genera and nine species: *Dactylopus* with one species and *Callionymus* with eight species. A key for their identification is given and their distribution and synonymy are discussed.

### Introduction

Thanks to McCulloch's (1923, 1926) beautifully illustrated revisions, the Callionymidae of Australia are systematically an easily accessible and comparatively well-known group. However, several of the species described by McCulloch were known from single specimens only, and their known distribution was limited to the type localities.

From Western Australia, McCulloch (1929-1930) knew four species: *Dactylopus dactylopus*, *Callionymus calauropomus*, *C. calcaratus*, and *C. apricus*. In subsequent years Whitley (1944, 1945) added *C. goodladi* (a new species), and *C. papilio* to the State list, bringing the total number to six (Whitley 1948b). Very recently I was able to record another two species (Mees 1959). Even this increased number of eight species does not complete the state list, for amongst material recently received by the Western Australian Museum are several specimens of yet another species.

The purpose of this paper is to give a key to the species of Callionymidae known from Western Australia, as well as additional information, mainly on their distribution. It has further been possible to synonymise two names which had been given as a consequence of insufficient knowledge of sexual dimorphism.

It is possible that for some of the species listed here older names will be found to be available when Australian material is compared with species described from the East Indies and the Philippines. Major revisional work, however, goes beyond the scope of this small contribution.

The bulk of the material this study is based on was provided by Mr. R. J. McKay of the Fisheries Department, and by Messrs. W. and W. Poole, owners of the "Bluefin". Mr. G. Mack, director of the Queensland Museum, Brisbane, sent on loan a cotype of *Callionymus grossi* Ogilby and specimens of *C. limiceps* Ogilby. Mr. I. S. R. Munro, of the C.S.I.R.O. Laboratory of Fisheries and Oceanography, Cronulla, N.S.W., sent on loan his whole collection of Callionymidae which includes many specimens from Western Australia. Mr. G. Palmer allowed me, during a visit to the British Museum (Natural History) in May 1962, to examine the specimen of *C. grossi* from the Monte Bello Islands recently recorded by him. Mr. T. D. Scott,

South Australian Museum, provided some specimens from South Australia, amongst which *Callionymus papilio*, a species of which no material from Western Australia was available. Mr. G. P. Whitley gave information on material of *C. calcaratus* in the Australian Museum, Sydney.

In the list of material examined, numbers preceded by a P refer to specimens in the collection of the Western Australian Museum, numbers preceded by A and C are in the C.S.I.R.O. collection, Cronulla.

### Key to the Genera known from Western Australia

- 1a. Spine and first ray of ventrals separated from the rest of the fin ..... *Dactylopus*
- b. Ventrals without detached rays ..... *Callionymus*

### Genus *Dactylopus* Gill \*

*Dactylopus* Gill, Proc. Acad. Nat. Sci. Philad., 1859, p. 130—type by monotypy, *D[actylopus] Bennetti* Gill = *Callionymus dactylopus* Valenciennes.

*Vulsus* Günther, Cat. Fish. Brit. Mus. III, 1861, p. 151—nomen novum for *Dactylopus* Gill, allegedly preoccupied.

Characterised by the detached spine and first ray of the ventral fin. Though this character is very useful and convenient for identifying the species, it seems hardly of generic value; however, the preopercular spine is also different from that of any other species I have seen, and as the genus has now been generally accepted for a century, I prefer to maintain it.

Only one species known.

### *Dactylopus dactylopus* (Valenciennes)

*Callionymus dactylopus* Valenciennes, in Cuvier & Valenciennes, Hist. Nat. Poiss. XII, 1837, p. 232—no locality.

*Dactylopus Bennetti* Gill, Proc. Acad. Nat. Sci. Philad., 1859, p. 130—nomen novum for *Callionymus dactylopus* Valenciennes, proposed to avoid tautonomy.

*Dactylopus dactylopus*; Ogilby, Ann. Qd Mus. 9, 1908, p. 38 (Moreton Bay, Queensland); Ogilby, Proc. Roy. Soc. Qd 23, 1910, p. 46 (Stradbroke Island and Wynnum in South-Eastern Queensland, and Moreton Bay, Queensland); McCulloch, Zool. Res. Endeavour III, 1915, p. 149, pl. XXVIII (Shark Bay, Western Australia, and off Hervey Bay, Queensland); McCulloch & Whitley, Mem. Qd Mus. 8, 1925, p. 173 (Queensland: Moreton Bay, Stradbroke Island, Wynnum, off Hervey Bay); McCulloch, Mem. Aust. Mus. 5, 1929, p. 337 (Queensland, Western Australia); Whitley, W. Aust. Fish. Dept., Fish. Bull. 2, 1948, p. 27 (Western Australia); de Beaufort & Chapman, Fish. Indo-Aust. Arch. IX, 1951, p. 80 (Western Australia, Queensland).

Diagnostic characters. D IV-8½, A 7½, P ii.15.ii or ii.15.iii, or ii.16.ii, sometimes i.15.ii or i.16.iii, V I. 1-4, C ii.7.ii or ii.7.iii; soft rays of dorsal fin divided except the first one which may be

\* Synonymy throughout this paper is confined to Australian records.

\* Western Australian Museum, Perth, Western Australia.

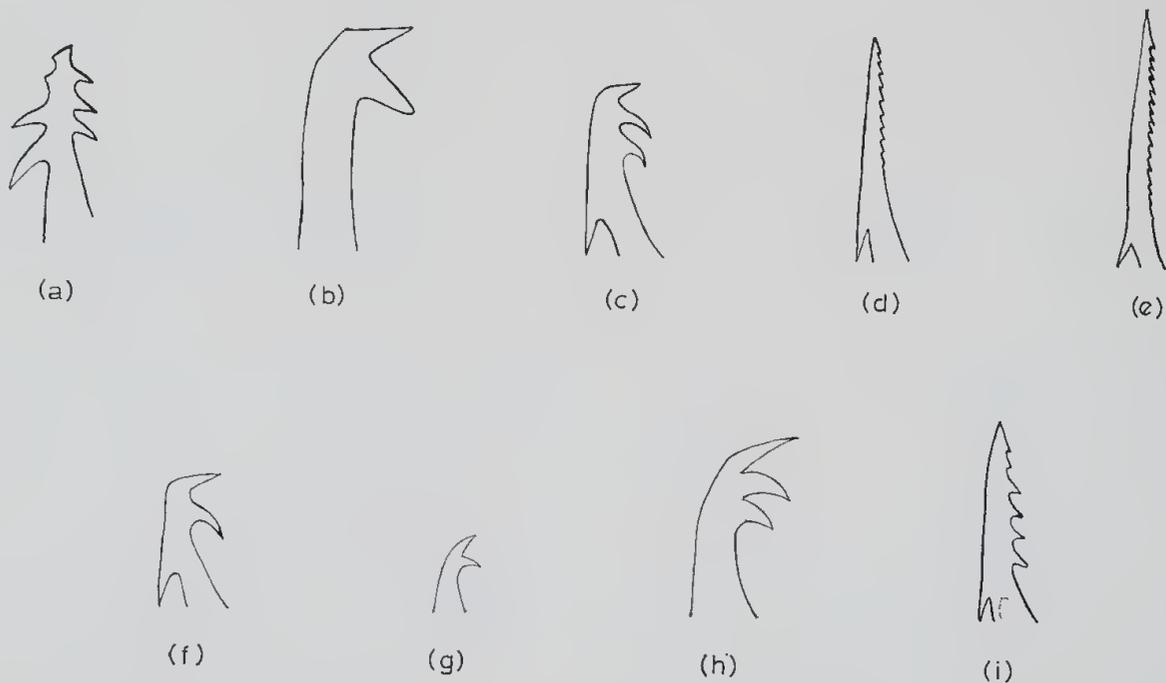


Fig. 1.—Right preopercular spines. (a) *Dactylopus dactylopus* (P 5263, standard length 129 mm), (b) *Callionymus calauropomus* (P 4563, s. l. 180 mm), (c) *C. calcaratus* (P 5392, s. l. 154 mm), (d) *C. goodladi* (P 5440, s. l. 118 mm), (e) *C. grossi* (P 5400, s. l. 128 mm), (f) *C. limiceps* (P 5407, s. l. 131 mm), (g) *C. papilio* (F 3076, s. l. 62 mm), (h) *C. phasis* (from literature), (i) *C. rameus* (P 5431, s. l. 129 mm). The spines of *C. calauropomus* and *C. phasis*, which are curved upwards, are shown in lateral view, the others in dorsal view.  $2\frac{1}{2}$  x natural size.

either simple or divided; origin of D 1 in advance of a line connecting the gill openings; preopercular spine with on each side three to five hooks (Fig. 1a); usually first and second rays of pectoral undivided, sometimes only the first.

**Distribution.** A widely distributed species, known from the Philippines, the East Indies, Queensland and Western Australia. In Western Australia known from Exmouth Gulf, Shark Bay, and the Perth area, from Scarborough to Point Peron. The species apparently reproduces at City Beach: in the aquarium of Mr. V. A. Dawson of Como I have seen several live specimens of less than 5 cm length, caught on a sandy bottom in shallow water at that locality.

Material examined, 43 specimens, varying in standard length from 64 to 150 mm. Exmouth Gulf (C 2319, C 2342, C 2363, C 2364, C 2381, C 2382, C 2383, P 4378, P 4952, P 5102 (3 sp.), P 5352, P 5367 (2 sp.) P 5368, P 5422), Shark Bay (P 4368, P 4375 (2 sp.), P 5451, P 5454), north of Peron Flats, Shark Bay (P 5268), between Kck's Island and Point Quobba, Shark Bay (P 4279), Entrance Denham Channel, Shark Bay (C 572), Palm Beach, Scarborough (P 4354, P 4715), Fremantle (P 752), Swan River (P 3096, P 3097), Woodman's Point (P 5494), Naval Base (P 1226, P 5501), Rockingham (P 1227, P 2050, P 2060, P 2061, P 2062, P 4359, P 4684), Rockingham Bay (P 5223), Garden Island (P 4691), Point Peron (P 996). Also examined one specimen from three to four miles east of Burnett River, Queensland (A 915).

#### Genus *Callionymus* Linnaeus\*

*Callionymus* Linnaeus, Syst. Nat. 10th ed. I, 1758, p. 249—based on *C. Lyra*, *C. dracunculus*, and *C. indicus*. *C. lyra* is generally accepted as type.

\* *Callimucenus* Whitley is also a synonym.

*Calliurichthys* Jordan & Fowler, Proc. U.S. Nat. Mus. 25, 1903, p. 941—type by original designation, *Callionymus japonicus* Houttuyn.

*Repomucenus* Whitley, Aust. Zool. 6, 1931 (Feb. 13), p. 323—type by original designation and monotypy, *Callionymus calcaratus* Macleay.

*Foetorepus* Whitley, Aust. Zool. 6, 1931 (Feb. 13), p. 323—type by original designation, *Callionymus calauropomus* Richardson.

*Yerutius* Whitley, Rec. Aust. Mus. 18, 1931 (March 25), p. 115—type by original designation, *Callionymus apricus* McCulloch = *Callionymus phasis* Günther.

*Velesionymus* Whitley, in McCulloch, Fish. N.S.W., 3rd ed., 1934, suppl. no. 418—type by original designation and monotypy, *Callionymus limiceps* Ogilby.

*Orbonymus* Whitley, Aust. Zool. 11 1947, p. 150—type by original designation and monotypy, *Callionymus (Calliurichthys) rameus* McCulloch.

There has been no lack of attempts to divide the large genus *Callionymus*, and the synonymy quoted above shows that almost every Australian species has been made into the type of a new genus. None of these attempts, however, has been very successful, and none has met with general approval. As a basis for separation, the shape of the preopercular spine has generally been taken, sometimes also the structure of the dorsal fin (with simple rays or branched rays) and other less obvious peculiarities. However, none of these characters seem to be correlated, they can occur in any combination in any species and their value as a criterion for generic separation is problematical. See further the discussion of *C. calauropomus*.

Obviously any attempt at subdividing the genus *Callionymus sensu lato* that is not based on an examination of at least the great majority of species is worthless, and until a revision on a world wide basis has been carried out, commonsense demands retention of all Australian species in the genus *Callionymus*.

The characters used to separate the species are the familiar ones used by previous workers; the number of rays in the dorsal and anal fins, the shape of the preopercular spine, the length of the snout in comparison to the orbit, etc. Further there is variation in the place of origin of the first dorsal fin, which may, in lateral view, be over the gill openings, or well behind them. A very useful character is whether or not the rays of the second dorsal fin are simple (except the last one) or divided (often with the exception of the first one). I have also used this character, which has the advantage of being very easy to ascertain, in the key, but there is one pitfall: it appears that in some (or all?) species with divided dorsal rays, small individuals have the rays simple. As no small specimens of Western Australian species have been available, I do not know if variation with size is universal; when using the key, however, it will be wise to consider this possibility whenever identifying specimens of less than about 50 mm standard length.

**Key to the Species Known from Western Australia**

- 1a. D IV-7½, A 6½ soft rays of D divided at the tips or simple, preopercular spine with two hooks, no antrorse spine on its base ..... *C. papilio*
- b. D IV-8½ to 10½, A 7½ to 9½ ..... 2
- 2a. All soft rays of D divided, or only first one simple ..... 3
- b. Only last ray of D divided, other rays simple ..... 4
- 3a. D IV-8½ (rarely 9½), A 7½ preopercular spine with two hooks, curved upwards, no antrorse spine on its base ..... *C. calauro-*  
*pomus*
- b. D IV-8½, A 7½, preopercular spine more or less straight, with about five fairly small barbules and with an antrorse spine on its base ..... *C. ramcus*
- c. D IV-8½, A 7½, preopercular spine curved upwards at its extremity, with three hooks, no antrorse spine on its base ..... *C. phasis*
- 4a. D IV-9½, A 9½, preopercular spine with two hooks, curved inwards, and with an antrorse spine on its base ..... *C. limiceps*
- b. D IV-9½ (rarely 8½ or 10½), A 9½ (rarely 8½), preopercular spine rather broad, with three to five teeth at tip and on inside, and with an antrorse spine on its base ..... *C. calcaratus*
- c. D IV-9½ (rarely 8½), A 8½ (rarely 7½), preopercular spine straight, spear-like with denticles on the inside and an antrorse spine (covered by skin) on its base ..... *C. grossi*
- d. D IV-8½, A 7½, preopercular spine straight, spear-like, with a number of fine serrations on the inside, and with an antrorse spine on its base ..... *C. goodladi*

**Callionymus calauropomus Richardson**

*Callionymus calauropomus* Richardson, Ichth. Voy. Erebus & Terror, 1844-1848, p. 10, pl. VII Figs. 4 and 5 —"this Australian species," but cf. p. iv where as locality of provenance Western Australia is mentioned.

*Callionymus achates* De Vis, Proc. Linn. Soc. N.S.W. 7, 1883, p. 620—Queensland.

*Callionymus calauropomus*; Günther, Cat. Fish. Brit. Mus. III, 1861, p. 147 (North-west Australia); Castelnau, Proc. Zool. Accl. Soc. Vict. 2, 1873, p. 49 (Hobson's Bay); Günther, Rep. Voy. Challenger, Zool. 1, 1880, Rep. Shore

Fishes, p. 28 (Bass Straits; 38 fathoms); Macleay, Proc. Linn. Soc. N.S.W. 5, 1881, p. 627 (North-west Australia, Port Jackson, Port Phillip); Macleay, Descr. Cat. Aust. Fish. I, 1881, p. 262 (North-west Australia, Port Jackson, Port Phillip); Tenison-Woods, Fish and Fisheries N.S.W., 1883, p. 19 (New South Wales); Lucas, Proc. Roy. Soc. Vict. N.S. 2, 1890 (June), p. 29 (Hobson's Bay); McCoy, Prodr. Zool. Vict., dec. XX, 1890, p. 333, pl. 192 (Hobson's Bay); Woodward in Fraser, W. Aust. Year-Book for 1900-01, I, 1902, p. 271 (N.W. Western Australia); Woodward in Fraser, Notes Nat. Hist. W. Aust. 1903, p. 153 (N.W. Western Australia); Waite, Mem. N.S.W. Nat. Cl. 2, 1904, p. 51 (no locality = New South Wales); Stead, Fish. Aust. 1906, p. 209 (around the coastline of Australia); Oglby, Proc. Roy. Soc. Qd 23, 1910, p. 48 (no locality); McCulloch & Waite, Rec. S. Aust. Mus. 1, 1918, p. 48 (South Australia); Glauert, J. Roy. Soc. W. Aust. 7, (1920-1921), 1921, p. 46 (Western Australia, no definite locality); Waite, Rec. S. Aust. Mus. 2, 1921, p. 142 (no locality = South Australia); McCulloch, Aust. Zool. 2, 1922, p. 103 (Port Jackson); Waite, Fish. S. Aust., 1923, p. 165 Fig. (no locality South Australia); McCulloch, Rec. Aust. Mus. 14, 1923, p. 12 (Port Jackson, also Victoria, New South Wales, and South Australia); McCulloch & Whitley, Mem. Qd Mus. 8, 1925, p. 173 (Queensland); McCulloch, Biol. Res. Endeavour V, 1925, p. 209 (East of Flinders Island, Bass Strait; off Marsden Point, Kangaroo Island, South Australia; Doubtful Island Bay, south-western Australia); McCulloch, Fish. N.S.W., 2nd ed., 1927, p. 77 (Port Jackson); McCulloch, Mem. Aust. Mus. 5, 1929, p. 338 (New South Wales, Victoria, South Australia, Tasmania, Western Australia, Queensland, North-Western Australia, New Ireland); McCulloch, Fish. N.S.W., 3rd ed., 1934, p. 77 (Port Jackson); Whitley, W. Aust. Fish. Dept., Fish. Bull. 2, 1948, p. 27 (Western Australia); E. O. G. Scott, Pap. Roy. Soc. Tasm. 87, 1953, p. 157 (Tamar River, at Launceston, Tasmania); Fowler, Fish. Fiji, 1959, p. 493 (Queensland, North Western Australia, Western Australia, South Australia, Victoria, New South Wales, Tasmania); T. D. Scott, Fish. S. Aust., 1962, p. 169 (Western Australia, South Australia, Victoria, New South Wales and Tasmania).

*Callionymus calauropomus*; Castelnau, Vict. Off. Rec. Philad. Exh. 1875, p. 21 (no locality, presumably Victoria).

*Callionymus achates*; Macleay, Proc. Linn. Soc. N.S.W. 9, 1884, p. 35 (Queensland).

*Foetorepus achates*; Whitley, Aust. Zool. 6, 1931, p. 323 (Queensland).

*Synchiropus calauropomus*; Schultz, Bull. U.S. Nat. Mus. 202, 2, 1960, p. 405 (no locality).

Diagnostic characters. D IV-8½, A 7½, P i.16.i or i.17.i or i.17.ii or i.18.ii, V 1.5, C ii or iii.7.iii; all rays of dorsal fin divided, except sometimes the first one; preopercular spine ending in two hooks, bent upwards, and without an antrorse hook near its base (Fig. 1b); origin of D 1 almost on one line with gill openings; only first ray of pectoral undivided (in one specimen there is no undivided first ray). Males have a long tail and a long anal papilla, females a shorter tail and a short anal papilla.

Distribution. In Western Australia only known from off the south coast, where apparently common. Also known from South Australia, Tasmania, Victoria, New South Wales and south Queensland.

Discussion. Schultz (in Schultz *et al.* 1960), the most recent author to attempt subdivision of the genus *Callionymus*, has placed *C. calauropomus* in *Synchiropus*. A genus, in my opinion, should normally be based on a combination of characters. Schultz (in key, p. 399) uses the following. *Callionymus*: preopercular spine with a basal antrorse spine or one near its ventral edge, all rays of dorsal and of anal fins unbranched except last one in both fins branched to the base. *Synchiropus*: no antrorse spine at base or on ventral side of preopercular spine; first soft dorsal ray usually unbranched, all the

rest branched (except in young), the last one to its base . . ." Thus Schultz uses a combination of only two characters: divided or single dorsal rays, and presence or absence of an antrorse hook on the preopercular spine. But *C. rameus*, of which Schultz says he has studied the description and figure, is placed by him without comment in *Callionymus*, though it has the combination of divided dorsal rays and an antrorse hook, and therefore cuts right across his generic limits. I note that Schultz described one new species as *Synchiropus laddi*, based on specimens of 8-24 mm standard length, though it has simple dorsal rays. While Schultz may be quite right in assuming that larger individuals would have divided dorsal rays, and therefore do come in the genus *Synchiropus* as defined by him, the assignment as it stands seems rather arbitrary and strengthens my doubts about the advisability of recognising the genus *Synchiropus* as defined by Schultz. Not having examined the type species of *Synchiropus*, I confine myself to taking out the Australian species, and prefer not to give an opinion on the validity of the genus as such.

As in Western Australia the species seems strictly limited to the temperate waters off the south coast, it is surprising that elsewhere it should have been recorded from the tropics, from Fiji and New Ireland. While I do not deny the possibility that these records are correct, a re-examination of the material on which some of the older records are based would be desirable to verify if they really pertain to the present species. It may be recalled that, though Richardson described *C. calauropomus* as from Western Australia, Günther (1861) changed this without explanation to North-west Australia—almost certainly in error.

On the east coast of Australia the species ranges apparently farther north than on the west coast. The type of *C. achates*, which was synonymized with *C. calauropomus* by Ogilby (1910) came from Queensland, presumably south Queensland. Admittedly Whitley (1931) resurrected the name, but the characters given by him for its separation are unconvincing. Unfortunately the type of *C. achates* can no longer be found in the collection of the Queensland Museum, but there is a specimen on display, which is recorded as having been obtained off the coast of south Queensland and was received from the Queensland Department of Fisheries on 19th May, 1919 (Mack, in litt.)

Material examined, 14 specimens, varying in standard length from 128 to 189 mm. Michaelmas Island, King George Sound (P 4563), off Limestone Island, King George Sound (P 4803), off Bald Island (P 726 (9 sp.)), between Albany and the Archipelago of the Recherche (P 5412 (3 sp.)). Also examined one specimen from off Yorke Peninsula, South Australia (S. Aust. Mus.), two from Eden, New South Wales (C 714, C 716) and two from Bridgport, Tasmania, the largest of which is 217 mm in standard length (C 2032, C 2033).

#### *Callionymus calcaratus* Macleay

*Callionymus calcaratus* Macleay, Proc. Linn. Soc. N.S.W. 5, 1881, p. 628—Port Jackson.

*Callionymus calcaratus*; Macleay, Descr. Cat. Aust. Fish. I, 1881, p. 263 (Port Jackson); Tenison-Woods, Fish and Fisheries N.S.W., 1883, p. 19 (New South Wales); Ogilby, Proc. Linn. Soc. N.S.W. 10, 1885, p. 121 (Port Jackson); McCulloch, Aust. Zool. 2, 1922, p. 103 (Port Jackson); McCulloch, Rec. Aust. Mus. 14, 1923, p. 10, pl. iii, Fig. 2 (Port Jackson and Houtman's Abrolhos); McCulloch, Biol. Res. Endeavour V, 1926, p. 204 (New South Wales and Houtman's Abrolhos, Western Australia; Queensland waters); McCulloch, Fish. N.S.W., 2nd ed., 1927, p. 77 (Port Jackson); McCulloch, Mem. Aust. Mus. 5, 1929, p. 338 (New South Wales, Western Australia, Queensland); McCulloch, Fish. N.S.W., 3rd ed., 1934, p. 77 (Port Jackson); T. D. Scott, Fish. S. Aust., 1962, p. 168 (Western Australia, South Australia, New South Wales and Queensland).

*Callionymus curvicornis*; Ogilby, Cat. Fish. N.S.W., 1886, p. 37 (Port Jackson); Stead, Proc. Linn. Soc. N.S.W. 25, 1909, p. 476 (Port Jackson); Waite, Mem. N.S.W. Nat. Cl. 2, 1904, p. 51 (no locality—New South Wales); Stead, Fish. Aust., 1906, p. 208 (Port Jackson).

*Callionymus reevesii*; Ramsay & Ogilby, Proc. Linn. Soc. N.S.W. (2) 1, 1886 (1887?), p. 942 (Port Jackson); Waite Mem. N.S.W. Nat. Cl. 2, 1904, p. 51 (no locality—New South Wales).

*Repomucenus calcaratus*; Whitley, Aust. Zool. 6, 1931, p. 323 (no locality); Whitley, W. Aust. Fish. Dept., Fish. Bull. 2, 1948, p. 27 (Western Australia).

*Repomucenus* sp. nov.; Whitley, Aust. Zool. 11, 1945, p. 42 (Shark's Bay).

*Repomucenus calcaratus*; Whitley, Aust. Zool. 11, 1948, p. 275 (Fremantle, the Houtman's Abrolhos, Shark's Bay, between Cape Jaubert and Wallal and even as far as the Northern Territory (Lat. 12°12'S. x Long. 130°36'E.)).

Diagnostic characters. D IV-9½ (rarely 8½ or 10½), A 9½ (rarely 8½), P i.16.ii or i.16.iii or i.17.ii or i.17.iii, V 1.5, C ii.7.iii; only last ray of dorsal fin divided; preopercular spine rather broad, with four or five teeth at tip and on inside, and with an antrorse spine on its base (Fig. 1c); origin of D 1 well behind gill openings; D 1 short, with a black blotch on a white background; only first pectoral ray undivided; eye 1.0 to 1.5 in snout.

Distribution. South Australia, one specimen known, from off Port Lincoln. New South Wales, apparently not uncommon at Port Jackson (Stead 1906), and northern New South Wales (McCulloch 1926). Queensland, mouth of Wide Bay (McCulloch 1926). Western Australia, distribution discussed below.

Discussion. As far as material in the Western Australian Museum is concerned, this is a rare species in the state; there are only three specimens from Shark Bay in our collection. Whitley (in litt., 18.IX.1962) mentions, however, that the Australian Museum has material from a number of localities: two specimens, dredged between Cape Jaubert and Wallal, about five miles offshore in 5 fathoms, September 1929, by Mr. A. A. Livingstone, I.B. 4139-4140; Hampton Harbour, Dampier Archipelago, trawled, 5.IX.1952, by Mr. K. Godfrey, I.B.3061; Exmouth Gulf, August 1952, Mr. K. Godfrey, I.B. 3021; Shark Bay, dredged, July 1939, Mr. G. P. Whitley, I.B. 326; Useless Inlet, Shark Bay, 1939, Mr. G. P. Whitley, I.B. 358; two specimens, Houtman's Abrolhos, received on exchange from the Western Australian Museum in 1905, I. 7239; Fremantle, 1937, Dr. D. L. Serventy, I.A. 7196. Some of these specimens have been mentioned in publications by McCulloch and Whitley. While some of these records are above suspicion, I note that Whitley (1948a) describes for his material a large variation. The fairly large number of specimens of various species examined by me.

points to members of the family being remarkably constant in numbers of finrays. While a variation of one ray does occasionally occur. I find it very difficult to believe that specimens with D IV-8. A 7, as mentioned by Whitley, would really belong to *C. calcaratus*, and a re-examination of the material in the Australian Museum is desirable.

Amongst 19 specimens examined, 17 have D IV-9½, A 9½; one D IV-10½, A 9½; one D IV-8½, A 8½.

Material examined, four specimens varying in standard length from 133 to 154 mm. Off Kok's Island, Shark Bay (C 564), Shark Bay (P 5392, P 5393, P 5409). Also examined 16 specimens from other states, varying in standard length from 25 to 138 mm. Off Yorke Peninsula, S.A. (S. Aust. Mus.), Port Douglas, Q. (A 750), near mouth of Mary River, Q. (A 1061), South Head, Mary River, Q. (A 1142, A 1143, A 1144, A 1145), Tangalooma Point, Moreton Bay, Q. (A 1030), off Point Lookout, Stradbroke Island, Q. (A 1035, A 1036), Tweed Heads, N.S.W. (C 2060), Wallis Lake, N.S.W. (A 861), Princess Royal Harbour, N.S.W. (A 856, A 857), Twofold Bay, N.S.W. (C 2846).

#### *Callionymus goodladi* (Whitley)

*Callinichthys goodladi*: Whitley, Aust. Zool. 10, 1944, p. 270 — Cheyne Beach, Albany district, Western Australia.

*Callinichthys goodladi*: Whitley, W. Aust. Fish. Dept. Fish. Bull. 2, 1948, p. 27 (Western Australia).

Diagnostic characters. D IV-8½, A 7½, P ii.14.i or ii.15.i or ii.15.ii or ii.15.iii or ii.16.i, V 1.5, C ii.7.ii or ii.7.iii: only last ray of dorsal fin divided; preopercular spine straight, spear-like, with about 8-10 small antrorse teeth on the inside, and with near its base a large antrorse spine on the outside (Fig. 1d); snout large, broad and prominent, twice length of eye; origin of first dorsal nearly on a line with gill openings; first and second pectoral rays undivided.

Distribution. As far as hitherto known confined to Western Australia, where recorded from the south coast: Cheyne Beach and near Michaelmas Island, King George Sound, and from the west coast: Cockburn Sound, Shark Bay (entrance to South Passage, and without precise locality) and Exmouth Gulf. This distribution is unusual inasmuch as it includes both tropical and temperate waters.

Material examined, 27 specimens varying in standard length from 81 to 160 mm. Exmouth Gulf (P 4377, P 5355), Shark Bay (P 2541, P 2542, P 2543, P 4360, P 4369 (4 sp.), P 5438, P 5439, P 5440, P 5441, P 5442), entrance to South Passage, Shark Bay (P 4966), Cockburn Sound (A 1359, A 1361, A 1362), Cockburn Sound (A 1340, A 1341, A 1342, A 1343), Michaelmas Island, King George Sound (P 4967), Frenchman Bay (P 5037), between Albany and the Recherche Archipelago (P 5453), Cheyne Beach (P 2528: type of species).

#### *Callionymus grossi* Ogilby.

*Callionymus grossi* Ogilby, Proc. Roy. Soc. Qd. 2, 1919, p. 43—Moreton Bay.

*Callionymus, Callinichthys, nasutus* McCulloch, Biol. Res. Endeavour 7, 1928, p. 167, pl. 14—12 miles south-east from Cape Capricorn, Queensland.

*Callionymus, Callinichthys, grossi*, McCulloch, Rec. Aust. Mus. 14, 1923, p. 8 Cape Moreton; McCulloch & Whitley, Mem. Qd. Mus. 2, 1925, p. 170 Moreton Bay, Cape Moreton; McCulloch, Biol. Res. Endeavour 7, 1926, p. 165 (in key) (no locality).

*Callionymus grossi*, McCulloch, Aust. Mus. Mem. 3, 1926, p. 386 Queensland; Schultz, Bull. U.S. Nat. Mus. 269, 2, 1961, p. 406 (no locality); Palmer, Ann. Mag. Nat. Hist. 13, 4, 1962, p. 348 Monte Bello.

*Callionymus Nasutus*, Marshall, Ichthyological Notes Brisbane 1, 1951, p. 5 Moreton Bay off Potts Point.

*Callionymus Callinichthys nasutus*, Mees, W. Aust. Fish. Dept. Fish. Bull. 6, 1969, p. 4 Shark Bay.

*Callinichthys nasutus*: Whitley, Marine Fishes II, 1969, p. 226 (no locality).

Diagnostic characters. D IV-9½, A 8½ (in one specimen, 7½), P ii.13.iii or ii.14.ii or ii.15.i, V 1.5, C ii.7.iii: only last ray of dorsal fin divided; preopercular spine straight, spear-like, serrated on the inside with about 10-18 small antrorse teeth, and with on the outside near its base an antrorse spine (Fig. 1e); origin of first dorsal on a line with gill openings, first and second rays of pectoral undivided. Interesting features of this species are that both sexes have the rays of the first dorsal fin elongated; and the sexual dimorphism in snout length (see discussion).

Distribution. Known from Queensland and Western Australia. In Queensland recorded from Moreton Bay (type locality; also Marshall 1951), and from Cape Capricorn (type locality of *nasutus*). Marshall's statement that the type of *nasutus* was trawled off Cape Moreton, South Queensland, must be a slip. In Western Australia the species is known from Shark Bay, Exmouth Gulf and the Monte Bello Islands.

Discussion. One of the main diagnostic features given by McCulloch 1926 in his key to and description of *C. nasutus*, which was based on a single individual, is the long snout. Marshall (1951) had six specimens, and as he makes no comment to the contrary, it can be assumed that they all have a snout much longer than the eye. Two specimens from Shark Bay, reported upon by me (Mees 1969) showed the same feature. Later, however, specimens were received which agreed in every detail with *C. nasutus* but for the fact that they had shorter snouts and a smaller anal papilla. In the long-snouted specimens the anal papilla is large and long (more than half an eye diameter), in the short-snouted specimens it is very small. Though the result of an attempt at sexing was inconclusive, I feel confident that snout-length in this species is a sexual character, the long-snouted fishes being males, the short-snouted females.

I had come as far as this, when I had the opportunity to examine the individual of *C. grossi* recorded by Palmer (1962). This proved to be identical with the specimens which I regarded as females of *nasutus*, and indeed, in McCulloch's 1926, p. 165 key, the only character given to distinguish *C. nasutus* from *C. grossi* is the length of the snout. In order to make quite certain that *C. grossi* and *C. nasutus* are female and male of the same species, I borrowed a type of the former and found my expectations fully confirmed.

Material examined, 20 specimens varying in standard length from 78 to 148 mm. Monte Bello Brit. Mus. Nat. Hist. 1961.8.16.69, Exmouth Gulf (P 5356 (3 sp.), P 5484, C 2576, C 2579, C 2587, C 2588, C 2589, Exmouth Gulf

or Shark Bay (P 5493), Shark Bay (P 4376 (2 sp.), P 5394, P 5395, P 5396, P 5397, P 5400, P 5447, P 5107). Also examined a specimen from Bulwer, Moreton Bay, Queensland (Queensl. Mus. I 1579; cotype of species), and two specimens from Tangalooma Point, Moreton Bay, Queensland (C 2092, C 2093).

#### *Callionymus limiceps* Ogilby

*Callionymus limiceps* Ogilby, Ann. Qd Mus. 9, 1908, p. 35—Moreton Bay, Queensland.

*Callionymus limiceps* var. *sublaevis* McCulloch, Biol. Res. Endeavour V, 1926, p. 204—7-10 miles north-west of Hummocky Island, near Cape Capricorn, Queensland, 14-16 fathoms, and 13 miles south-east from Cape Capricorn, Queensland, 13 fathoms.

*Callionymus limiceps*; McCulloch, Rec. Aust. Mus. 14, 1923, p. 9 (between Hervey Bay and Port Denison, Queensland, at various depths between 13 and 26 fathoms); McCulloch & Whitley, Mem. Qd Mus. 8, 1925, p. 173 (Moreton Bay; between Hervey Bay and Port Denison); McCulloch, Biol. Res. Endeavour V, 1926, p. 203 (various localities off the coast of southern Queensland); Whitley, Rec. Aust. Mus. 17, 1929 (27 June), p. 115, figs. 3 and 4 (over Sow and Pigs Reef, Port Jackson); McCulloch, Mem. Aust. Mus. 5, 1929 (28 Nov.), p. 340 (Queensland); Schultz, Bull. U.S. Nat. Mus. 202, 2, 1960, p. 4C3 (no locality).

*Callionymus limiceps* var. *sublaevis*; McCulloch, Mem. Aust. Mus. 5, 1929, p. 340 (Queensland).

*Veslionymus limiceps*; Whitley, in McCulloch, Fish. N.S.W., 3rd ed., 1934, suppl. no. 418a (Port Jackson).

Diagnostic characters. D IV-9½, A 9½, P i.14.iii or i.15.i or i.15.ii or i.15.iii or i.16.i or i.16.ii or i.17.i, V 1.5, C ii.7.ii or ii.7.iii; only last ray of dorsal fin divided; preopercular spine with a tip bent inwards, with one antrorse hook on the inside, and with an antrorse spine near its base on the outside (Fig. 1f); only first pectoral ray undivided; origin of first dorsal well behind gill openings. Males have all four rays of first dorsal elongated; there is only a small amount of black on the first dorsal fin; females have a short first dorsal, which is largely black.

Distribution. Queensland, New South Wales and Western Australia. In Queensland the species has been recorded from a number of localities between Hervey Bay and Port Denison; for a full list of localities I refer to McCulloch (1926). For New South Wales there is only Whitley's (1929) record of a single specimen caught at Port Jackson. In Western Australia known from Shark Bay, Exmouth Gulf and the Dampier Archipelago.

Discussion. From the Queensland Museum I received on loan a pair of *C. limiceps*, collected and identified by Ogilby himself; the material from Western Australia differs from these only in having the bony upper surface of the head almost smooth with two slightly elevated radiating centres. This material therefore fully agrees with McCulloch's variety *sublaevis* as figured by Whitley (1929). As there are no other differences, I do not think that *limiceps* and *sublaevis* are different species, and they cannot be recognised as subspecies either, as they co-occur along the Queensland coast.

Material examined, 17 specimens varying in standard length from 53 to 131 mm. Dampier Archipelago (A 1461), Exmouth Gulf (P 5353, P 5354, P 5425, C 2380), Shark Bay (P 4370 (2 sp.), P 5401, P 5402, P 5403, P 5404, P 5405, P 5406, P 5407, P 5408, P 5421 (2 sp.)). Also examined two specimens from Moreton Bay, Queensland (Queensl. Mus. I 487), and one from Tangalooma Point, Moreton Bay, Queensland (A 868).

#### *Callionymus papilio* Günther

*Callionymus papilio* Günther, Ann. Mag. Nat. Hist. (3) 14, 1864, p. 197—Melbourne.

*Callionymus ocellifer* Castelnau, Proc. Zool. Accl. Soc. Vict. 2, 1873, p. 49—Cape Schanck.

*Callionymus lateralis* Macleay, Proc. Linn. Soc. N.S.W. 5, 1881, p. 628—Port Jackson.

*Callionymus nucleayi* Ogilby, Cat. Fish. N.S.W., 1886, p. 37—nomen novum for *Callionymus lateralis* Macleay, nec *Callionymus lateralis* Richardson.

*Callionymus Papilio*; Macleay, Proc. Linn. Soc. N.S.W. 5, 1881, p. 627 (Melbourne); Macleay, Descr. Cat. Aust. Fish. I, 1881, p. 262 (Melbourne).

*Callionymus lateralis*; Macleay, Descr. Cat. Aust. Fish. I, 1881, p. 263 (Port Jackson); Johnston, Pap. Roy. Soc. Tasm. (1890), 1891, p. 33 (Tasmania).

*Callionymus latealis*; Tenison-Woods, Fish and Fisheries N.S.W., 1883, p. 19 (New South Wales).

*Callionymus papilio*; Lucas, Proc. Roy. Zool. Soc. Vict. N.S. 2, 1890, p. 29 (Hobson's Bay); Waite, Mem. N.S.W. Nat. Cl. 2, 1904, p. 51 (no locality — New South Wales);

McCulloch, Aust. Zool. 2, 1922, p. 103 (no locality — New South Wales); Lord, Pap. Roy. Soc. Tasm., (1922),

1923, p. 69 (no locality — Tasmania); McCulloch, Rec. Aust. Mus. 14, 1923, p. 13 (New South Wales, from Port Jackson southward to Victoria and Tasmania); Lord &

H. H. Scott, Synops. Vertebr. Anim. Tasm., 1924, p. 12, 78 (Tasmania); McCulloch, Fish. N.S.W., 2nd ed., 1927,

p. 77 (no locality = New South Wales); Lord in Giblin, Lewis & Lord (editors), Handb. Tasm., 1927, p. 87 (Tas-

mania, especially in the north); McCulloch, Mem. Aust. Mus. 5, 1929, p. 338 (Victoria, New South Wales, Tas-

mania); McCulloch, Fish. N.S.W., 3rd ed., 1934, p. 77 (no locality = New South Wales); E. O. G. Scott, Pap. Roy. Soc. Tasm. 87, 1953, p. 157 (Tasmania); T. D. Scott,

Fish. S. Aust., 1962, p. 168 (South Australia, Victoria New South Wales and Tasmania).

*Foetorepus papilio*; Whitley, Aust. Zool. 6, 1931, p. 323 (Victoria); Whitley, Aust. Zool. 11, 1945, p. 42 (Cottesloe);

Whitley, W. Aust. Fish. Dept., Fish. Bull. 2, 1948, p. 27 (Western Australia).

Diagnostic characters. D IV-7½, A 6½, P 18 or 19, V 1.5, C ii.7.iii; first dorsal ray simple, others

divided at the tips; preopercular spine as in *C. calauropomus* pointing outwards and upwards,

with, besides the decurved tip, one single hook, curved forwards, on its inside; no antrorse hook

at its base (Fig. 1g). A small species.

*C. papilio* can easily be distinguished from other Australian species of the genus by the

short dorsal and anal fins, though I note that McCulloch (1923) mentions a specimen that has

eight rays in its dorsal fin instead of the usual seven.

Distribution. New South Wales, Tasmania, Victoria, one record for South Australia (Cape

Elizabeth, Yorke Peninsula), and two specimens recorded from Western Australia (Cottesloe).

The Cottesloe specimens should be in the collection of the Western Australian Museum, but

I have been unable to find them.

Material examined. No material from Western Australia has been available. The only

specimen examined was one of 62 mm standard length from Cape Elizabeth, Yorke Peninsula,

S.A. (S. Aust. Mus. F3076).\*

#### *Callionymus phasis* Günther

*Callionymus phasis* Günther, Voy. Challenger, Zool. I, 1880, p. 28, pl. XV Fig. C—Twofold Bay; 120 fathoms (?).

*Callionymus apricus* McCulloch, Biol. Res. Endeavour V, 1926, p. 209, pl. liv, Fig. 2—Great Australian Bight, south from Eucla, 350-450 fathoms.

*Callionymus phasis*; Macleay, Proc. Linn. Soc. N.S.W. 9, 1884, p. 35 (Twofold Bay); Waite, Mem. N.S.W. Nat. Cl. 2, 1904, p. 51 (no locality — New South Wales);

McCulloch, Aust. Zool. 2, 1922, p. 103 (no locality — New South Wales); McCulloch, Rec. Aust. Mus. 14, 1923, p. 9

\*Amongst our unidentified collections, I have since found a single individual of this species from Salmon Bay, Rottneest Island, collected 25.II.1955, reg. no. P5691, standard length 52 mm.

(Gippsland Coast, Victoria, 80 fathoms); McCulloch, Biol. Res. Endeavour V, 1926, p. 212 (Gippsland coast, Victoria, 80 fathoms; South of Cape Everard, Victoria, 200 fathoms); McCulloch, Fish. N.S.W., 2nd ed., 1927, p. 77 (no locality = New South Wales); McCulloch, Aust. Mus. Mem. 5, 1929, p. 338 (New South Wales, Victoria); McCulloch, Fish. N.S.W., 3rd ed., 1934, p. 77 (no locality = New South Wales); Norman, Fishes. B.A.N.Z.A.R.E., Rep. (B) I, 1937, p. 56 (off Tasmania, 42°40'S., 148°27'30"E., 122m.).

*Callionymus apricus*; Waite, Rec. S. Aust. Mus. 3, 1927, p. 231 (the Australian Bight in 350 to 450 fathoms); McCulloch, Aust. Mus. Mem. 5, 1929, p. 339 (Border of South and Western Australia).

*Yerutius apricus*; Whitley, Rec. Aust. Mus. 18, 1931, p. 115 (no locality); Whitley, W. Aust. Fish. Dept., Fish. Bull. 2, 1948, p. 27 (Western Australia (south coast)); T. D. Scott, Fish. S. Aust., 1962, p. 170 (Western Australia and South Australia in the Bight).

Diagnostic characters. D IV-8½ or 9½, A 7½; all dorsal rays divided but apparently simple in small specimens; preopercular spine curved upwards at its distal extremity to form a hook of the same size as two others on its upper margin; no antrorse spine at the base below (Fig. 1h). Eyes large, rising high above the profile of the head; interorbital very narrow. Anterior margin of D 1 only a little behind gill openings.

Distribution. Temperate seas of Australia, where known from Twofold Bay, New South Wales; the coast of Victoria, the east coast of Tasmania, and the Great Australian Bight south from Eucla. Apparently a deep water species that has been taken at depths of from 80 to 350-450 fathoms. Recently recorded from Japan (Ochiai, Araga and Nakajima 1955).

Discussion. I have not examined material of this species, which as far as I am aware, in Western Australia is known from the type specimen of *C. apricus* only. The particulars given are after McCulloch (1926), who noted the close resemblance of *C. apricus* to *C. phasis* Günther (1880) and, though not actually saying so, more or less suggested that the two might be identical. Nearly forty years have passed since, and no additional material that might confirm the validity of *C. apricus* has turned up. As the type locality of *C. apricus* is in a region where *C. phasis*, already known from the coasts of New South Wales, Victoria and Tasmania, would be expected to occur, and as both were found in deep water, it seems justified to synonymize the former. McCulloch (1926) mentioned only colour differences to distinguish between the two, but there may well be sexual dimorphism in this character.

All specimens recorded until recently, including the types of *C. phasis* and *C. apricus*, were reported to have divided dorsal rays; their size range was from 48 to 123 mm standard length. In the specimen of 44 mm standard length recently recorded from Japan, the dorsal rays are described as simple.

#### *Callionymus rameus* McCulloch

*Callionymus, Calliurichthys, rameus* McCulloch, Biol. Res. Endeavour V, 1926, p. 201, pl. liii—Cape Capricorn, Queensland.

*Callionymus rameus*; McCulloch, Aust. Mus. Mem. 5, 1929, p. 339 (Queensland); Schultz, Bull. U.S. Nat. Mus. 202, 2, 1960, p. 403 (no locality).

*Orbonymus rameus*; Whitley, Aust. Zool. 11, 1947, p. 150 (no locality).

*Callionymus (Calliurichthys) rameus*; Mees, W. Aust. Fish. Dept., Fish. Bull. 9, 1959, p. 9 (Shark Bay); Palmer,

Ann. Mag. Nat. Hist. (13) 4, 1962, p. 548 (Monte Bello Islands).

Diagnostic characters. D IV-8½, A 7½, P i.15.ii or i.15.iii or i.16.ii or i.17.i or 17.iii or i.18.i, V 1.5, C ii.7.ii to iii.7.iii; all dorsal rays divided or the first ray simple; preopercular spine with about five small teeth on the inside and with an antrorse hook on its base (Fig. 1i); origin of D 1 on a line with the gill openings, only first ray of P simple, once even the first ray divided; snout short, slightly shorter than eye. Apparently no sexual dimorphism.

Distribution. Queensland: Cape Capricorn, also 25 miles south-east from Double Island Point, 33 fathoms, and 4-20 miles north-east of Gloucester Head, 19-35 fathoms (McCulloch 1926). Western Australia: Shark Bay (without exact location) and 40 miles South of Carnarvon (Western Australian Museum); off the Monte Bello Islands (Palmer 1962).

Material examined, 12 specimens varying in standard length from 80 to 153 mm. Various localities in Shark Bay (P 4361, P 5106, P 5267, P 5269, P 5366, P 5413 (2 sp.), P 5414, P 5415, P 5416, P 5431, C 565).

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\*The volume in which Ogilby's article appeared bears the date 1911, but the Royal Society of Queensland pre-issued author's reprints and according to McCulloch (1929-1930), the paper was published in November, 1910.



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Part 4

15.—Some Pelecypods from the Cretaceous Gingin Chalk, Western Australia,  
together with Descriptions of the Principal Chalk Exposures

By F. R. Feldtmann\*

Manuscript received—18th September, 1962

In this paper a number of pelecypods (lamelli-branches), mostly new, from the Gingin Chalk are described in detail and named, and descriptions are also given of the principal chalk exposures. The pelecypods include species of *Perna*, *Anomia*, *Spondylus*, *Plicatula*, *Ostrea*, *Gryphaea*, *Pycnodonta* and *Exogyra*. In the descriptions of the species occasional reference is made to specimens from the Toolonga Calcilutite of the Lower Murchison area.

Introduction

Pioneer geological and palaeontological work in the Gingin area was carried out by Mr. Ludwig Glauert, firstly as a member of the Geological Survey staff, and subsequently as Curator of the Western Australian Museum. Mr. Glauert was responsible for several papers and made the first geological map of the area.

With the exception of the Pectens (Feldtmann 1951) no new pelecypods from the Gingin Chalk have been described since the publication of Etheridge's paper on the Cretaceous fossils of the Gingin Chalk (Etheridge 1913). Glauert's list of Upper Cretaceous fossils (Glauert 1926) included, in addition to those described by Etheridge, species of *Pecten*, *Chlamys* and *Amusium*, but no descriptions were given.

Etheridge described and named *Pycnodonta ginginensis*, *Chlamys ellipticus* and *Mytilus piriiformis*, and in addition to mentioning various species of *Inoceramus*, which he compared to species from Queensland and elsewhere, he also mentioned briefly and figured, but did not name, three species of oysters under the titles of "*Ostrea* sp. a," "*Ostrea* sp. b," and "*Ostrea* or *Pycnodonta* (Junr.)." These three last are described and named in this paper as well as species of *Perna*, *Anomia*, *Spondylus*, *Plicatula*, *Ostrea*, *Gryphaea*, *Pycnodonta* and *Exogyra*.

In connection with distribution of the various species, brief descriptions have been given of the more important exposures of the Gingin Chalk.

In 1944, a very large number of fossils was collected by the late Professor E. de C. Clarke and Dr. Curt Teichert from the Toolonga Calcilutite at various localities on the northern side of the lower Murchison River (Clarke and Teichert 1948), and more recently, a number of

specimens was collected by Dr. B. F. Glenister and Mr. B. E. Balme from Thirindine Point in the same area. In the description of the Gingin species occasional reference is made to specimens from these collections.

Location and General Geology

The small farming town of Gingin is situated 50 miles by rail north of Perth, on the Midland Company's line to Geraldton. It lies on both sides of the permanently flowing Gingin Brook, which, north-east of the town, flows in a south-south-westerly direction, but, after taking an abrupt U-shaped bend to the east immediately east-north-east of the town, changes to a west-south-westerly course through and west of the town. The town lies near the western edge of remnants of a former plateau of Mesozoic rocks situated between the main north-striking Darling Fault, which separates it from the Precambrian meta-sediments to the east, rather more than 8 miles east of Gingin railway station, and a second fault striking about north-north-west, which apparently diverges from the Darling Fault a little south of Bullsbrook some 24 miles to the south-south-east. Shot-holes put down for the West Australian Petroleum Proprietary Co. Ltd., and examined by Mr. S. Warne (unpublished data) indicate that this second fault is approximately  $1\frac{3}{4}$  miles west of Poison Hill, 4 miles north-north-west of Gingin railway station. In the immediate neighbourhood of Gingin, the plateau has been largely eroded by Gingin Brook and its tributaries, but from about a mile north-west of Poison Hill, northward, the western escarpment of the plateau is remarkably regular with a general trend of N.24°W., and this is very probably the approximate strike of the fault. This would put it about a mile west of the escarpment north of Poison Hill and approximately the same distance west-south-west of One Tree Hill and Gingin railway station. From 3 miles south of Gingin it is probably very close to the Midland railway line. The higher points on the plateau are now mostly between 700 feet and 780 feet above sea-level. West of the fault, the surface is much lower, mostly between 180 feet and 270 feet above sea-level, and the rocks are largely obscured by the sands of the coastal plain.

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The Mesozoic succession, and the approximate thicknesses of the formations are as follows:—

Upper Cretaceous.—

Poison Hill Greensand—possibly 170 feet to 250 feet.

Gingin Chalk—nil to 70 feet.

Molecap Greensand—20 feet or less to more than 90 feet?

Unconformity.

Lower Cretaceous.—

Strathalbyn Beds—between 170 feet and 180 feet exposed in the Gingin area.

*Strathalbyn Beds*

The Strathalbyn Beds were formerly regarded as Upper Jurassic from the identification by Walkom (1944) of plant remains found in ferruginous sandstone near the top of the formation in Cheriton Gully, 22 chains east of McIntyre Gully. In addition to the species identified by Walkom, specimens of an *Otozarnites*, associated with *Taeniopteris*, were found more recently at approximately the same horizon about 15 chains west of McIntyre Gully. The beds are now regarded by Mr. B. E. Balme (personal communication) as of Lower Cretaceous (Aptian) age, from material obtained from some of the shot-holes and from shallow holes below the floor of Molecap quarry.

The longest exposure of the beds is in McIntyre Gully, in the Strathalbyn property, where they consist mainly of fine and coarse ferruginous sandstones, partly bleached and finely micaceous in places. In McIntyre Gully the uppermost beds are pale grey to pale brownish yellow, and appear to be more shaly in character. At the northernmost exposure in the gully, the Strathalbyn Beds are separated from the overlying Molecap Greensand by a pale yellowish lateritic layer, four inches thick, containing fragments of fossil wood. This lateritic layer, found elsewhere at the top of the beds in places, doubtless represents a former land surface, much eroded in places before the Upper Cretaceous marine sediments were laid down. Less weathered examples of the beds occur in two small watercourses near the foot of the southern slope of Moorgup Hill, about  $1\frac{1}{4}$  miles south-east of the railway station. Here the beds, immediately below their contact with the Molecap Greensand, consist of bands, from 4 inches to 8 inches thick, of fine-grained, pale grey arenaceous shales containing a few coarse quartz grains and with inch-wide flakes of muscovite on bedding planes, alternating with bands of coarser red sandy grit. Small angular fragments of black carbonaceous material were noticed in one 6-inch band of more sandy shale. The beds here have a very slight easterly dip.

The beds also occupy a low ridge partly enclosed by the U-shaped bend of Gingin Brook north-east of the town. Here, pale grey, fine-grained, apparently argillaceous sandstone with much fine white mica is exposed in a few shallow potholes on the backbone of the ridge. In Molecap quarry, auger-holes exposed yellowish brown clay, very similar in appearance to the

top layers of the Strathalbyn Beds in McIntyre Gully, below the greensand at 7 feet 8 inches below the main floor of the quarry. Water was encountered at the junction of the two formations.

*Molecap Greensand*

The Molecap Greensand (Feldtmann 1934) a glauconitic sandstone, is a fairly fine-grained, dark greyish green rock, usually of homogeneous appearance and without visible bedding. At the type locality, a thickness of about 28 feet is exposed in the quarry, and auger-holes show it to have a total thickness here of 36 feet. The last 2 feet 6 inches encountered in the auger-holes above the Strathalbyn Beds was oxidised to a ferruginous brown sand. A thin band with phosphatic nodules was said to have been found at the base, in an auger-hole put down for the company quarrying the greensand, the glauconite being used as a water-softener. At the top of the greensand, a band, from about 3 inches to 30 inches thick, of dark reddish brown ferruginous material, with phosphatic nodules up to about 8 inches in diameter as well as rare bone fragments and other fossils, separates it from the overlying chalk.

At One Tree Hill, nearly  $1\frac{3}{4}$  miles north-north-west of Molecap, the thickness of greensand appears to be about the same. The phosphatic band is absent here. At McIntyre Gully, the observed thickness between two points was only 21 feet 7 inches and as the junction between the Strathalbyn Beds and the greensand showed a slight southerly dip the thickness is probably even less farther north, and in a shot-hole three-quarters of a mile north-east it was only 20 feet. It appears, however, to thicken fairly rapidly to the west. At one point in McIntyre Gully, the lowest foot of the greensand has been altered to a yellowish brown colour and contains small irregular phosphatic nodules. The uppermost five feet of the greensand in the gully becomes gradually paler in colour as it approaches the base of the chalk and appears to pass into it without any defined break.

Although the Molecap Greensand is usually of even texture and fine grains, occasional coarser facies occur. In small watercourse rather more than half a mile north-west of One Tree Hill, greensand with fairly numerous grains of quartz and orthoclase up to about 3 mm in length was seen.

Not many fossils are found in the Molecap Greensand. The writer found two small saurian limb bones, one about 7 inches long, as well as smaller fragments, in McIntyre Gully at about five feet below the base of the chalk and specimens of *Spirulaea gregaria*, small belemnites, and two species of *Chlamys* were found by Dr. R. W. Fairbridge at about 10 feet below the base of the chalk (Feldtmann 1931, p. 24). A few rare bones occur near the top of the formation at Molecap and bone fragments were also seen, near the top, in a watercourse immediately north of the Mooliabeenie road, a short distance east of Musk's Chalk. The writer also found specimens of fossil wood in the greensand in the more westerly small gully near the base of the southern slope of Moorgup

# GEOLOGICAL SKETCH MAP OF GINGIN

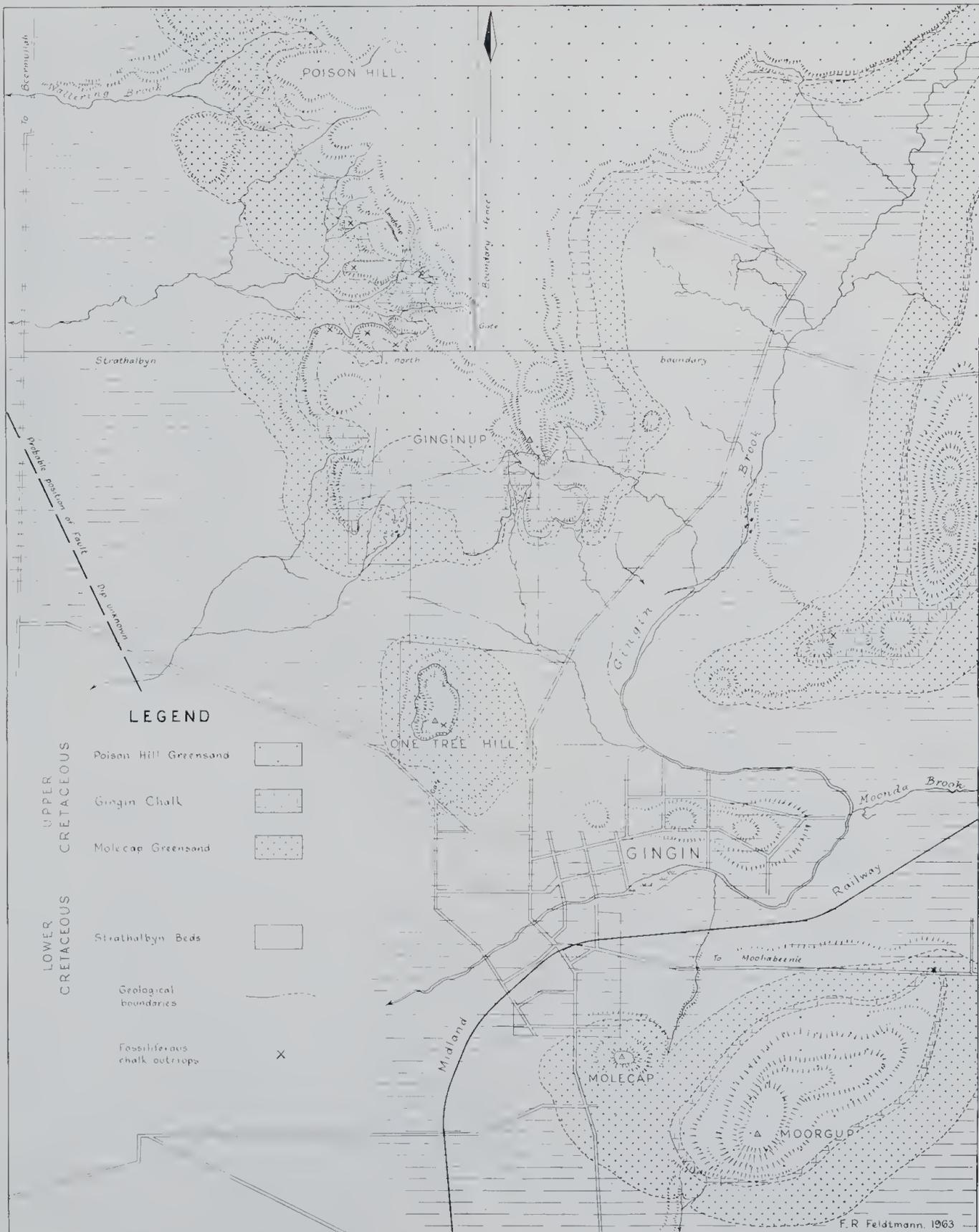


Fig. 1.

At Poison Hill, where the chalk is absent, the Molecap Greensand appears to pass into the Poison Hill Greensand without a break.

The heavy mineral content of the Molecap Greensand, mainly magnetite, was estimated at about one per cent. by Carroll (1941).

### *Gingin Chalk*

The Gingin Chalk forms a discontinuous layer of varying thickness between the Molecap and the Poison Hill Greensands. It consists mainly of carbonate of lime with varying proportions of grains of glauconite, quartz and some orthoclase. The heavy mineral content was described in detail by Carroll (1939) who estimated it at 0.07 per cent. Detailed descriptions of the principal chalk exposures are given on subsequent pages.

### *Poison Hill Greensand*

The best exposures of the Poison Hill Greensand are at the type locality and immediate vicinity and at a prominent landslip, about  $\frac{3}{4}$ -mile south-south-east. Good exposures of the base of the formation, above the chalk, are visible in two small gullies south-east of the landslip and about half-way between Poison Hill and Ginginup, and also at Southern's Chalk\*, about  $\frac{3}{4}$ -mile north-west of Ginginup. The slightly weathered rock was exposed on the southern slope of Moorgup, about a mile south-east of the railway station, by a landslip, about 40 years ago, but has since been partly covered up by further slipping. Like the Molecap Greensand, the Poison Hill Greensand is a fairly fine-grained dark greenish rock consisting mainly of glauconite and quartz with some orthoclase; a little clay is present in places. According to Carroll (1941, p. 85), the heavy mineral content is very small, less than in the Molecap Greensand. The unweathered rock is usually of more or less homogeneous appearance, but an exposure of much-weathered oxidised rock on the south-eastern face of the Ginginup escarpment shows it too consists of beds, three or four inches thick, of both fine and coarse sandstones, some even approaching a grit.

Small pea-shaped nodules of the rare mineral gearsutite ( $\text{CaF}_2\text{AlFOH}(\text{F},\text{OH})\text{H}_2\text{O}$ ) were found by Simpson (1920, p. 27) in a rather clayey bed, about 12 inches thick, with abundant glauconite and small phosphatic nodules. The bed was exposed in a small shaft on the north-eastern slope of Moorgup, about 2 chains south of the Mooliabeenie road and nearly opposite Musk's Chalk. Simpson also mentioned other somewhat clayey bands carrying small phosphatic nodules farther up the slope.

So far as I know the only organic remains found in the Poison Hill Greensand are coprolites, which, according to Simpson (1937, p. 38, Fig. 3) are abundant in certain bands, associated with bands carrying the phosphatic mineral dufrenite ( $\text{Fe}_2(\text{OH})_3\text{PO}_4$ ), at the landslip south-south-east of Poison Hill.

\* Note that the terms Southern's Chalk, Musk's Chalk, Hosking's Chalk and North Chalk are not formation names. They refer to exposures of the Gingin Chalk, and may be located on the map (Fig. 1) from the information in the text.

On much of the high ground between Ginginup and Poison Hill, the greensand is capped by dense ferruginous laterite up to about two feet thick in places.

No Upper Cretaceous rocks have been found south of Lennard's Brook, about two miles south-south-east of the railway station. Eclipse Hill, south of the brook and about  $3\frac{1}{4}$  miles south-east of the station, presents a very different appearance from Moorgup, north of the brook, on the southern face of which the Upper Cretaceous succession shows up very noticeably, whereas on Eclipse Hill, which is slightly higher, there are no rock outcrops and the hill is entirely covered by white or grey sand very different from the dark reddish brown sand derived from the greensands. It is probable that the straight easterly portion of Lennard's Brook follows a line of transverse faulting.

### *Pleistocene Drift*

An unexpected discovery early in May, 1949, was that of a fairly extensive deposit of Pleistocene drift in the upper portion of McIntyre Gully. The best exposure is on the west side of the gully, 120 feet south of where joined by the second small eastern tributary, and 590 feet south of the head of the gully. Here, portion of a lower jawbone with four large teeth, identified by Mr. Glauert of the Western Australian Museum as belonging to the extinct giant marsupial *Nototherium mitchelli*, was found lying on the floor of the drift by a student, D. A. Woodman. Other bone fragments were also found lying on the drift-floor, which is 2 feet 6 inches above the present floor of the gully. The base of the drift, which here is lying on greensand, is marked by an inch-thick layer of red ferruginous material. Above it, the drift consists of compacted greensand containing nodules and some larger boulders of chalk to 1 foot 9 inches above the base, followed by a 3-inch layer of grit, then soil to about 3 feet above the base, followed by soil with layers of grit to about 6 feet 6 inches above the base. The top of the drift is about 16 feet above the present stream-bed. On the west bank of the gully, the drift appears to tail out a few feet south of the exposure, but it extends northward for about 160 feet. Further search, a fortnight after the first discovery, revealed a second exposure of the drift about 135 feet north of the first and a few feet north of the junction with the small eastern tributary. Here, the drift is resting on the chalk and consists of material derived therefrom. Bones found resting on the floor of the drift at this exposure included a limb bone, scapula, vertebra, and two terminal toe-bones. The top of the drift here is also about 16 feet above the present stream bed. The post-Pleistocene portion of the gully is considerably narrower than that of Pleistocene times, indicating rejuvenation. The drift appears to be present in places on the eastern side of the gully, but its boundaries are ill-defined and there are no exposures.

### *The Chalk Exposures*

In the Gingin area the Gingin Chalk forms a more or less tabular layer of varying thickness deposited when and where conditions, such as depth of water, were favourable between the

lower or Molecap Greensand and the upper or Poison Hill Greensand. Where fully exposed the chalk grades into the greensands below and above, the boundaries between them being somewhat indefinite and difficult to determine with accuracy. At most of the exposures however, the section is incomplete, either the lowest or uppermost layers of the chalk being absent and the junctions between the chalk and the greensand abrupt.

The northern limit of the Gingin Chalk is about 3½ miles north-north-west of the Gingin railway station and half a mile south of Poison Hill, the most prominent point on the escarpment. At Poison Hill, where it is absent, the Molecap Greensand appears to pass without a break into the Poison Hill Greensand. The combined formations probably range from Coniacian to Campanian or even Maestrichtian in age (McWhae *et al.* 1958, pp. 116, 117, Table 7), the Gingin Chalk itself being Santonian. The Gingin Chalk reaches its maximum thickness of about 70 feet in the vicinity of McIntyre Gully, a little more than two miles north of the railway station. To the south, it appears to be thinning again at the southernmost exposure on the southern slope of Moorgup Hill, not quite 1½ miles south-east of the station, and near the southern limit of the Upper Cretaceous rocks.

The chalk consists mainly of varying proportions of carbonate of lime, quartz grains and glauconite, and according to Carroll (1939, p. 228) grains of orthoclase are also present. Clay is present at some horizons, particularly at McIntyre Gully. In a typical specimen of purer chalk from Molecap quarry, Carroll estimated the carbonate of lime at 87.3% and the glauconite at about 9%; the heavy mineral content was estimated at about 0.07%; this last (Carroll 1939, pp. 228-230) consisted mainly of minerals of metamorphic origin, without doubt derived from the Chittering Valley belt of meta-sediments and gneisses east of the Darling Fault.

From south to north, the principal exposures of the Gingin Chalk are at Molecap Hill, Musk's Chalk, One Tree Hill, McIntyre Gully, Southern's Chalk, the Springs Gullies, Hosking's Chalk, and North Chalk (refer Fig. 1). Of these, the most important is McIntyre Gully, just over two miles north of the railway station, as only there, is the formation complete, either the lower or upper layers or both, being missing from the other exposures. A detailed survey of the gully and its tributaries by the writer in 1939, showed the total thickness of the formation to be approximately 67 feet 4 inches, but the position of the base of the Gingin Chalk, at its junction with the lower or Molecap Greensand, is determinable only with difficulty under the most favourable conditions, and is more or less arbitrary, as the last five feet of the greensand becomes progressively paler and less highly glauconitic, with small lenticles of chalk, and appears to pass into the formation without any defined break. As determined by the writer, the base of the Gingin Chalk is situated near the base of the second small eastern tributary, at its junction with the main gully at about 470 feet south of the head of the gully. Here it is approximately 2 feet 6 inches above the stream bed of the main gully. It is also exposed on

a cliff face about 200 feet farther south, where the gradual change from a fairly dark grey, mottled, highly glauconitic rock, with a few lenticles of chalk and a few fragments of small pelecypods, to a paler rock with less glauconite and more numerous lenticles of chalk can be seen. Above the base, the Gingin Chalk may be described as follows:—

- 0 ft-4 ft 2 in.: mottled grey glauconitic chalk, probably somewhat clayey.
- 4 ft 2 in.-about 10 ft; more even-textured pale grey chalk.
- 10 ft-19 ft 3 in.: fine-grained pale yellowish to white, somewhat sandy, fairly typical chalk, slightly glauconitic.
- 19 ft 3 in.-20 ft 3 in.: very clayey fine-grained grey chalk.
- 20 ft 3 in.-23 ft: fairly typical, nearly white chalk.
- 23 ft-about 33 ft: mottled grey, probably clayey, marly chalk with more glauconite.
- 33 ft-about 42 ft: less distinctly mottled, grey, marly, somewhat glauconitic chalk.
- 42 ft-48 ft: grey glauconitic chalk without mottling.
- 48 ft-62 ft: increasingly glauconitic and darker greenish grey rock.
- 62 ft-67 ft 4 in.: rock practically indistinguishable from greensand in appearance.

The last two sections were exposed in the first small eastern tributary, which enters the main gully at about 307 feet south of the head.

The position of the top of the formation was determined on the noticeable change of soil and a marked change of slope, rather than on the appearance of the rock itself. A definite outcrop of the Poison Hill Greensand was exposed a few inches above the assumed top of the Gingin Chalk.

Regarding the fossil distribution, plates of *Uintacrinus* are fairly common between the base of the chalk and 13 ft 3 ins. above, particularly between 4 feet and 10 feet. At approximately 13 ft 3 in. *Uintacrinus* gives place to *Marsupites*. An overlap of the two stalkless crinoids has not been established in this locality, but at Molecap there is a definite overlap of about 8 inches. Between 8 ft 9 ins. and 10 feet in the main gully, a layer of the large quadrate *Inoceramus* compared by Etheridge (1913, p. 21) to *I. maximus* Lumholtz forms the lip of a small waterfall. This species appears to be confined to the *Uintacrinus* zone, as do the small coral *Coelosmia ginginensis*, *Chlamys subtilis*, and the large pachydiscoïd ammonite compared to the English *Parapuzosia* by Spath (1926, p. 54). *Tubulostium pyramidale* is commonest in this zone, but its vertical range extends to 17 feet or 18 feet above the base of the formation. Some of the commoner fossils, such as *Cidaris* spines, *Spirulaea* (*Tubulostium?*) *gregaria*, the brachiopods *Bouchardiella cretacea*, *Kingena mesembrinus*, and *Inopinatarcula acanthodes*, *Plicatula glauerti* and the oysters *Ostrea etheridgei*, *Pycnodonta ginginensis* and *Exogyra variabilis* have a much wider range, extending from the base to at least 44 feet or 45 feet above.

The *Marsupites* zone extends from 13 ft 3 ins. to 20 ft 3 ins. above the base. A few plates of the smooth form are found in the lowest portion of this zone, plates with the typical *M. testudinarius* sculpture being more numerous in the middle and upper portions. This zone is richest in fossils, characteristic forms being *Peronella globosa*, various brachiopods including, in addition to the commoner forms, species of *Terebratulina* and *Magnithyris*. Pectens, including *Syncyclonema subreticulata* and *Chlamys ginginensis* occur in the upper half of this zone, where also *Pycnodonta ginginensis* attains its greatest size, and plates of the cirripedes *Calantica ginginensis* and *Scalpeilum glauerti* are not uncommon. The characteristic species of *Inoceramus* is a large ovate nearly smooth form, of which a nearly perfect specimen 27 inches in length was found by Dr. Curt Teichert between 17 ft 9 ins. and 18 ft 3 ins. above the base. Equally large specimens seem to have been particularly common at this horizon, although, judging by the thickness of the fragments found, the species evidently extended to about 35 feet above the base.

The band of grey clayey chalk between 19 ft 3 ins. and 20 ft 3 ins. is particularly rich in small smooth or faintly plicate rhynchonellids, somewhat resembling "*Rhynchonella*" *limbata* Sow. and probably representing more than one species. A new *Terebratulina*, as well as other brachiopods, are fairly common at and just below this horizon. A few small sponges, including conical forms, a rare squat, mushroom-shaped species, and one resembling *Peronella globosa* Eth. fil., but more elongate in shape, were found immediately above the clayey band. A narrow zone between 21 feet and 23 feet above the base is characterized by numerous specimens of *Ostrea philbeyi*, which is almost wholly restricted to this zone, although a single small right valve was found close to the top of the *Marsupites* zone. The species is particularly common in the second small eastern tributary. Specimens of a small finely ribbed rhynchonellid resembling some species of *Burmirhynchia* occur between 23 feet and 28 feet above the base and a few unusually large specimens of *Inopinatarcula* were found at about 28 feet. From about 29 feet to 44 feet the fossils are mostly restricted to the commoner forms, but specimens of a small *Terebratulina* were found between 32 feet and 39 feet, and a few of the small pecten *Pseudamussium candidus* were found in the second eastern tributary at about 35 feet above the base. No macrofossils have, so far as I know, been found between about 45 feet and 64 feet above the base. Between 64 feet and the top of the formation, however, fragments of a thin-shelled *Inoceramus*, probably of a species different from those occurring at lower horizons, were found.

At Molecap Hill, half a mile south-east of the railway station, the thickness of chalk and chalk soil is 14 feet 7 ins., about 11 feet of chalk being exposed in the quarry, but of this only the lower 9 feet contain recognizable fossils. Distribution of the fossils in general, and of the two stalkless crinoids in particular, indicates that, compared with McIntyre Gully, approximately the lowest 11 feet of chalk is missing,

probably due to contemporaneous erosion, and as the 28 ft 6 ins. of Molecap Greensand exposed in the quarry—bores show the total thickness of greensand to be 36 feet—is homogenous in appearance, possibly as compared with McIntyre Gully, a small thickness is missing from the top of this formation also. The junction between the chalk and the greensand is abrupt and is marked by a ferruginous band from 3 inches to 30 inches thick, containing numerous phosphatic nodules. Fossils found in this band include many small shark teeth, portion of the lower jawbone, as well as a few small teeth, probably of a small *Mosasaurus*, several centra of *Ichthyosaur* vertebrae, a vertebra of one of the Salmonidae, and fragments of fossil wood containing numerous *Teredo* casts.

The Gingin Chalk at Molecap Hill has proved rich in all the commoner fossils and single specimens of species not found elsewhere have been found here. These include a single valve of *Crania* sp., a small rhynchonellid unlike those of McIntyre Gully, and a small conical coral.

The lowest foot of the formation is more highly glauconitic and of slightly coarser texture than that above and contains numerous coarse quartz grains and a few small phosphatic nodules. The remainder consists of typical white or pale yellowish rather sandy rock from which most of the glauconite has disappeared. There is a definite overlap of 8 or 9 inches of the two stalkless crinoids, *Uintacrinus* extending from the base of the formation to at least 3 ft 2 ins. above, where a smooth plate of *Marsupites* was found at approximately 2 ft 6 in. The two forms of *Marsupites* also overlap, the smooth form extending to about 5 feet above the base, whereas the sculptured forms range from about 4 feet to the top of the less weathered portion of the exposure, some large plates occurring between 7 feet and 8 feet. Of the rarer fossils, the large pachydiscoid ammonite appears to be confined to the lowest foot of the formation, whereas the other ammonites *Eubaculites* and *Glyptoxoceas* have been found in the *Marsupites* zone. *Perna* and *Spondylus* appear to be confined to the *Uintacrinus* zone and the lower portion of the *Marsupites*, as do also *Mytilus piriformis* and a *Dentalium*. Of the pectens, *Chlamys subtilis* is confined to the *Uintacrinus* zone, and *C. ginginensis* to the lower portion of the *Marsupites* zone. *Syncyclonema* ranges from about 3 feet to 8 feet above the base. Strangely enough, whereas in McIntyre Gully *Pseudamussium candidus* was found only at about 15 feet above the top of the *Marsupites* zone, at Molecap it is common between 3 feet and 6 feet above the base of the formation. Rare fragments of a *Holaster*-like echinoid occur in both zones. Although fragments of *Inoceramus* are very common, some occurring in thin layers, recognizable specimens are rare. Most of the fragments appear to belong to the large smooth form characteristic of the *Marsupites* zone. A few poorly preserved specimens resembling *I. cripsi* have also been found. Very rare needle-like teeth of one of the Salmonidae, resembling those of the genus *Apateodus*, have been found in the lower portion of the *Marsupites* zone, as well as rare posterior plates of an amphineuran.

At Musk's Chalk, about 130 chains east of the railway station and a short distance north of the Mooliabeenie road, about 6 feet of chalk was exposed in a cut, apparently just above the top of the Molecap Greensand. About 1½ feet was also exposed in a second small cut, the top of which was about 12 feet above the base of the first. When last visited by the writer, both cuts were largely obscured by soil and vegetation. The rock consists of fine-grained greyish glauconitic chalk with very few quartz grains and appears to be mainly, if not wholly, in the *Uintacrinus* zone, as, so far as I know, *Marsupites* has not been found here, whereas plates of *Uintacrinus* are common in the lower cut. A well-preserved specimen of *Spondylus ginginensis* was found in highly glauconitic chalk at the base of the lower cut about 40 years ago by the late Dr. E. S. Simpson, as well as portion of a gastropod resembling a *Pleurotomaria* in brown weathered greensand, probably from just below the chalk. Only *Cidaris* spines and fragments of *Inoceramus* were seen in the higher cut.

At One Tree Hill, just over a mile north-north-west of the railway station, the thickness of chalk and chalk soil is about 18 feet. The junction between the chalk and the Molecap Greensand is exposed behind an old lime-kiln on the southern slope below the quarry. Here, it is abrupt and well defined, suggesting that some of the lower chalk is absent, though perhaps not as much as at Molecap. The Molecap phosphatic layer is absent here. The junction is also exposed near the base of a small cut on the south-eastern slope of the hill. Here the junction is very irregular, suggesting the presence of local currents. Fossils found in this cut include *Porosphaera globularis* and casts of other small sponges, *Coelosmia ginginensis*, rare plates of *Holaster*, very numerous plates of *Uintacrinus*, *Kingena mesembrinus*, *Ostrea etheridgei*, *Pycnodonta ginginensis*, and large shark teeth, as well as a few coprolites.

The main quarry is 8 feet to 9 feet deep, the top being about four feet below the highest point of the hill. It was somewhat deeper at the south-west corner, now partly filled in, where plates of *Uintacrinus* are common in the darker grey, more glauconitic chalk. Many fossils were obtained during the excavation of the quarry. Glauert (1910, p. 117) stated that "the large Lamellibranchs are found in the upper portion of the main bed, and seem rare or entirely absent in the lower strata, where dwarfed Corals, Brachiopods, Lamellibranchs and Gastropods, as well as numerous Serpulae and Echinoderm spines represent . . . the animal life of the day . . ." Good specimens of ammonites are said to have been found near the south-western corner, as well as a very few well-preserved echinoids resembling *Holaster* and *Hemiaster*. *Marsupites* has been recorded from the quarry, but appears to be very scarce.

The upper portion of the quarry is in fine-grained white chalk, which differs from that of the other exposures in the occurrence, in places, of fairly numerous tabular, lenticular layers of indurated and probably silicified chalk, usually thin, but up to 6 or 7 inches thick in places.

Southern's Chalk is situated about 2½ miles north-north-west of the railway station, about 50 chains north-west of the head of McIntyre Gully, and immediately north of the northern boundary fence of the Strathalbyn property. It is in a small gully which runs north from the fence to join a more mature west-running gully 194 feet farther north. The junction of the chalk with the Poison Hill Greensand is exposed a few feet north of the fence. The chalk, of which a thickness of about 12 feet is exposed, differs from that of the other exposures, consisting of a very fine-grained even-textured fairly dark grey to putty-grey rock, with much glauconite in fine grains.

The relative position of Southern's Chalk is not easy to determine, as neither *Marsupites* nor *Uintacrinus* has been found here. Although actually situated at a lower level than Hosking's Chalk, 32 chains farther north, it appears to represent a higher horizon, which may have reached its present position by slipping. The only fossils of index value found by the writer were a single small left valve of *Ostrea philbeyi*, associated with *Pycnodonta ginginensis*, from about four feet below the top of the chalk, and two faintly plicated small rhynchonellids from 6 or 7 feet below the top. These suggest that the exposure extends from about the middle of the *Marsupites* zone to about 7 feet above that zone, and that, compared with McIntyre Gully, about 45 feet is missing from the top of the chalk. Other fossils found here include a fairly large rudistid from about 6 feet below the top; some large *Pycnodonta* and *Kingena* from between 5 feet and 7 feet; also a few specimens of *Bouchardiella* and *Ostrea etheridgei*, and the posterior plates of an amphineuran. A large capillate *Magnithyris*, associated with unusually large specimens of *Inopinatarcula acanthodes* was found a little lower down.

The Springs Gullies are situated on the lower slope of the escarpment between 60 and 70 chains north-west of the head of McIntyre Gully and about 25 chains north-north-east of Southern's Chalk. They include three fairly deep narrow gullies which owe their origin to springs emerging at a few feet above the top of the chalk. They run westward to join a rather more mature gully from farther south, which, in turn, runs north-westerly to join a still older gully from the north-east. The junction of the Gingin Chalk with the Poison Hill Greensand is well exposed near the heads of the two more northerly of the three small gullies, which also give the best exposures of the chalk. The chalk here is coarse-grained and highly glauconitic, especially near the top. Specimens of the small, finely ribbed rhynchonellid found between 23 feet and 28 feet above the base of the chalk in McIntyre Gully are common between the top of the chalk and 6 feet below, associated with many relatively large specimens of *Bouchardiella* and a few tiny *Terebratulina*. *Spirulaea*, *Kingena* and *Inopinatarcula* were found at about 6 feet in the middle gully. Fossils found below 6 feet in the more northerly gully include *Serpula*, *Spirulaea*, a small conical sponge, *Kingena*, *Inopinatarcula*, *Magnithyris* and numerous *Plicatula*. A single small valve of *Ostrea philbeyi*, associated with a fairly

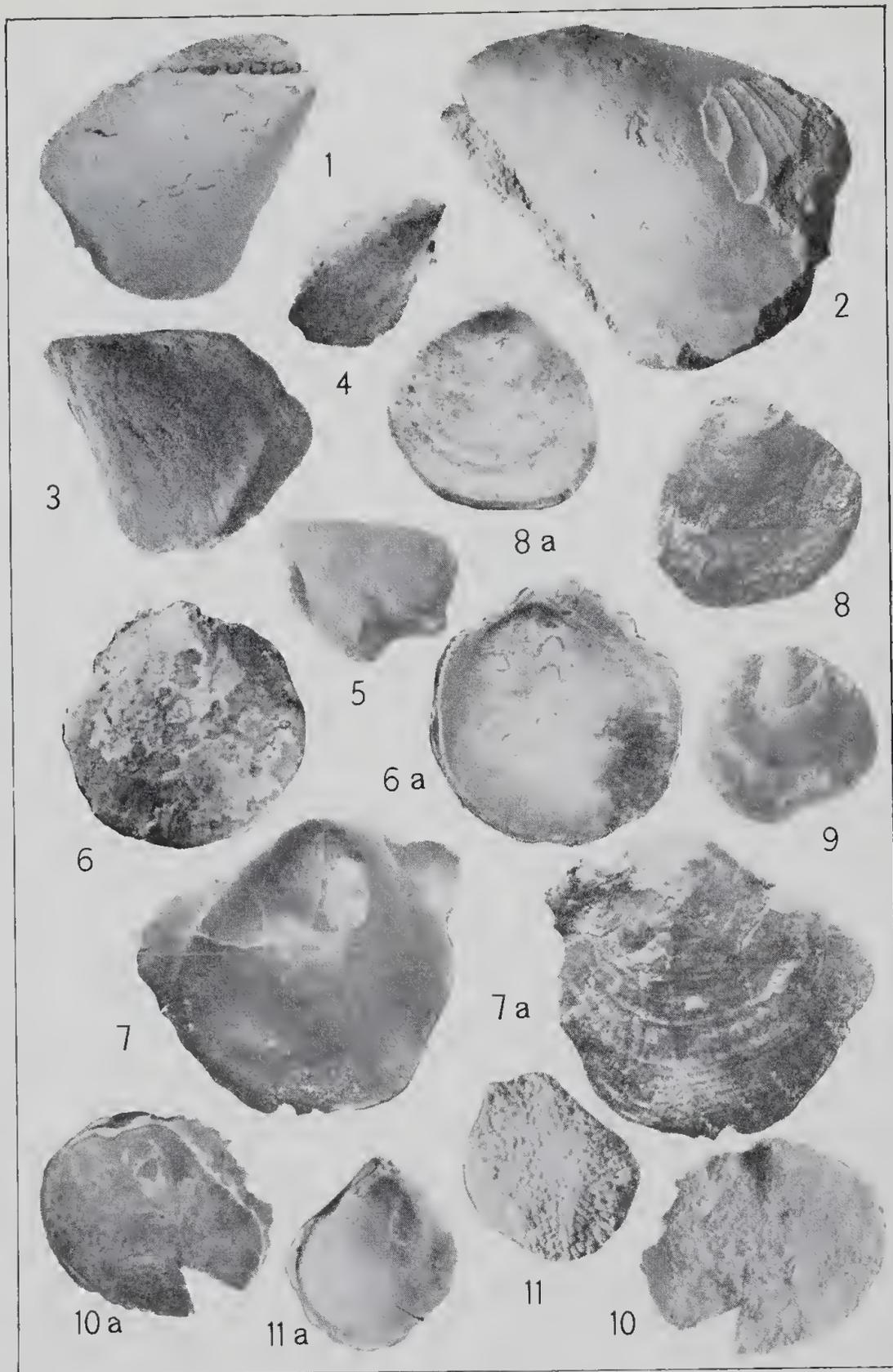


PLATE I

*Perna coolyenensis*

1.—The holotype (48932); cast of right valve and ligament pits of left valve, X 1½; 2.—The same (48932), left valve, further enlarged to show pattern of shell fragment, X 2; 3.—Paratype (48933); cast of left valve, X 1½; 4.—Cast of small right valve, X 1½; 5.—Cast of small left valve, X 1½. (All from Molecap.)

*Anomia fragilis*

6.—Exterior; 6a.—Interior of holotype (48936), a left valve, X 3; 7.—Exterior; 7a.—Interior of paratype (48937), a very large right valve, X 2; 8.—Exterior; 8a.—Interior of a smaller right valve, X 3; 9.—Exterior of a very small right valve (48938), with well-developed umbo, X 3. (All from McIntyre Gully.)

*Anomia prideri*

10.—Exterior; 10a.—Interior of holotype, a left valve (48939), X 2; 11.—Exterior; 11a.—Interior of a right valve, the exterior covered by a colony of bryozoans (48940), X 2. (Both from McIntyre Gully.)

large *Pyenodonta* was found at about 8 feet below the top, and also portion of a new *Chlamys*. A fragment of the carapace of a new crustacean was also found. Tiny specimens of *Magnithyris* and *Terebratulina* were found just below 9 feet. The horizons at which the index fossils were found suggest that approximately 40 feet is missing from the top of the chalk.

Hosking's Chalk is situated at the top of the western end of a long spur which runs west from the escarpment north of the Springs Gullies. It is 32 chains north-west of Southern's Chalk and one mile north-west of the head of McIntyre Gully. Only about six feet of chalk is exposed here, about half being in the *Uintacrinus* zone and half in the *Marsupites* zone. The exposure has proved to be fairly rich in the commoner fossils found at this horizon. Rarer forms found here include a few small smooth rhynchonellids, many *Magnithyris*, plates of both *Calantica ginginensis* and *Scalpellum glauerti*, small *Lamna* teeth, and one probably of one of the Salmonidae. Good specimens of *Plicatula glauerti* sp. nov. are fairly common, the holotype having been found here. The chalk is somewhat weathered, but still contains a fair amount of glauconite. A large percentage of yellowish quartz, in small grains, is also present.

The northernmost exposure, the North Chalk, is situated about 3¼ miles north-north-west of the railway station, 15 chains north of Hosking's Chalk, and ¾-mile south-east of Poison Hill. It consists of fairly coarse-grained chalk, somewhat similar to that of Hosking's Chalk but slightly more weathered and containing a larger proportion of evenly distributed grains of glauconite and rather larger grains of yellowish quartz. A thickness of only about three feet of chalk is exposed here, at the junction of the *Uintacrinus* and *Marsupites* zones. The fossils are much weathered. The assemblage appears to be similar to that of Hosking's Chalk. Rarer forms include part of a valve of *Spondylus ginginensis*, wholly attached to a fragment of *Inoceramus*, *Syncylonema perspinosus*, *Pseudamussium candidus*, *Ostrea macintyreii*, and two unusually large cirripede keel plates, possibly of a new species.

#### Systematic Descriptions

Superfamily	... PTERIACEA
Family	... PERNIDAE, Zittel
Genus	... <i>Perna</i> , Brugière, 1789

#### *Perna coolyenensis*,\* sp. nov.

Plate 1, Figs. 1-5

The available material consists of three fairly large and three smaller casts, all more or less imperfect. The only fragment of shell remaining is on the left valve of the holotype near the posterior ventral margin. Five of the specimens are from Molecap and the sixth is probably also from the same locality. I have not found the species elsewhere. Approximate original dimensions are given in Table I.

\* Coolyena—The name of the former trigonometrical station on Molecap Hill and probably the aboriginal name.

TABLE I

Approximate original dimensions of *Perna coolyenensis*, sp. nov.

	Holotype 48932† Molecap		Paratype 48933 Molecap		48935 Molecap	48934 Molecap
	R. valve	L. valve	R. valve	L. valve	Very imperfect R. valve	Small R. valve
Height	mm. 26	mm. 26+	mm. 25.5	mm. ?	mm. 27	mm. ?
Length	mm. 20.2	mm. 19.1	mm. 20	mm. 18.5	mm. 16?	mm. 16
Thickness	10.1		9.1			

Hinge of left valve of holotype, 16 mm.

Description.—Shell of moderate size, the test thin and fragile; nearly equivalve, inequilateral, height greater than length, both valves moderately inflated, the right valve very slightly more so; beak sharp, apical angle about 65°; hinge-line long and straight, multivincular, postero-ventral margin rounded, anterior margin slightly concave to nearly straight, posterior margin slightly convex and forming a very obtuse angle with the hinge-line. Surface of test with low, somewhat irregular but clearly defined growth-lines, about 2 to 2½ mm apart at their widest on the holotype. Length of hinge nearly two-thirds the height of the shell. The interior of the hinge of the left valve of the holotype, 16 mm in length, is exposed to show six U-shaped ligament pits.

Remarks.—The Gingin specimens show some variation in shape. The holotype and paratype show a slight resemblance to the casts from the Cambridge Greensand figured by Woods (1905, p. 94), the holotype particularly to figure 19C, which, according to Woods, was referred to *P. lanceolata* Geinitz by Seeley, and to figure 19D, *P. semielliptica* Seeley and the paratype to figure 19F, referred to *P. subspathulata* Reuss by Seeley. The ventral portion of the Gingin species is, however, relatively wider than that of *P. lanceolata* and the anterior and posterior margins are straighter than those of *P. semielliptica* and *P. subspathulata* and the hinge-line appears to be longer than those of the English specimens. The third large cast from which the beak and postero-ventral portion are missing was apparently relatively narrower than the others and more nearly resembles a specimen of *P. raulineana* d'Orb., figured by Woods (1906, Plate XII, Fig. 9), as does the small right valve, of which, however, the ventral portion is less produced.

The small right valve is the only specimen of which the horizon was recorded. This was the lower portion of the *Marsupites* zone, at five feet above the base of the chalk. The other specimens most probably came from about the same horizon.

Superfamily	ANOMIACEA
Family	ANOMIIDAE Gray
Genus	ANOMIA Linné, 1758

† Registered number, Geology Department Collection, University of Western Australia.

*Anomia fragilis*, sp. nov.

Plate 1, Figs. 6-9

Eighteen specimens, mostly small and some poorly preserved, were available for examination. These included ten from McIntyre Gully and eight from Molecap. Dimensions are given in Table II.

TABLE II

Dimensions of *Anomia fragilis*, sp. nov.

	Holo- type 48936	Para- type 48937	Para- type 48938	Shell and cast		
	L. valve	R. valve	R. valve	R. valve	L. valve	R. valve
	mm.	mm.	mm.	mm.	mm.	mm.
Height	10.6	19.7	9.9	16.1	12.5	7.5
Length	10.1	22.0	10.0	16.5	10.8	7.4

Description:—Shell rather small, thin to moderately thick, disc sub-circular, ovate, to subtrigonal in shape, relative proportions of height and length variable, usually slightly inequilateral; nearly equivalve, slightly convex, usually most inflated near the dorsal margin. Disc surrounded by a thin flange, apparently of varying width, but very imperfect in the specimens examined. Umbo small, at or near the margin. Hinge very narrow, edentulous. Holotype decorated with a number of well-defined, rather irregular overlapping concentric lamellae of varying width and traces of indistinct and rather irregular radial striae near the ventral margin. Interior of right valve shows nearly circular depressed muscle area, immediately below the hinge, about 6½ mm in height on the holotype, with a large well-defined elongate elliptical adductor scar, situated immediately posterior to the median line and extending practically to the posterior edge of the muscular depression. The edge of the disc is marked by well-defined ridge, apparently strongest on the postero-dorsal portion. The pallial line is simple and fairly well defined. Interior of the disc generally smooth, rarely showing faint concentric ridging near the ventral margin.

Left valve shows depressed nearly circular muscle area about equal in height to one-third the height of the shell, but with a U-shaped extension from its posterior end, extending ventrally to about half-way down the shell. Major byssal scar, elliptical in shape, high up under the umbo and immediately anterior to the median line; nearly separated into two halves by a narrow, curving ridge which enters it from its posterior side. Adductor scar subtrigonal in shape, situated immediately below the major byssal scar; minor byssal scar not so well defined, apparently more nearly elliptical in shape and situated at a distance from the adductor scar a trifle greater than the width of either and dorsally of a line at right angles to a line running through the other two scars. Remarks.—The largest right valve somewhat resembles in shape a specimen of *A. pseudoradiata* d'Orb. figured by Woods (1899, Plate VI, Fig. 2)

but lacks the fine radial riblets of that species. It also resembles fairly closely *A. subtrigonalis* Meek and Hayden from the Fort Pierre group of the North America Cretaceous (Meek 1876, p. 22, Plate 16, Fig. 4a). Other specimens show a resemblance in shape to specimens of *A. ponticulana* Stephenson (1952, Plate 20, Figs. 1-4), but the umbo of that species is farther from the margin and the hinge is stronger.

At McIntyre Gully the range of the species is from the base of the chalk to 18 feet above. At Molecap, it has been found between one foot and seven feet above the base. Most of the specimens from Molecap are particularly fragile, especially the left valves, and it is almost impossible to obtain one intact.

*Anomia prideri*, sp. nov.

Plate 1, Figs. 10, 11

Two specimens from McIntyre Gully differ from those of the preceding species in their marked obliquity and in the greater depth of the hinge. The larger specimen (the holotype), a left valve, is from about 14 feet above the base of the chalk; the location of the smaller specimen, a right valve, was not recorded. Dimensions are given in Table III.

TABLE III

Dimensions of *Anomia prideri*, sp. nov.

	Holotype 48939	Paratype 48940
	L. valve	R. valve
	mm.	mm.
Height	14.0	12.5
Length	15.8	11.0

Description.—Shell fairly small and moderately thin, obliquely ovate to piriform, inequilateral, the anterior half being somewhat the larger. Proportions of height to length variable, both valves slightly convex, the right valve rather more so. Umbo very small, marginal, directed slightly anteriorly. Hinge edentulous fairly thick and deep, particularly posterior to the umbo. Exterior surface of holotype nearly smooth, that of the paratype is almost wholly obscured by a colony of tiny bryozoans. Pallial line simple and well defined.

Interior of right valve smooth, the muscle attachment area only very slightly depressed, with the large elliptical adductor scar immediately posterior to the median line and extending from about 2.5 to 5 mm below the umbo. The interior surface of the left valve is much eroded. The anterior margin of the specimen shows the remnants of a fairly wide flange; 6 or 7 tiny crenulations are present immediately below the hinge on the ridge separating the body of the valve from the flange. The muscular area, circular in shape, extends to about half the height of the valve below the beak; the position and shape of the minor byssal and adductor scars are difficult to determine; the major byssal scar is slightly larger than that of *A. fragilis*; it is situated a little below the hinge immediately posterior to the median line,

with the adductor scar at about half way down the muscle area below it and slightly anterior to it; the minor byssal scar is very faint; it appears to be larger than the adductor scar, circular in shape and situated nearly opposite the middle of the major byssal scar below the posterior portion of the hinge.

Remarks.—In its obliquity and shape, *A. prideri* resembles a species of *Anomia* from the Crackers of Atherfield, figured by Woods (1899, p. 28, Plate V, Figs. 4, 5) but it lacks the radial ribs of the English species. It also resembles somewhat some specimens of *A. psamatheis* Bayan from the Auverian and Bartonian of Aquitaine (Cossman 1922, p. 215, Plate XV, Figs. 23-25) but the shape of the muscular area appears to be different.

Superfamily . . . . . PECTINACEA  
 Family . . . . . SPONDYLIDAE  
 Genus . . . . . SPONDYLUS Linné, 1758

*Spondylus ginginensis*, sp. nov.

Plate II, Figs. 1, 2

Represented by four more or less imperfect specimens of united valves of varying size, three from Molecap and one from Musk's Chalk, as well as a small imperfect right valve showing the interior and wholly attached to a fragment of *Inoceramus* from the North Chalk. Dimensions are given in Table IV.

TABLE IV

Dimensions of *Spondylus ginginensis*, sp. nov.

	Holotype 48941 Molecap		Paratype 48942 Molecap		Molecap		48943 Musk's Chalk	
	L. valve	R. valve	L. valve	R. valve	L. valve	R. valve	L. valve	R. valve
Height	mm. 45.6	mm. 51.5?	mm. 37.3	mm. 40.8?	mm. 30.2	mm. 36.4	mm. 29.0	mm. 32.5
Length	40.9	44.0?	35.2	37.0?	28.0	?	28.2	26.6
Thick- ness	33.6		28.3		14.0		20.7	

Description.—Shell fairly large, ovate, oblique, height greater than length, the left valve usually highly inflated, the right valve less so, but higher and perhaps slightly wider. Attached by the right valve, usually by the umbonal part only, this part usually much produced, some specimens showing a marked gap between the umbones of the two valves. Exterior surfaces of both valves ornamented with 70 to 80 fine evenly-spaced radial threads, and rather indistinct concentric growth lamellae; fine concentric threading, more noticeable on the right valves, is also present. A number of irregularly spaced small spines are present on the dorsal half of the left valve of the paratype.

Left valve usually highly convex, the beak terminal and sharp, and curved approximately at a right angle to the commissure. Postero-dorsal margin of body of shell, where joined by ear, concave, the anterior and ventral margins convex. Ears descending slightly from the umbo; posterior ear large, extending on the holotype, from the beak to 24 mm below; dorsal

margin straight, distal margin concave; anterior ear smaller, extending to 17 mm below the beak, dorsal and distal margins straight, meeting at a very obtuse angle. On the paratype the width of the posterior ear is about 8 mm. Both ears show faint concentric threading continued upwards from the body of the valve. The left valve of the holotype is ornamented with about 80 radial threads. On the other specimens the number is about 70.

Right valve less convex than the left, but considerably higher and apparently slightly longer. The umbo is produced well above that of the left valve. The area of attachment is very variable in size; on the holotype the attachment is to a smooth surface of *Inoceramus*, on the paratype the umbonal half of the attached portion shows fine radial ribbing, the other half well marked concentric lamellae; the other two specimens do not show any area of attachment. Ornament similar to that of the left valve, except that spines appear to be absent.

Remarks.—The third specimen of which the dimensions are given is much flatter than the others, its thickness being only half the dimension of the length of the shell, whereas in the other specimens the proportion is three-quarters. It may represent a different species, but in some European species the proportions of thickness to length appear to be variable. In the Musk's Chalk specimen, the point of greatest width is situated higher than in the other specimens. *S. ginginensis* appears to resemble most nearly the European species *S. gibbosus* d'Orbigny, particularly the specimens from the Cambridge Greensand figured by Woods (1901, Plate XX, Figs. 5-11), but the right valves of the Gingin specimens are relatively flatter, except in the Musk's Chalk specimen, and the ears of the left valves appear to be larger. Woods (1901, p. 118) states that the right valve of *S. gibbosus* is variable, flattened when attached by its entire surface, more convex when attached by a part only. The regularly spaced stronger ribs found on some specimens of *S. gibbosus* (Woods 1901, Fig. 5) are absent from the Gingin specimens.

The holotype of *S. ginginensis* was found in a block of chalk that had fallen from the back of the Molecap quarry. The paratype was from 2 ft 6 ins. above the base of the Gingin Chalk, at the junction of the *Uintacrinus* and *Marsupites* zones. Judging from the dark brown colour of the test, the Musk's Chalk specimen must have come from near the base of the formation at that locality. The North Chalk specimen was from the junction of the *Uintacrinus* and *Marsupites* zones. The range of the species would appear to be the *Uintacrinus* zone and lower half of the *Marsupites* zone. Four imperfect right valves, wholly attached to fragments of *Inoceramus*, similar to the North Chalk specimen, were found by Dr. Glenister and Mr. Balme in the Toolonga Calcilutite of the Murchison River valley at Thirindine Point and a similar fairly large specimen was obtained by Clarke and Teichert from Pillarawa Hill farther north, as well as two small ones from Meanarra Hill south of the Murchison River.

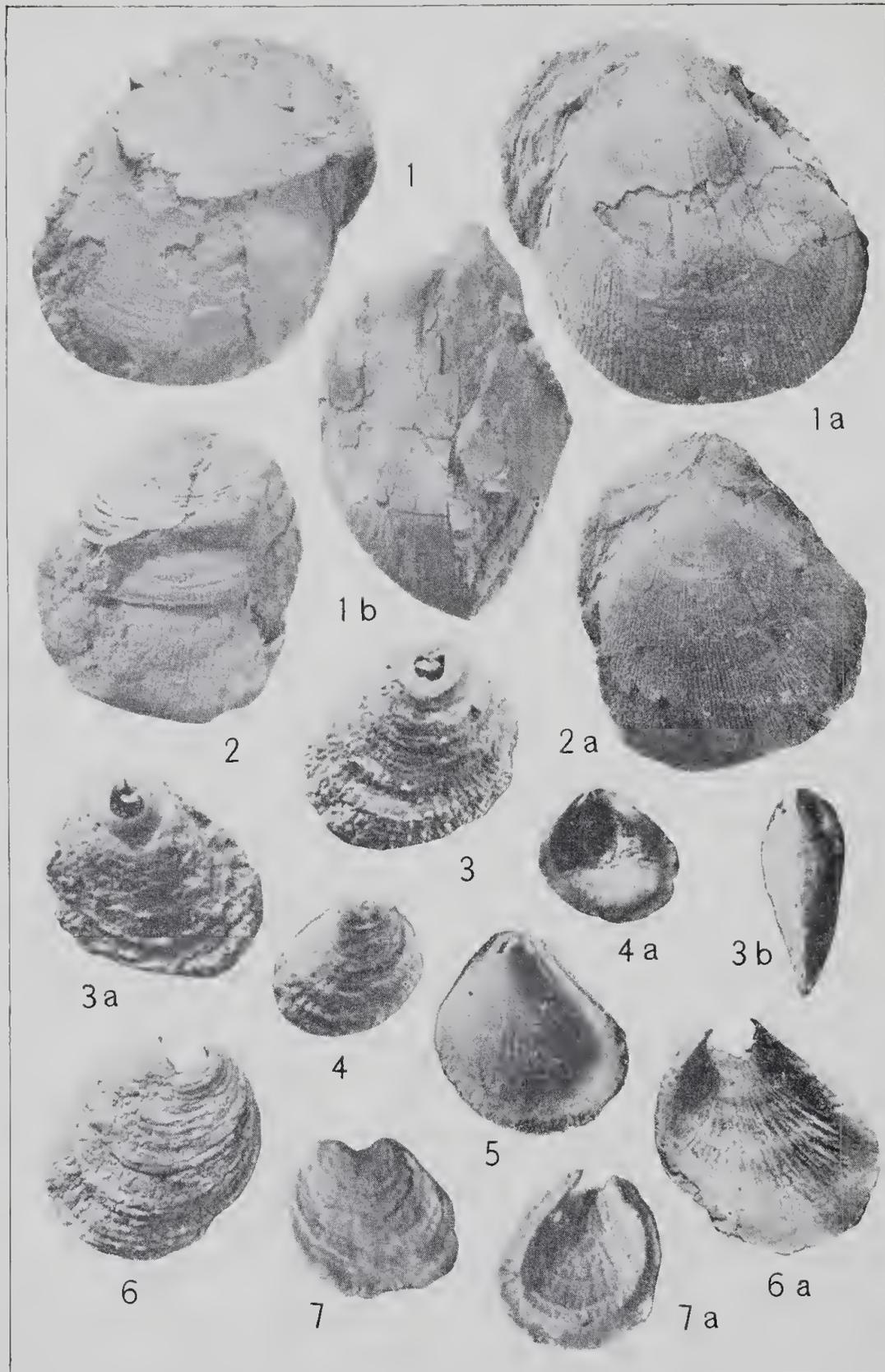


PLATE II

*Spondylus ginginensis*

1.—Right valve of holotype (48941), from Molecap, nat. size; 1a.—Left valve of same (48941), nat. size; 1b.—Posterior profile (48941), nat. size; 2.—Paratype, right valve (48942), nat. size; 2a.—Paratype, left valve (48942), nat. size.

*Plicatula glauerti*

3.—Right valve of holotype (48944); 3a.—Left valve; 3b.—Posterior profile, Hosking's Chalk, X 3; 4.—Exterior of paratype, a right valve (48947); 4a.—Interior, showing teeth, Molecap, X 3; 5.—Interior of right valve, with teeth, Middle Springs Gully (48946), X 3; 6.—Exterior of imbricated right valve (48948); 6a.—Interior showing anastomosing ribbing, McIntyre Gully, X 3; 7.—Exterior of a left valve (48945); 7a.—Interior showing ribbing, Hosking's Chalk, X 3.

Genus *PLICATULA* Lamarck, 1801

*Plicatula glauerti*, sp. nov.

Plate II, Figs. 3-7

About 150 specimens, mostly right valves, from various exposures, were available for examination. Left valves are comparatively rare and I have only seen three specimens of united valves. The hinge with the characteristic *Plicatula* teeth was preserved in only four right valves. The umbo was absent from nearly all the specimens. Dimensions are given in Table V.

TABLE V

Dimensions of *Plicatula glauerti*, sp. nov.

	Holotype 48944		Para- type 48947	Para- type 48946	Imbricated 48948		48945	Mole- cap
	Hoskings Chalk		Mole- cap	Springs Gullies	McIntyre Gully		Hos- kings Chalk	
	R. valve	L. valve	R. valve (with teeth)	R. valve	R. valve	L. valve	L. valve	L. valve
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Height	9.5	9.1	6.0	9.0	10.0	8.3	7.5	6.0
Length	8.8	8.7	6.1	8.5	9.3	8.1	6.7	6.9

The thickness of the united valves of the holotype is 3.9 mm.

Description.—Shell small, obliquely ovate to broadly piriform, the degree of obliquity varying; height and length nearly equal, but height usually the greater; inequivalve, the right valve moderately to strongly inflated except where wholly attached, the left valve rather less so. Attached by the right valve, but individual specimens range from unattached to wholly attached; in many, the area of attachment appears as a small subcircular truncation of the umbonal area; this is present in about 40 of the specimens examined; margins rounded. Body of shell thin near the umbo, thickened at the margins, especially the ventral margin, the width of the thickened portion varying considerably. Pallial line simple, well-defined on better preserved specimens.

Right valves range from those in which the whole exterior surface is covered with from about 20 to 40 closely spaced small radial riblets or plications to those from which radial ornament is absent; the riblets may be confined to the ventral half of the shell. They usually become obsolete near the anterior and posterior margins. Very rarely a single rib bifurcates near the ventral margin. The ribbed forms appear to predominate, although ribless specimens are fairly common. Concentric ornament of a number of closely spaced slightly irregular growth rings, of which from three to five may be more prominently imbricating. The interior surface appears to be slightly eroded as I could find no trace of an adductor scar on any of the specimens, the innermost layer of the shell apparently consisting of more soluble material. The interior decoration visible consists of 16 to 20 rather irregular bifurcating riblets. The hinge shows the typical divergent teeth, of which the

anterior is slightly the longer. The left valves are usually more nearly circular in outline, and are less inflated than the right valves, and very rarely may be even slightly concave; radial ribs are absent, the valves showing only concentric ornament, similar to that of the right valve. Where the hinge is present there is usually a nearly circular hole immediately below. The interior decoration consists of 15 or 16 anastomosing riblets. On some small specimens the interior ribbing is very indistinct, the ornament consisting of four or five concentric threads.

Remarks.—*Plicatula glauerti* is one of the commonest Gingin fossils and has a wide vertical range extending, at McIntyre Gully, from the base of the chalk to about 43 feet above. It is particularly common at Molecap and Hoskings Chalk and has been found at the Springs Gullies and the North Chalk, but, so far, I have not found it at One Tree Hill or Southern's Chalk.

In general appearance and in type of ribs the Gingin species most nearly resembles the European Cretaceous species figured by Woods. *P. minuta* Seeley (16-20 ribs) and *P. barroisi* Peron (13-25 ribs) (Woods 1901, p. 138, Plate XXV, Figs. 22-25 and pp. 141-143, Plate XXVI, Figs. 12-18 respectively), particularly the former species. Woods says that it seems probable that *P. minuta* is only the young form of *P. gurgites* (Woods, 1901, Plate XXV, Figs. 13-21) but that species shows little resemblance to the Gingin shell. *P. glauerti* is, however, considerably larger than *P. minuta* and its ribs are usually more numerous. *P. barroisi* also is smaller than the Gingin species, its ribs are usually fewer, and bifurcation of the ribs is common.

The Gingin species also resembles fairly closely specimens of the supposed genus *Diploschiza*, founded by Conrad on imperfect specimens of a single species *D. cretacea* Conrad and revived by Stephenson (1934, pp. 273-280, Plate 38). The Gingin shells are rather more oblique than those of Conrad's species and plicated specimens resembling those of Stephenson's variety *D. cretacea striata* (Stephenson 1934, Plate 38, Figs. 15-17) are more common; also the ribless form of the Gingin species appears to be rather more rugose than Stephenson's neotypes (Stephenson 1934, Figs. 3-9). Stephenson's specimens were from the southern extension of the Pecan Chalk Member of the Taylor Marl of Texas.

The genus *Diploschiza* was founded on specimens of which the hinge was imperfect and from which the innermost layer of the shell was missing. According to the description of the genus given by Shimer and Schrock (1944, p. 407) teeth are absent, and the inner surface of both valves is lined to near the margin with fine sharp irregularly spaced radiating ridges. Stephenson (1934, p. 276) stated that the hinge is edentulous, but also mentioned that "an occasional right valve supported the fragment of extraneous shell to which it is attached exhibits a faint suggestion of a pair of small short crural ridges diverging inwardly" (the *Plicatula* teeth). He suggested that the absence of muscle scars on the inner surfaces

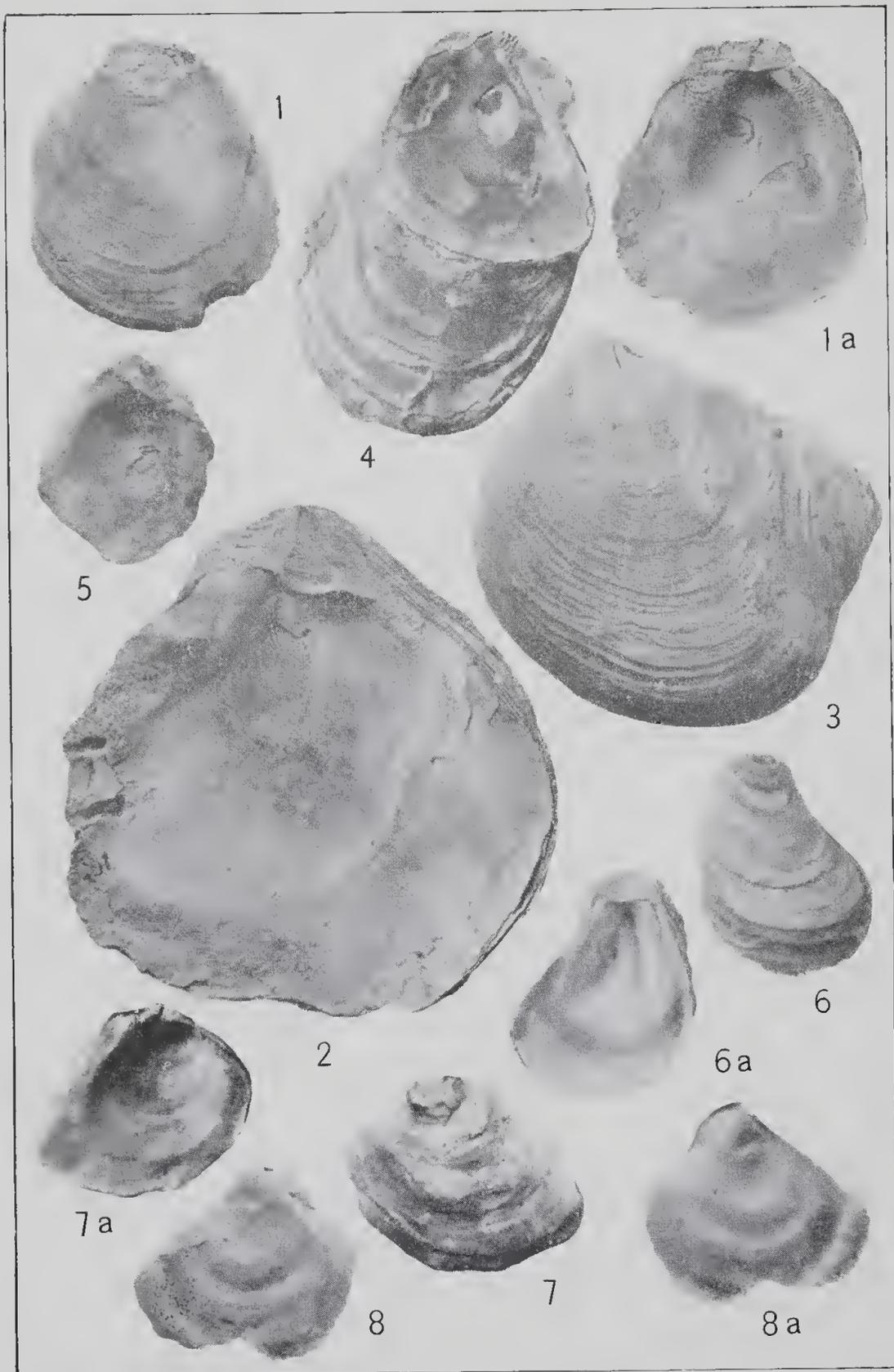


PLATE III

*Ostrea philbeyi*

1.—Exterior; 1a.—Interior of holotype: a left valve (48950), nat. size; 2.—Interior of a left valve: the largest specimen seen (48957), nat. size; 3.—Exterior of a slightly alate left valve (48958), nat. size; 4.—Interior of a right valve attached to a larger left valve (48951), nat. size; 5.—Interior of a small right valve (48952), nat. size. (All from McIntyre Gully.) 6.—Exterior; 6a.—Interior of a small left valve (48954). Nungajay Springs area,  $8\frac{1}{2}$  miles N. of the mouth of Murchison River. Nat. size.

*Ostrea macintyreii*

7.—Exterior; 7a.—Interior of holotype, a left valve (48955), x 2; 8.—Exterior; 8a.—Interior of a small right valve (48956), X 3. (Both from McIntyre Gully.)

"may be due to the failure of preservation of a thin inner layer of the shell." This is a regular feature of the Gingin species and Eudes-Deslongchamps (1858, p. 2) has mentioned that some of the *Plicatulas* from the neighbourhood of Caen were greatly attenuated in the cardinal region, and did not show in the interior any trace of teeth, groove, ligamental cavity, or muscular impression, the interior surface showing only growth striae, whereas others, from rocks of a different character, with thick test in the cardinal region showed the muscle impression, the teeth and groove. He attributed the different states of preservation of the two groups to their occurrence in rocks of different character.

Without doubt the shells of Conrad's species are really *Plicatula* from which the teeth and innermost layers of the shell have been eroded. Therefore, as a generic name *Diploschiza* is invalid.

The wholly attached valves of *P. glauerti* are most commonly found on nearly flat surfaces such as fragments of *Inoceramus*, valves of *Ostrea philbeyi* and right valves of *Pycnodonta ginginensis*, but I have found them also on *O. etheridgei*, on a larger *Plicatula* and even on the small brachiopod *Bourchardiella cretacea*.

Superfamily . . . OSTREACEA Goldfuss  
 Family . . . OSTREIDAE Lamarck  
 Genus . . . . . OSTREA Linné, 1758

*Ostrea philbeyi*,\* sp. nov.

Plate III, Figs. 1-6.

*Ostrea* sp. a. R. Etheridge, Junr., Geol. Surv. W. Aust. Bull. No. 55, p. 17, Plate IV, Figs. 8, 9, 1913.

Etheridge's brief mention of this species is: "A single example of a very thin-shelled flat valve, of common form and with no particular characters. The type is, however, new to our Cretaceous rocks, and therefore of interest, but resembles an Oyster met with in the oolitic beds of the Greenough River." His excellent drawings are of a fairly well-preserved specimen a trifle more oblique than the holotype.

A fairly large number of specimens from McIntyre Gully, nearly all left valves and mostly somewhat eroded, was available for examination, as well as single small left valves from Southern's Chalk and the northernmost of the Springs Gullies. Right valves are comparatively rare and only four were available. Dimensions are given in Table VI.

All specimens from McIntyre Gully except 48954 which is from Nungajay, Murchison River area.

Description.—Shell fairly large, moderately thick, ovate, slightly oblique, height slightly greater than length, nearly equivalve but the right valve may be slightly smaller than the corresponding left valve, inequilateral, rarely alate. Left valve slightly inflated, right valve nearly flat. Umbo straight, or slightly curved, fairly sharp when well-preserved, left valve occasionally showing small area of attachment. Ligamental groove broadly triangular; liga-

\* After the late Mr. W. R. Philbey, who collected the specimens described by Mr. Etheridge.

TABLE VI  
 Dimensions of *Ostrea philbeyi*, sp. nov.

	Holo- type 48950	Para- type 48957	Alate 48958		48951	48954	
	L. valve	L. valve	L. valve	L. valve	L. valve with small R. valve at- tached	L. valve	Right valves
Height	mm. 37.8	mm. 65	mm. 52.5	mm. 50	mm. 46.7	mm. 30.5	mm. 38 + 32.5 27
Length	mm. 32.8	mm. 62	mm. 50.5	mm. 44	mm. 37	mm. 24.5	mm. 36? 30.6 24.5

mental area large, with well-marked transverse striae. Exterior surface fairly rough, with closely spaced rather irregular growth lamellae. Interior surface smooth except for the well-defined adductor scar. Depressed area for accommodating the body of the animal well-defined, extending below the umbo for about two-thirds of the height of the shell. On the interior of the valve the anterior submargin, immediately below the ligamental area, shows a line often to eighteen short transverse, rarely bifurcating crenulations extending usually to approximately opposite the top, rarely the middle, of the adductor scar. On the posterior submargin is a shorter, wider area of slightly waved crenulations. Adductor scar fairly large, nearly elliptical in outline, the centre situated from slightly less than one-third to about two-fifths the height of the shell below the umbo.

Right valve usually flatter and thinner than the left. So far as could be judged from the poorly preserved specimens the exterior surface is smoother than that of the left valve. The crenulations on the interior submargins appear to be similar to those of the left valve. The position of the adductor scar varies considerably. On the two larger specimens and also on a small specimen (48953) from the *Marsupites* zone it is situated at about the same height as those of the left valves, but on the smallest specimen figured it is about half-way down the valve.

In Clarke and Teichert's large and comprehensive collection from the Murchison River area the only representatives of *O. philbeyi* are four small specimens from the Nungajay Springs area on the westward-facing escarpment about 8½ miles north of the mouth of the Murchison River. Two of these specimens are similar in shape to the McIntyre Gully specimens, but the other two, and particularly the one figured (Plate III, Figs. 6, 6a) are narrower and more obliquely piriform in shape; the anterior margin is curved inwards, the shell is much thicker, particularly the interior marginal portion enclosing the pallial line; and the exterior surface more rugose. These features suggest their growth in waters more disturbed by local currents than those in the McIntyre Gully area.

Remarks.—Etheridge (1910) stated that *O. philbeyi* resembled "an oyster met with in the Oolitic beds of the Greenough River," probably from the Newmarracarra Limestone, east

of Geraldton. Etheridge's figure shows the interior of a right valve obliquely subtriangular in outline (Etheridge 1910, Plate IX, Fig. 2). The specimen does not show the large triangular ligamental area characteristic of *O. philbeyi* and the adductor scar is larger, apparently less deeply cut, more centrally situated and more nearly circular in outline.

The Gingin species somewhat resembles the European *O. leymeriei* Leymerie (ex Deshayes) (Woods 1912, pp. 355-358, text-figs. 139, 140) but the latter is a much larger and apparently thicker shell. In shape and size *O. philbeyi* most nearly resembles the widely spread *O. acutirostra* Nilsson, especially to the rather poorly preserved specimens from the *Cardita beaumonti* beds of Baluchistan figured by Cossman and Pissaro (1927, Plate I, Figs. 1-5). Possibly owing to erosion, these do not show the ligamental groove and transversely striated area characteristic of *O. philbeyi*. The shells appear to be thicker, the adductor scar of the left valve is situated much lower than in the Gingin shell, being below the transverse median line and where the specimens are slightly alate, the alation is anterior instead of posterior. The slightly curved beak shown by some of the specimens from the Arrialoor beds figured by Stoliczka (1871, Plate XLV, Figs. 3 and 3a) is absent from the Gingin species. Stoliczka's specimens show the ligamental groove and area.

As far as I know, *Ostrea philbeyi* has not been found below the uppermost foot of the *Marsupites* zone, in which one small right valve was found, and at McIntyre Gully is practically restricted to a zone between about 21 feet and 23 feet above the base of the chalk. Although found in the main gully it is commonest in the second small eastern tributary. From its restricted occurrence, the species appears to be a good horizon marker.

***Ostrea macintyrei*, sp. nov.**

Plate III, Figs. 7, 8

*Ostrea* sp. or *Pycnodonta* sp. (Juvenile form): R. Etheridge, Junr., Geol. Surv. W. Aust. Bull. No. 55, p. 19, p. 29, Plate III, Figs. 10, 11, 1913.

Etheridge's figures show a small right valve of which the original dimensions were apparently about 14 mm in height by 13 mm in length; unfortunately, the ventral portion is imperfect, and it is impossible to say whether the specimen was originally ovate or subtriangular in shape. Etheridge evidently regarded his specimen as a young form of some larger shell, but it was more probably an adult shell as the only other specimens that could be assigned to the same species are even smaller.

A single small left valve (48955), height 12.3 mm, length 14.2 mm, from McIntyre Gully at about 17 or 18 feet above the base of the chalk, doubtless belongs to the same species as Etheridge's specimen, as does a small right valve (48956), height 9.8 mm, length 10 mm, from about 19 feet above the base.

Description.—Shell small, fairly thin, both valves slightly convex, obliquely subtriangular to ovate; length usually slightly greater than height, nearly equivalve, inequilateral, the posterior portion produced; umbo small, sharp,

except where truncated by area of attachment; attached by the left valve; posterior margin straight and making an obtuse angle with the ventral margin, anterior margin rounded and passing almost insensibly into the ventral margin; exterior surface rugose with strongly marked concentric ridges and rather faint growth lamellae. Interior surface smooth, but shallowly grooved in harmony with exterior concentric ridges.

The left valve shows a small but prominent area of attachment immediately behind the beak. The exterior shows two fairly prominent rather irregular concentric ridges as well as fine, rather indistinct growth lamellae. The hinge is small and shows a rather narrowly triangular ligamental groove, and shallow triangular area on which transverse striae could not be detected. On the posterior submargin, immediately below the hinge, is a short, broad area showing three fairly strong dental crenulations, nearly parallel to the median line. A slightly longer line of crenulation is present on the much narrower anterior submargin. The interior of the valve is shallowly grooved in harmony with the exterior ridges. The adductor scar is fairly large, rather shallow, elliptical in outline, and is situated at a distance below the hinge nearly equal to its major diameter. The pallial line is well defined and remote.

Right valve similar in shape to the left. Its exterior also shows two low broad rounded concentric ridges separated by a narrow groove; growth lamellae very faint. The rather narrow ligamental area is very similar to that of Etheridge's specimen and does not show any defined groove. Interior of valve with faint grooves corresponding to the exterior ridges. Adductor scar rather small and very shallow, semi-elliptical in shape and situated at about one-third of the distance from the median line to the postero-ventral angle.

Remarks.—This species is very rare. The only two examples of which the locality is known are from the uppermost portion of the *Marsupites* zone. So far as I can determine it does not resemble any of the European Upper Cretaceous *Ostreidae*.

***Ostrea etheridgei*, sp. nov.**

Plate IV, Figs. 1-4

*Ostrea* sp. b. R. Etheridge, Junr., Geol. Surv. W. Aust. Bull. No. 55, p. 17, Plate II, Figs. 19-21, 1913.

Etheridge stated:—"I have associated together a few very small and delicate valves, perhaps only the young of some larger form. They are rudely deltoid in outline, with high pointed umbos, and very short area. The adductor impressions, on the other hand, are large for such small shells. The two largest have lost much of the pointed umbo feature, and the valves have broadened out."

Etheridge's figures are of two small, rather squat specimens, not very characteristic in shape.

Right valves of this species are among the commonest Gingin pelecypods, but left valves are rare and I have only seen four small specimens, of which only one is reasonably well preserved. Dimensions are given in Table VII.

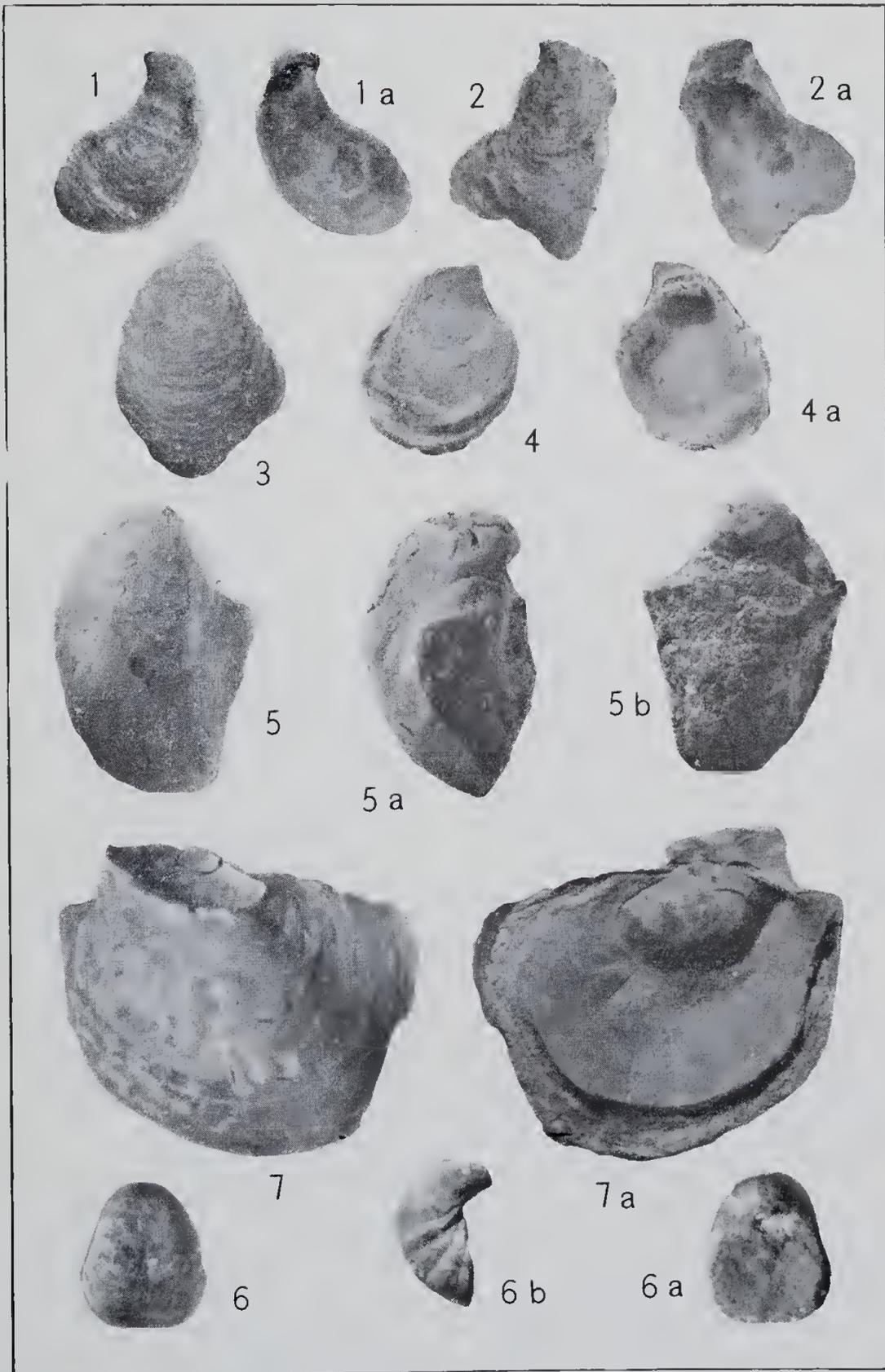


PLATE IV

*Ostrea etheridgei*

1.—Exterior; 1a.—Interior of holotype, a right valve (48959), X 2; 2.—Exterior; 2a.—Interior of paratype, a right valve (48960), X 2; 3.—Exterior of a large piriform right valve (48961), X 2; 4.—Exterior; 4a.—Interior of a small left valve (48962), X 3. All from McIntyre Gully except (48961).

*Gryphaea teicheri* (23025)

5.—Exterior of cast of a left valve, nat. size; 5a.—Posterior profile of same cast, nat. size; 5b.—Front view of cast, nat. size. Locality uncertain.

*Gryphaea minuta* (48964)

6.—Cast of left valve of holotype, X 4; 6a.—Cast of right valve of holotype, showing trace of test, X 4; 6b.—Posterior profile of holotype, X 4. From McIntyre Gully.

*Pycnodonta ginginensis*. Eth. fil.

7.—Left valve; 7a.—Right valve of a well-preserved specimen from Molecap (48965), X 1 1/2.

TABLE VII

Dimensions of *Ostrea etheridgei*, sp. nov.

	Right valves			Left valves			Molecap
	Holo-type 48959 Mc- Intyre Gully	Para- type 48960 Mc- Intyre Gully	Larg- est Spec. 48961 Mole- cap	Para- type 48962 Mc- Intyre Gully	Alate Mole- cap	48963 North Chalk	
Height	mm. 13.2	mm. 14.3?	mm. 16.0	mm. 8.5	mm. 11.8	mm. 10.7	mm. 8.9
Length	8.2	9.7	11.35	6.5	12.0	10.0	6.9

Description.—Shell small, fairly thin, shape very variable, usually considerably higher than long, obliquely piriform or ovate, the degree of obliquity varying greatly, inequivalve, usually very inequilateral, rarely nearly equilateral; beak usually directed posteriorly, rarely upright; right valve slightly convex, left valve more so; ligamental area varying in depth.

Posterior margin of right valve usually strongly concave below the beak for about half the height of the shell, passing insensibly into the convex ventral margin, but it may be nearly straight or even slightly convex; anterior margin convex. The exterior surface slightly rugose to nearly smooth with numerous closely spaced growth lamellae. Interior surface smooth except for the unusually large, shallow, more or less elliptical or piriform adductor scar of which the centre is situated from a little more than three-fifths to nearly three-quarters of the distance from the beak to the ventral margin. Ligamental groove apparently absent; ligamental area varies somewhat in size, and usually shows faint transverse striae. Marginal crenulations are absent.

Left valve very similar in shape to right but considerably more convex. The paratype (Plate IV, Figs. 4, 4a) appears to show a small flattened area of attachment immediately below the beak. The ligamental area is relatively large. The adductor scar is very faint, but appears to be elliptical in shape, and situated immediately below the hinge-line and slightly nearer the median line than the posterior margin.

Remarks.—At McIntyre Gully, right valves of this species are common between the base of the chalk and 20 feet above. Above that horizon they appear to be rare, but have been found as high as 42 feet above the base. They are also common at Molecap and other exposures in the *Uintacrinus* and *Marsupites* zones.

Etheridge (1913, p. 17) compared the outline of this species with that of a specimen described by Meek (1876, p. 18, Plate XI, Figs. 4a, b) as *O. patina* var. C, but the latter is a much larger, coarser shell. There is also some resemblance to *Gryphaea arrialocrensis* Stoliczka (1871, p. 464, Plate XLV, Figs. 13, 14) but the left valves of that species appear to be more slender and more oblique than those of *O. etheridgei*.

On the whole the Gingin species appears to resemble most nearly the specimens of *O. incurva* Nilson figured by Woods (1912, Plate

IX). Like those of *O. etheridgei* individual specimens of *O. incurva* vary greatly in shape, and except that the Gingin specimens do not show the radial riblets seen on some of Woods' specimens, especially his Figs. 12, 14 and 16, the resemblance is very close. The beak of *O. incurva*, however, appears on the average perhaps to be more sharply curved posteriorly and the adductor scar of the right valve is situated much higher and is more elliptical in shape than that of *O. etheridgei*.

Genus GRYPHAEA Lamarck, 1801

*Gryphaea teichert*, sp. nov.

Plate IV, Figs. 5, 5a, 5b

This species is represented by a single cast of the left valve of a typical *Gryphaea* from which the lower portion of the anterior part is missing (23025). Unfortunately, neither the exposure nor the horizon from which it came was recorded, but the partly brown-stained somewhat glauconitic chalk of which it is composed closely resembles the lowest foot of the Molecap Chalk. There is only an irregular mass of chalk where the right valve should be. Approximate original dimensions of the specimen are: height 38.5 mm, length probably about 30 mm, thickness 21 mm. Shell inequivalve. Left valve fairly large, higher than long, strongly inflated, inequilateral, slightly oblique, exterior contour in a fairly even curve, slightly more marked at the umbo. Exterior of cast smooth. Posterior half noticeably alate, with a shallow depression between the alate portion and the body of the shell; alation extending nearly to the ventral margin. Anterior half of specimen imperfect but apparently without alation. Valve apparently narrowing towards the ventral margin. Umbo prominent, directed approximately at right angles to commissure, rather short, about 4 mm in length and about 6.5 mm thick at the base, distal end rounded, slightly incurved.

Among the European Cretaceous species figured by Woods, *G. teichert* appears to resemble most nearly *G. vesiculosa* Saw (Woods 1912, Plate LV, Figs. 10-14; Plate LVI, Figs. 1a, 1b) in general shape, but the beak of the Gingin species is much thicker, blunter and more prominent than these of Woods' specimens. In profile, *G. teichert* is very similar in shape and convexity to a specimen of *G. vesicularis* Lam. figured by Stoliczka (1871, Plate XLIII, Figs. 1, 1a) but here also the beak of the Gingin specimen is larger and more rounded.

*Gryphaea minuta*, sp. nov.

Plate IV, Figs. 6, 6a, 6b

This species is represented by a single well-preserved cast of united valves from McIntyre Gully (48964), so small that were it not for the number of well-defined growth rings, one would regard it a young specimen of a larger species.

Dimensions.—Height 4.8 mm; length 4 mm; thickness 2.3 mm. The height of the right valve was probably 3.7 mm.

Description.—Shell very small, outline ovate approaching trigonal, higher than long, nearly equilateral, very inequivalve; left valve convex, right valve flat or slightly concave.

Left valve nearly semi-circular in profile, its continuity broken by several well-defined growth lamellae. Anterior margin strongly convex near the umbo and the ventral margin, nearly straight between; posterior margin rather more evenly convex; ventral margin straight in the middle, strongly convex at junction with anterior and posterior margins. Beak small, prominent, fairly sharp, slightly incurved. Exterior surface with apparently five growth ridges of which the middle three are more prominent, and are fairly high and rounded.

Right valve broadly ovate in outline; it shows faint traces of the test. The exterior surface appears to be smooth and no growth lines could be distinguished.

I have been unable to find descriptions of any other species resembling *G. minuta* at all closely.

Subgenus **PYCNODONTE** Fischer de Waldheim 1835

**Pycnodonta ginginensis** Eth. fil., 1913

Plate IV, Fig. 7; Plate V, Figs. 1-3

*Pycnodonta ginginensis* R. Etheridge junr. Geol. Surv. W. Aust. Bull. 55, pp. 17-19, Plate III. Figs. 6-9, Plate IV, Figs. 3-7, 1913.

*Pycnodonta ginginensis* was described in detail and figured by Etheridge but he made the mistake (Etheridge 1913, p. 18) of regarding the lower inflated valve as the right valve instead of the left. Although, as stated by him, the adductor impressions are sub-central, they are definitely posterior to the median line.

Apart from some species of *Inoceramus*, *P. ginginensis* is probably the commonest pelecypod in the Gingin area and it appears to be equally common in the Murchison River area, but the shells, though thick, are brittle and really well-preserved specimens are rare, few being sufficiently well-preserved for accurate measurement. With the exception of a specimen (Plate V, Figs. 1, 1a) from Toolong Hill near the Murchison River, I have not seen any as complete as those shown by Etheridge's Plate IV, Figs. 5-7. Dimensions are given in Table VIII.

**TABLE VIII**

Dimensions of *Pycnodonta ginginensis*

	Left valves				Right valves	
	McIntyre Gully	48965 Molecap	Molecap	48966 Toolong Hill	48967 Molecap	48968 McIntyre Gully
Height	mm. 42.0?	mm. 30.7	mm. 30.0	mm. 36.0	mm. 62.5	mm. 58?
Length	58.0	32.0	31.5	37.5	69.0	72.5

The two right valves are the largest I have seen. Only fragments of the corresponding left valve of the McIntyre Gully specimen were recovered and this was evidently even larger than the right valve. These fragments show a very large tabular area of attachment which makes an obtuse angle of about 105° with the sides of the valve.

Description.—Shell large, thick, longer than high, oblique, inequilateral, very inequivalve, the left valve highly inflated, globose, and larger than the right, the right valve flat or concave; attached by the left valve.

Left valve variable in shape, alate, the posterior alation usually the larger and more strongly lobate, occasionally separated from the body of the valve by a deep narrow groove. Anterior alation not always noticeable and rarely lobate. Exterior surface smooth except for the widely spaced, somewhat irregular margins of thin growth laminae. In some large specimens, these are very noticeable and imbricating. Etheridge's Plate IV, Fig. 7, shows the umbo as fairly long and strongly incurved with the point close to the body of the valve; almost invariably however, the beak is truncated by a flat or concave area of attachment which may be small or may occupy a large proportion of the surface of the valve (Plate V, Fig. 3a). Owing to truncation of the umbo the ligamental area and groove are rarely present; the groove is fairly wide and shallow; the rather small area shows faint transverse striae. Interior of the valve smooth; adductor scar fairly large, shallow, semi-circular in shape and situated in the dorsal half of the valve, immediately posterior to the median line.

Right valve broadly and obliquely elliptical in outline; usually slightly concave, but some valves are very slightly convex with reverted edges (Plate V, Figs. 2, 2a); in others, the umbonal half is convex, probably corresponding to the attached area of the left valve, the remainder concave and making a considerable angle with the convex portion, a well-marked groove separating the two portions. The umbo is rarely very noticeable being, as a rule, raised only slightly above the general surface, but in some concave valves the umbonal portion takes the shape of a low dome or boss, about equal in length to half the length of the valve (Plate IV, Fig. 7a). Exterior surface usually smooth, with faint growth rings; rarely, fairly regularly spaced faint radial striae are also visible. Cardinal margin long and straight; the ligamental area varies in size, but is usually wide. In the large Molecap valve (Plate V, Figs. 2, 2a), it is about 30 mm in width, with a wide groove, but it is relatively small in the even larger McIntyre Gully specimen. Only two specimens, from Thirindine Point in the Murchison River area, are sufficiently well-preserved to show the transverse dental crenulations on each side of the ligamental area figured by Etheridge (1913, Plate IV, Fig. 3). Adductor scar large, semi-circular to nearly circular in shape, deeply incised in aged shells, and situated immediately posterior to the median line and usually just above a transverse median line.

Remarks.—At McIntyre Gully, the vertical range of *P. ginginensis* is from just above the base of the chalk to about 42 feet above. The largest specimens are usually found in the upper half of the *Marsupites* zone, the largest found by the writer being from about 18 feet above the base of the chalk. At Molecap, the largest specimens occur near the middle of the *Marsupites* zone.

The general resemblance of *P. ginginensis* to *Pycnodonta vesicularis* Lam. was noted by Etheridge (1913, p. 19), and the resemblance of specimens both from Gingin and from the Toolong Chalk of the Murchison River area to the specimens of *P. vesicularis* figured by Woods (1912, Figs. 143-182) is so close that doubt arises as to

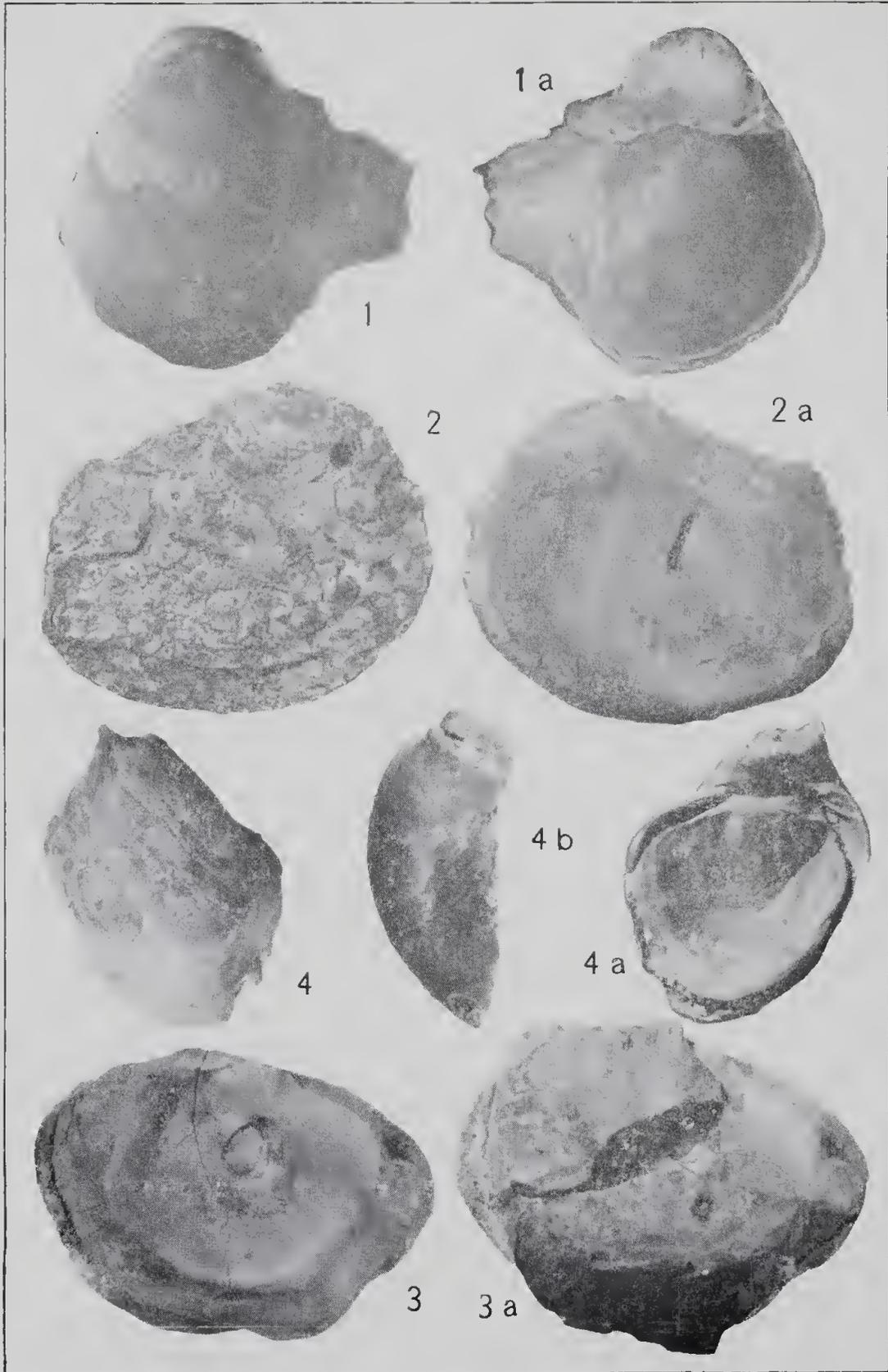


PLATE V

*Pycnodonta ginginensis* Eth. fil.

1.—Exterior; 1a.—Interior of hypotype, a left valve from Toolonga Hill, Murchison River area (48966), X  $1\frac{1}{4}$ ;  
 2.—Exterior; 2a.—Interior of an aged right valve from Molecap (48967), X  $\frac{2}{3}$ ; 3.—Interior of a very large right  
 valve from McIntyre Gully; 3a.—The same, with fragments of left valve superimposed (48968), X  $\frac{2}{3}$ .

*Pycnodonta strathalbynensis*

4.—Exterior of left valve of holotype (48969), X 2; 4a.—Exterior of right valve of holotype (48969), X 2; 4b.—  
 Posterior profile of holotype (48969), X 2. From McIntyre Gully.

whether they do not actually belong to the one species. The radial striae characteristic of the right valves of *P. vesicularis* were visible on only two right valves from Molecap, the exterior surfaces of other right valves both from Gingin and from the Murchison River area being too eroded to show whether this feature was originally present. In Etheridge's profile (Etheridge 1913, Plate I, Fig. 7) the beak is more incurved than that of Woods' Fig. 178 (Woods 1912, p. 371) but in some small specimens from Thirindine Point in the Murchison River area, the curvature is very similar or even less than that of Woods' figure. I have not seen any right valves of which the umbo is as well developed as that of Woods' Fig. 150 (p. 367) but on the whole, the great similarity between that of *P. ginginensis* and *P. vesicularis* suggests that they belong to the same species and that any differences are those of individuals.

***Pycnodonta strathalbynensis*, sp. nov.**

Plate V, Figs. 4, 4a, 4b, Plate VI, Fig. 1

A single fairly well-preserved small shell showing both valves, from McIntyre Gully at about 37 feet above the base of the chalk (48969), differs greatly in its proportions from typical specimens of *P. ginginensis* and appears to represent a different species. The horizon from which it comes is nearly 20 feet above that at which the largest specimens of *P. ginginensis* occur. Dimensions are given in Table IX.

**TABLE IX**

Dimensions of *Pycnodonta strathalbynensis*, sp. nov.

	Left valve	Right valve
Height	mm. 21.3	mm. 14.4
Length	16.0	11.3

The thickness of the united valves is 8.6 mm.

Description.—Shell small, fairly thin, higher than long, inequilateral, obliquely ovate, very inequivalve, the left valve inflated and larger than the right, the right valve convex in the umbonal area, the remainder concave; attached by the left valve.

Left valve grypheate, fairly strongly inflated, obliquely ovate; the lateral margins somewhat compressed to form a rounded ridge extending from the umbo to the ventral margin; slightly alate posteriorly, the alate portion separated from the remainder of the valve by a shallow furrow; anterior portion of the valve slightly concave for a short distance immediately below the umbo, the remainder convex; posterior margin very slightly concave for about a quarter of the height of the valve, becoming strongly convex in the alate portion; the anterior-ventral and postero-ventral margins meet in a fairly sharp arch. Exterior surface of valve slightly rugose with fairly distinct growth rings, shaped similarly to the shape of the valve. Umbo fairly high and grypheate, but truncated in the holotype by a small, slightly concave area of attachment. Ligamental area high and fairly wide with a narrow groove directed posteriorly and set obliquely with the top immediately below the posterior edge of the truncated umbo, the

anterior edge of the triangular ligamental area being much longer than the posterior. Hinge-line straight and not very long. Interior of valve smooth, the adductor scar small, shallow, nearly circular in shape and situated a little below the base of the umbonal area, posteriorly to the median line.

Right valve obliquely ovate, the umbonal portion convex, the remainder concave, a shallow groove separating the two portions in the anterior half of the valve. Anterior margin fairly evenly convex; posterior margin slightly concave immediately below the hinge-line, thence convex and bulging outwards almost to an angle opposite the alate portion of the left valve, thence nearly straight to form a rounded arch with the anterior margin at the ventral end of the valve. Umbo marginal, sharply pointed and set obliquely with its point directed towards the posterior end of the hinge; the hinge area long, flattened and bent slightly forward in the middle, the ligamental area occupying the flattened portion. Exterior of valve smooth except for a few faint narrow growth rings round the umbo. Interior surface smooth except for a few low growth ridges in the middle third, adductor scar large and ovate in shape, situated immediately posterior to the median line and occupying a large part of the ventral half of the concave portion which corresponds to the convex umbonal portion of the exterior. The concave area extends ventrally for nearly half the height of the valve, being deepest immediately below the hinge.

Remarks.—The principal difference between this species and *P. ginginensis* is in the proportions of height to length. In both valves of *P. ginginensis* the length is almost invariably greater, sometimes much greater, than the height, whereas in *P. strathalbynensis* the height of the left valve is much greater, that of the right valve very slightly greater, than the length.

*P. strathalbynensis* shows a very close resemblance to *Gryphaea vesiculosa* Sow. from the Upper Greensand of Warminster, England (Woods 1912, pp. 374, 375; Plate LV, Figs. 10-14. Plate LVI, Fig. 1). Indeed Woods' description of that species might very well fit the Gingin shell. So far as can be judged from the single specimen, *P. strathalbynensis* is rather more oblique than *G. vesiculosa*, the ligamental area of its left valve being particularly so and a median line from the apex of the ligamental groove to the middle of the ventral margin would show a much greater curve than those of the specimens of *G. vesiculosa* figured by Woods, which show the ligamental area of the left valve to be directly below the umbo, whereas in the Gingin specimen it is situated posteriorly to the umbo, which is evidently grypheate, but owing to truncation of the holotype its exact shape is unknown.

Genus *EXOgyra* Say, 1820

***Exogyra variabilis*, sp. nov.**

Plate VI, Figs. 2-10

Specimens of *Exogyra* are fairly common in the Gingin area, especially at McIntyre Gully, where their vertical range is from the base of the chalk to possibly 40 feet above. They are also fairly common at Molecap.

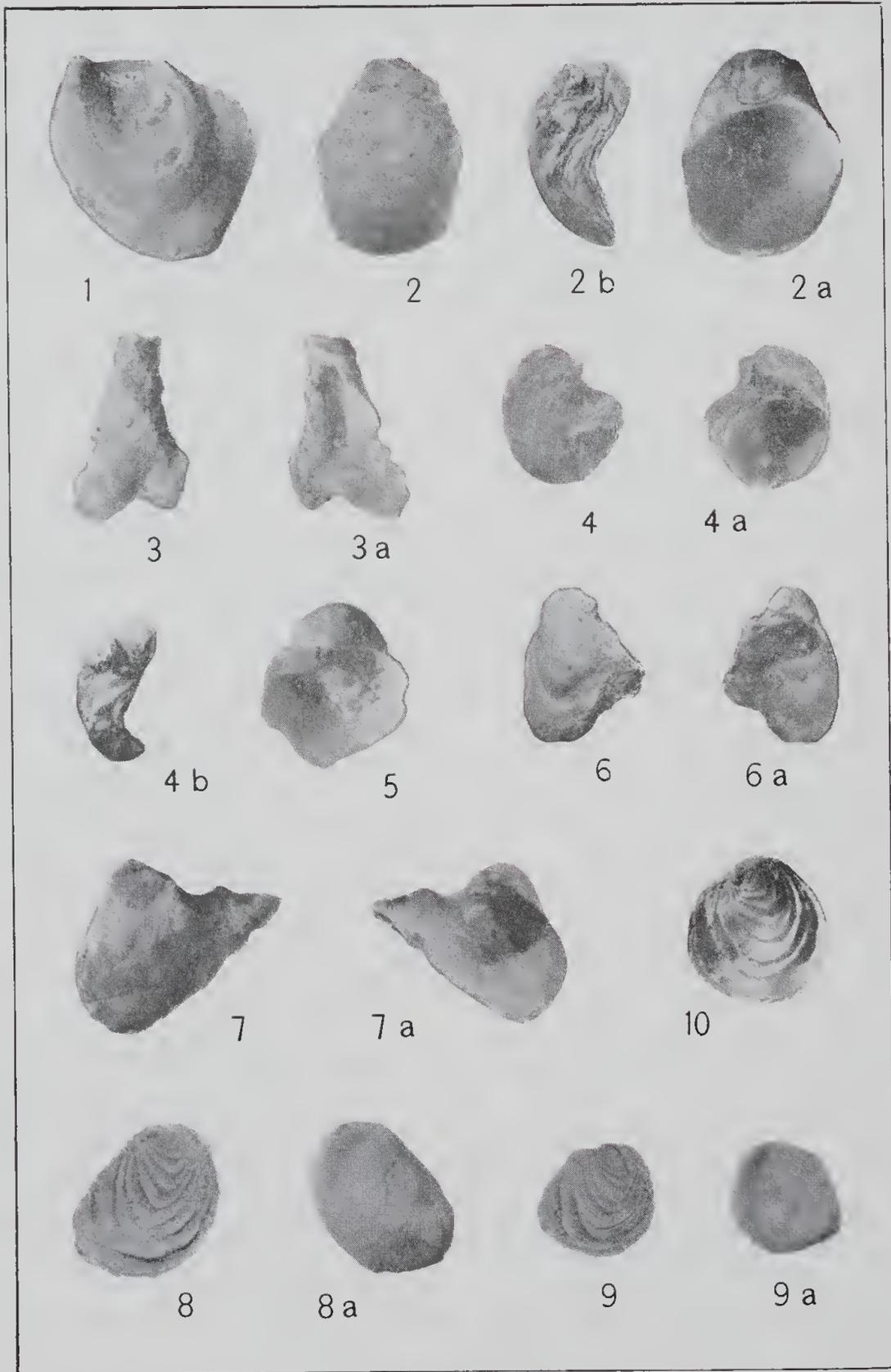


PLATE VI

*Pycnodonta strathalbynensis*

1.—Interior of right valve of holotype (48969), X 2.

*Exogyra variabilis*

2.—Exterior; 2a.—Interior; 2b.—Posterior profile of holotype (48970), a left valve from McIntyre Gully, X 2; 3.—Exterior; 3a.—Interior of left valve, variation A (48971), from McIntyre Gully, X 2; 4.—Exterior; 4a.—Interior; 4b.—Posterior profile of left valve, variation B (48972), from Molecap, X 2; 5.—Interior of left valve, variation C (48973), from McIntyre Gully, X 2; 6.—Exterior; 6a.—Interior of left valve between variations B and D (48974), from McIntyre Gully, X 2; 7.—Exterior; 7a.—Interior of left valve of variation D (48975), from McIntyre Gully, X 2; 8.—Exterior; 8a.—Interior of a typical right valve (48976), from Molecap, X 2; 9.—Exterior; 9a.—Interior of another right valve (48977), from Molecap, X 2; 10.—Exterior of a more nearly circular right valve (48978), locality not stated, X 2.

Individual left valves vary so greatly in shape that at first sight one is inclined to regard them as representing more than one species. A careful analysis of 34 fairly well-preserved specimens however, showed every gradation between the extreme forms and all would appear to be merely variations of the one species. The different variations do not appear to be characteristic of any particular horizon and two very different forms may come from approximately the same horizon.

The principal variations are as follows:—

The type. A nearly elliptical and nearly equilateral form, non-alate or with only a trace of posterior alation. Approximately half the specimens are of this type, from which the other forms probably originated, and a well-preserved specimen from McIntyre Gully has been chosen as the holotype of the species.

A. A high trigonal non-alate form, widest near the ventral margin, with high beak which is twisted, rather than curved, posteriorly.

B. A broad, very inequilateral form with broad and deep rounded posterior alation only.

C. A broadly ovate, more nearly equilateral form with nearly equal rounded posterior and anterior alation.

D. A very inequilateral more oblique form with high, very elongate, and sharply pointed posterior alation.

Two small valves without posterior alation show narrow anterior alation.

Only six specimens show definite areas of attachment, the position depending on the form of the valve. One large imperfect specimen is almost wholly attached.

The right valves of the species are operculiform and are all very similar to each other whatever the form of the corresponding left valve. Dimensions are given in Table X.

TABLE X

Dimensions of *Exogyra variabilis*, sp. nov.

	Left valves					Right valves	
	Holo-type 48970 Mc- Intyre Gully	Variant A 48971 Mc- Intyre Gully	Variant B 48972 Mole- cap	Variant C 48973 Mc- Intyre Gully	Variant D 48975 Mc- Intyre Gully	All from Molecap	
	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Height	12.7	12.5	9.4	9.8	10.8	9.4	11.0
Length	9.7	7.5	7.9	9.5	13.7	9.0	8.0

Description.—Shell small, thin, ovate, height greater than length, usually slightly oblique and inequilateral, very inequivalve, the left valve highly inflated, non-alate to alate, and larger than the right which is operculiform and usually concave. The beaks of both valves are curved posteriorly, that of the left valve being moderately large, that of the right valve very small. The type (Plate VI, Figs. 2, 2a, 2b).—Left valve highly inflated, fairly evenly convex in profile, ovate, with the widest portion opposite the middle of the valve, higher than long, the length equal to approximately three-quarters

the height, nearly equilateral, non-alate; margins fairly evenly convex, the anterior and posterior merging into the ventral. Umbonal portion large and shaped like a hood above the remainder of the valve, with the hinge-line situated at about one-third the height of the valve below the top of the umbo. The hinge-line forming an even concave curve with the highest point anterior to the median line. The beak itself is long and broad, but not very prominent; it extends from the top of the valve almost to the hinge-line, and is curved posteriorly. Except for faint growth ridges the exterior surface is fairly smooth, except near the posterior margin. Interior surface smooth. Adductor scar of moderate size, elliptical and situated high up in the posterior half of the valve, being nearly hidden by the umbonal hood.

Right valve operculiform, concave, obliquely ovate to nearly circular in outline; height greater than length, inequilateral; anterior margin with an even convex curve and merging into the ventral; posterior margin nearly straight to strongly convex in the nearly circular specimens. Beak exceedingly small, curved posteriorly. Exterior surface decorated usually with about 7 to 9 fairly evenly spaced strongly imbricating growth-rings, each ending in an arch directed ventrally. A line joining the points of the arches would show a fairly marked curve, convex anteriorly. Interior of valve smooth except for the fairly large, shallow ovate adductor scar situated about half-way between the median line and the posterior margin and with its centre on or slightly above a median transverse line. On the average the height of a right valve is about three-fifths that of the corresponding left valve.

Variation A (Plate VI, Figs. 3, 3a).—Left valve moderately inflated, height much greater than length, sub-trigonal in outline, approaching a scalene triangle with the most acute angle at the umbo, an interior margin being the longest; anterior margin of specimen imperfect but apparently nearly straight; posterior margin slightly concave and considerably shorter than the anterior; ventral margin fairly evenly convex but imperfect in the specimen figured. The valve widest at a little more than three-quarters the height of the valve below the umbo. The umbo twisted rather than curved posteriorly; top of umbo of the specimen flattened by a small concave area of attachment. Hinge-line fairly sharply angular. Exterior surface somewhat rugose, with narrowly-spaced growth-ridges on the umbonal half; interior surface smooth. The specimen is from the *Ostrea philbeyi* zone of McIntyre Gully at about 22 feet above the base of the chalk.

Variation B (Plate VI, Figs. 4, 4a, 4b).—With posterior alation only. Left valve strongly inflated, height somewhat greater than length, slightly oblique, very inequilateral; markedly alate posteriorly, the alation both wide and deep, with the widest portion about opposite the middle of the valve. The posterior portion of the valve is concave between the umbo and the alation, but the remainder of the valve is strongly convex; the margins are all convexly curved; the hinge-line showing a fairly even

curve and merging into the anterior and posterior margins which, in turn, merge into the ventral. The umbonal portion of the valve extends in depth to nearly two-fifths of the height of the valve, the beak itself is large, rather thick and shows a marked posterior curve. Exterior surface of the body of the valve slightly rugose, with rather faint growth-lamellae, the alate portion strongly rugose; interior of valve smooth; adductor scar fairly large, ovate, hidden by the umbonal hood. The specimen figured is from Molecap.

Variation C (Plate VI, Fig. 5).—The bi-alate form. Left valve fairly strongly inflated, height only slightly greater than length, nearly equilateral in outline. Hooded umbonal portion wide and fairly deep; the beak large, curved posteriorly; hinge-line of specimen somewhat irregular, thickest and with a convex curve at the top of the posterior wing; margins below the hinge-line fairly evenly rounded. Posterior alation usually larger than the anterior, but in one small specimen, the two are approximately equal; the alations are usually moderately wide and deep and merge into the ventral margin. The widest portion of the valve is at about three-fifths of the height of the valve below the top of the umbo. The position of the area of attachment of this form and of variation B is usually at the base of the umbo. The specimen figured is from McIntyre Gully, but from what height above the base of the chalk was not recorded.

Variation D (Plate VI, Figs. 7, 7a).—The high-winged form. Left valve fairly strongly inflated, very inequilateral. Excluding the wing, the valve is obliquely ovate, the length about equal to three-quarters the height; with the wing, the length is much greater in well-developed specimens, but in some the wing is quite narrow; in the specimen figured, the length of the wing is equal to more than half the height of the valve. The wing is not sharply marked off from the body of the valve; the widest portion is in continuation with the hinge-line and about opposite the base of the umbo from which it is separated by a fairly wide furrow; the dorsal margin is nearly straight and ends in a sharp point from which the posterior margin descends, usually in a straight line, to the ventral margin; anterior margin of the valve convexly curved, the convexity being greater in the ventral half. Hinge-line slightly curved. Umbo usually not so deep, proportionally, as in the other forms and the beak itself is relatively slightly smaller. Exterior of valve fairly smooth except for rather faint growth-rings, the alate portion being rather more rugose. Interior of valve smooth; the adductor scar situated very high up and hidden by the umbo. The area of attachment is in the furrow between the base of the umbo and the wing.

This form apparently merges into the broad mid-wing form of variation B. The specimen figured is from the *Ostrea philbeyi* zone of McIntyre Gully at about 22 feet above the base of chalk.

Remarks.—*Exogyra variabilis* shows some resemblance to the European *E. canaliculata* Sow. (Woods 1912, pp. 375-379, plate LVI, Figs. 2-16), the more alate specimens figured by Woods in particular resembling less markedly developed

specimens of Variation D. Woods' Fig. 6 is somewhat like the non-alate form of *E. variabilis* but is narrower and more sharply ovate. The right valves of the two species are very similar.

Apart from the direction of curvature of the beak, *E. variabilis* resembles fairly closely shells of the sub-genus *Gryphostrea* Conrad, in which, however, the beak is always curved anteriorly; the non-alate form much resembling a specimen of *G. inscripta* d'Arch. figured by Cossman (1922, Plate XIII, Figs. 8, 9, 21) and specimens of Variation C are not unlike *G. boussaci* Doncieux which Cossman (1922, p. 211, Plate XIII, Figs. 28, 29) regarded as an alate variety of *G. inscripta*.

Authors differ as to the relationships of the subgenus *Gryphostrea* which appears to have taken the place of *Exogyra* in Eocene times. It first appeared in Upper Cretaceous times as *G. vomer* Morton, considered to be identical with the Eocene *G. eversa* Deshayes, chosen as the type species by Conrad. Stoliczka (1871) placed *Gryphostrea* under *Gryphaea*, but Mayer (1875) and some later authors regarded *G. eversa* as an *Exogyra* (see Cossman 1922, p. 210). Woods who recognised only *Ostrea* and *Exogyra* as genera, considered (1912, pp. 378, 379) that *Gryphostrea canaliculata* was probably related to *Pycnodonta vesicularis*. Gardner (1916, p. 579) stated: "*Gryphostrea* suggests *Exogyra* in the gyrate umbones of the left valve. The beak of the right valve of the former, however, is orthogyrate or at the most slightly inclined, and this, together with the inflation of the beak of the left valve, allies it more closely with *Gryphaea* than with *Exogyra*." Gardner's remarks could be applied equally well to *Exogyra* of the *E. variabilis* group. Cossman (1922) placed *Gryphostrea* together with *Pycnodonta* under the genus *Liostrea* Douville, of which *Ostrea sublamellosa* is the type species. Shimer and Schrock (1944) gave generic rank to *Gryphaea*, but placed *Gryphostrea* under *Ostrea*.

The only important difference between *Exogyra* and *Gryphostrea* is in the direction of curvature of the beak, which in *Exogyra* is curved posteriorly in *Gryphostrea* anteriorly. Other differences are of no greater than specific value, and the difference in the direction of curvature may be only one of a few degrees; as, for example, between the holotype of *Exogyra variabilis* (Plate VI, Fig. 2a) and the specimen of *Gryphostrea inscripta* figured by Cossman (1922, Plate XIII, Fig. 8), and it seems most probable that *Gryphostrea* was originally derived from species of *Exogyra* and should be regarded as a subgenus of that genus.

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## 16.—The Effect of the Suppression by the International Commission on Zoological Nomenclature of Zimmermann 1777 upon the Stability of the Generic Name *Macropus* Shaw 1790

By W. D. L. Ride\*

Manuscript received—11th June, 1963

As the result of a ruling of the International Commission on Zoological Nomenclature, *Yerboa gigantea* Zimmermann (the type species of *Macropus* Shaw 1790) has no status in nomenclature. *Macropus giganteus* Shaw 1790 must thus be regarded as new and as the type species of *Macropus* but it is a junior secondary homonym of *Jaculus giganteus* Erxleben 1777 which is in turn an objective synonym of *Mus canguru* Statius Müller.

It is proposed that the situation be stabilised by the selection of the type of *Mus canguru* as the lectotype of *Macropus giganteus*.

### Introduction

The type species (by monotypy) of *Macropus* is *Macropus giganteus* Shaw 1790, which is generally regarded as a junior objective synonym of *Yerboa gigantea* Zimmermann 1777. This latter name is entirely based upon material collected by Captain Cook's party at the Endeavour River, Queensland.

To date no author working with marsupials has doubted the validity of Zimmermann's name *Yerboa gigantea* as applied to Captain Cook's Kangaroo and all (including myself and co-workers) have accepted it (see Thomas 1888, Cabrera 1919, Iredale & Troughton 1934, 1937, Raven 1939, Tate 1948, Morrison-Scott & Sawyer 1950, Calaby, Mack & Ride 1962) although there is some disagreement as to the animal species represented by it. However, I now find that the International Commission on Zoological Nomenclature ruled in 1950 that Zimmermann 1777 (Specimen Zoologiae Geographicae) is not available for zoological nomenclature (Bull. Zool. Nomencl. 4: 547); thus *Yerboa gigantea* Zimmermann 1777 carries no more status than a vernacular name.

It is now necessary to ensure that:

- (a) the generic name *Macropus* (of which *Yerboa gigantea* Zimmermann 1777 was believed to be the type species by monotypy) is stable in its present usage, and
- (b) the objective synonymy of *Mus canguru* Statius Müller† and the various usages of the specific name *giganteus* as applied to Macropoidea are retained. All of the authors since 1777 (Erxleben, Vol. 1, p. 409) who have used *canguru* have regarded these as synonyms.

\* Western Australian Museum, Perth, Western Australia.

† This author's name is often given as Müller, or as P.L.S. Müller. Holthuis & Junge (1958), in a footnote, show that the family name is Statius Müller—a name today well known in Holland.

### To Stabilize *Macropus*

As a result of the action of the International Commission, the description of *Macropus* Shaw 1790 now contains no reference to any valid species name other than *Macropus giganteus* Shaw 1790. This name can now be regarded as a new name although it is a junior secondary homonym of *Jaculus giganteus* Erxleben 1777.

No type specimen is known to exist for *Macropus giganteus* Shaw and only one specimen is known to be in existence today which had been seen by Shaw. This is a spirit-preserved juvenile in the collection of the British Museum (Nat. Hist.), No. 145b of a manuscript catalogue by Gray; it weighs 2 lb. 4 oz. and is noted to be "the one described by Dr. Shaw". It is not known whether this note refers to Shaw's 1790 description, or to his later work of 1800, so the specimen cannot be assigned to the type series of *M. giganteus* and is therefore unsuitable for selection as a lectotype. Since the Grey Kangaroos possibly merit treatment at a subspecific level, it is desirable that the types of any names of Grey Kangaroos should have adequate locality data and this specimen has none. I therefore reject it for the purposes of neotype designation as well.

Shaw's 1790 description of *M. giganteus* is based upon material from various sources among which are the three specimens collected by Cook's party at the Endeavour River. Thus any of these (and in particular the holotype of *Mus canguru* Statius Müller) is available for selection as the lectotype of *M. giganteus* Shaw.

Subsequent to Shaw's 1790 description, in 1800 Shaw himself replaced the name *giganteus* with the replacement-name *major* formally stating at the same time that the new name *major* was synonymous with *giganteus* Shaw and also with *Didelphis gigantea* of Gmelin and Schreber. This last name is simply the employment of *Jaculus giganteus* Erxleben 1777 by these authors in combination with the different generic name *Didelphis*. Thus, it is clear that Shaw regarded both his *major* and *giganteus* as being equal to the earlier *Jaculus giganteus* Erxleben 1777 which is itself no more than a replacement name for the earlier *Mus canguru* Statius Müller 1776. *Macropus major*, *Jaculus giganteus* and *Mus canguru* thus all possess the same type specimen (International Code Article 72(d)). Since Shaw (1800, p. 505) formally equated his *giganteus* with all of these, I hereby propose the holotype of *Mus canguru* Statius Müller as its lectotype.

The holotype of *Mus canguru* now no longer exists and Calaby, Mack & Ride (1962) have proposed an undoubted specimen of a Grey Kangaroo as its neotype—Queensland Museum specimen No. J 10749 male, skin and skull, collected at Kings Plains, 20 miles south of the Endeavour River, November 24, 1960, by D. P. Vernon and S. Breeden and as figured in Calaby, Mack & Ride 1962, Plates 5, 6, 7, 8. An application for recognition of this neotype is at present before the International Commission on Zoological Nomenclature.

By adopting this procedure the generic name *Macropus* is unequivocally fixed to the Grey Kangaroos.

The alternative to the procedure which I outline here would be to have proposed a neotype from Botany Bay for *Macropus giganteus* Shaw because Shaw's description is based in part upon material from that locality described by Penant. But, since *M. giganteus* Shaw is a junior homonym of *Jaculus giganteus* Erxleben (and of Schreber which was in the early 19th century in use as its senior homonym; see Waterhouse 1846, p. 62), it would then require as a substitute the first available replacement name for the Grey Kangaroo. This is possibly *Dipus tridactylus* Perry 1811 or *Kangurus labiatus* Desmarest 1817. (*Macropus major* Shaw is an objective synonym of *Mus canguru* Statius Müller and is not available as a replacement name for *M. giganteus* Shaw). I believe that this would cause greater upset in the literature than the course which I follow.

#### The Synonymy of the Names *canguru* and *giganteus*

Calaby, Mack & Ride have proposed that the Queensland Museum specimen mentioned above should be recognized as the neotype of *M. canguru* Statius Müller and the lectotype of *M. giganteus* Zimmermann. This reference to Zimmermann is now no longer necessary. Erxleben (1777, p. 409) proposed *Jaculus giganteus* as a replacement name for *Mus canguru* Statius Müller and the name *giganteus* is thereby an objective synonym of *canguru* without the need for selection of a lectotype since it automatically possesses the same type specimen as the name which it is proposed to replace (Code Art 72).\*

#### The Controversy over Captain Cook's Kangaroo

While this controversy is only of indirect concern here, some comment should be made on Iredale & Troughton's (1962, p. 183) statement that our arguments (Calaby, Mack & Ride 1962) are based upon a specimen of doubtful authenticity. Iredale & Troughton do not qualify this remark but, because it is made from their venerable position in Australian mammalogy, it casts very real doubt upon our published conclusions.

Briefly, the factual basis of our argument is that Cook's party was known to have collected

three animals and it is possible to find published records of three specimens which, it is reasonable to assume, were brought home to Britain by the party. One is a *robustus* (identified from a contemporary drawing by Morrison-Scott & Sawyer, whose specific identification was confirmed by ourselves), the other two are Grey Kangaroos (identified by J. E. Gray 1843, by Owen 1853, and by Flower 1884). One of these three specimens must be the holotype of *canguru*. From these three we eliminated the juvenile spirit-specimen identified by Gray as a Grey Kangaroo because the holotype was known to have been eaten. The *robustus* was also eliminated because our investigations showed that it would clearly have been too large to have agreed with the known weight of the holotype; we were thus left with only a specimen in the Hunterian collection which from Richard Owen's description we then demonstrated is at a stage of dentition (based on both dental progression and eruption) consistent with the weight specified by Statius Müller for the holotype in his original description.

The specimen listed in the Hunterian catalogues has unambiguous data, i.e., it was presented to Hunter by Banks and came from the Endeavour River. It was identified as a Grey Kangaroo by Owen and later by Flower. Its exact dental-age was specified by both authors who were eminent in this field.

I suspect that the reason for Iredale & Troughton's statement is that the Royal College of Surgeons' lantern slide of this skull (published as a plate in Morrison-Scott & Sawyer 1950) probably has a mis-matched mandible. (The skull has been destroyed and this is the only known illustration of it). In this photograph, the skull is clearly numbered on the maxilla with its catalogue number but, whereas the catalogue states that it has a right mandibular ramus [? only], the illustration is of the left side of a skull with a left mandibular ramus. This ramus is unnumbered. The photograph cannot have been reversed because the catalogue number is the correct way round. To this extent the illustration of the skull—as a picture of a "complete skull" (i.e. cranium and mandible)—could be said to be unreliable. I drew Troughton's attention to this some years ago.

It is important to realize that the arguments in Calaby, Mack & Ride are not based, in any way, upon this illustration but upon Owen's published description of 100 years earlier. They are also based upon Owen's and Flower's identification of the specimen with the Grey Kangaroo and their statements that it was a Banksian specimen from the Endeavour River. Unfortunately, since our argument as to the choice of the holotype from these specimens depended, in part, upon the probability that certain weights and dental ages can be correlated, we believed that action by the International Commission on Zoological Nomenclature was warranted in order to establish nomenclatural stability through placing the nomenclatural problem beyond the upsetting effect of a biologically sterile argument which has gone on since 1927. We thus asked the Commission to accept an undoubted Grey Kangaroo as the neotype of *canguru*.

\* The only other usage of *gigantea* for Macropodidae in 1777 is Schreber, *Säugethiere*, 3, p. 552. Pages 455 onwards were published after Erxleben (Sherborn 1891, p. 588, footnote).

In fairness to Morrison-Scott & Sawyer, whose conclusions are strongly criticized by Iredale & Troughton, it must be pointed out that Iredale & Troughton neglect to bring out certain facts which argue against their own conclusion that Captain Cook's Kangaroo is a Whiptail Wallaby. These are, firstly that the outcome of their controversy with Morrison-Scott & Sawyer over the interpretation of the ambiguous descriptions by Solander, in Latin, of the incisors is still an argument against the species being the Whiptail. They conclude that the third upper incisor of Captain Cook's Kangaroo has a smaller anterior lobe. In fact, the anterior lobe of the third incisor of the Whiptail is not smaller than the posterior lobe, being slightly larger (to markedly greater) than it. Of a series of 12 skulls in the British Museum measured by me the index (Anterior lobe  $I^3$ /Total length of  $I^3$ ) x 100 has a mean of 56.7, with a range from 64.4 to 50.7. Secondly, Iredale & Troughton (1937, p. 68) said that the general coloration of the Cooktown Whiptails agrees with the nondescript colour accorded to Cook's species in the early accounts. This is not so. The Whiptail Wallaby of the Endeavour River is prominently and vividly marked and quite distinct from the Grey Wallaroo and the Grey Kangaroo of the same area. While it is conceivable that a person unfamiliar with kangaroos and wallabies could group Grey Wallaroos and Grey Kangaroos together in the same sample, he could not avoid remarking on the brilliant facial and hip patterns of the Whiptail. The large series collected by the Queensland Museum in the Cooktown district in order to clarify this problem, illustrates this well.

Finally, I am unable to understand the statement (Iredale & Troughton 1962, p. 177) that "the name *giganteus* as applied to the Great Grey Kangaroo is superseded by *major* as type of Shaw's genus *Macropus*". The facts are otherwise and are summarized thus:

(a) Until 1950 (Bull. Zool. Nomencl. 4: 547), the type species of *Macropus* by monotypy was *Yerboa gigantea* Zimmermann 1777. (See Shaw 1790, Vol. 1, text to Plate 33).

(b) Today the type species is *Macropus giganteus* Shaw also by monotypy.

(c) *Macropus major* was first described in synonymy with *Macropus giganteus* Shaw, *Didelphis gigantea* Gmelin, and Schreber. Accordingly, it is either a replacement name for these, i.e. a junior objective synonym of the most senior of them (Code Art. 72(d)), or, being originally described in synonymy with other more senior names, has no status in nomenclature (Code Art. 11(d)). It is certainly not the type species of *Macropus*, and unless the Commission uses its plenary powers in accordance with the recommendations of Calaby, Mack & Ride, its use in any form at all is invalid.

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## 17.—Eight New Plants From Western Australia

By C. A. Gardner\* and A. S. George\*

Manuscript received—16th July, 1963

Descriptions and illustrations are given of one new genus (*Neogoodenia*) and eight new species of plants from Western Australia, viz., *Grevillea variifolia*, *Grevillea prostrata*, *Stackhousia umbellata*, *Verticordia staminosa*, *Calytrix superba*, *Eremaea rosea*, *Leschenaultia subeymosa*, and *Neogoodenia minutiflora*.

### Introduction

The following eight species have been collected during the past three years. We are indebted to Mr. C. Chapman for the specimens of *Calytrix superba*, and to Mr. W. H. Butler for the specimens of *Verticordia staminosa*.

The English descriptions do not parallel the Latin, but include additional information on certain characters. The holotype and some syntype specimens will be housed in the Western Australian Herbarium. Syntypes of all except *Neogoodenia minutiflora* will be distributed to Kew Herbarium and the National Herbarium of Victoria. Only a single specimen of *Neogoodenia* has been collected to date. It is, however, an excellent one, bearing full flowering and fruiting material.

### PROTEACEAE

#### *Grevillea variifolia*, sp. nov.

Fig. 1

Frutex diffusus, 30-70cm altus, ramis pubescentibus. Folia oblanceolata vel angustecuneata, 15-40 mm longa, 3.15 mm lata, 3-7-acute-lobata, sericea vel supra demum glabra, marginibus recurvis. Flores rubrae, racemis 20-65 mm longis densifloris terminalibus; pedicellis 2.5-3.5 mm longis sericeo-pubescentibus divarticatis. Perianthium 7-8 mm longum, sub limbo revolutum, ad basin dilatatum, extus parce pubescens, intus supra medium dense hirsutum. Ovarium glabrum stipite 3 mm longo; stylus 25-27 mm longus, glaber, exsertus, disco stigmatico laterale, glandula hypogyna laterale, toro fere recto. Folliculus obovoideus, 10-11 mm longus, 5 mm latus. Semina angusta, 6-8 mm longa, anguste alata, marginibus revolutis.

A spreading shrub 30-70 cm tall. Branches silky-pubescent, becoming glabrous with age. Leaves oblanceolate or narrow-cuneate, 15-40 mm long, 3-15 mm wide, shortly petiolate, with 3-7 pungent lobes, occasionally entire, both surfaces covered with fine appressed hairs, the upper surface becoming glabrous, margins recurved. Flowers red in dense terminal racemes of 20-65 mm long; rachis silky-pubescent, the lower part without flowers; pedicels 2.5-3.5 mm long, divaricate or somewhat reflexed. Perianth 7-8 mm long, revolute under the limb, broadened in lower half, with scattered appressed hairs out-

side, short spreading hairs along margins of segments and inner surface densely hirsute above the middle. Ovary glabrous on a stipes of 3 mm; style 25-27 mm long, slender, glabrous, exserted, stigmatic disc lateral, hypogynous gland lateral, torus slightly oblique or straight. Follicle obovoid, 10-11 mm long, 5 mm wide, smooth, the style persistent. Seeds narrow, orange, 6-8 mm long, margins narrowly winged and revolute. Holotype and Syntypes: Cape Range, near No. 3 Well, in red sand over limestone, A. S. George 2477, June 2, 1961.

*Grevillea variifolia* falls in the Section *Leio-gyne*. It is closest to *G. thelemanniana*, Hueg., and *G. stenomera*, F. Muell.; but the leaves are never pinnatisect or divided into linear lobes and are grey-green in colour. The species is noteworthy as being the only representative of the Section known to occur outside the South-West Province in Western Australia.

The following collections have also been examined: Cape Range (Charles Knife Rd.), A. S. George 1340, August 30, 1960.—A shrub of 1.3 m (no fls.); leaves up to 50 mm long and 20 mm wide.

Vlaming Head (Lighthouse Hill), A. S. George 1369, August 31, 1960.—A shrub to 70 cm, leaves silver-green, fls. red; style 20 mm long.

1 mile S. of Vlaming Head lighthouse, on W. side of Cape Range, A. S. George 2577, June 3, 1961.—A spreading shrub of 30-70 cm, fls. red; perianth 9-10 mm long, style 28-30 mm.

79 miles S. of Learmonth, in red sand with spinifex and low shrubs, A. S. George 2402, June 2, 1961.—A shrub of 70 cm, fls. red; leaves with 3, sometimes 5 divaricate lobes, perianth 6-7 mm long, style 19-23 mm.

Learmonth rd., 22 miles N. of Warroora turn-off, in red sand, A. S. George 3286, February 22, 1962.—Leaf lobes very variable, sometimes divaricate; leaves on young branches lanceolate, entire.

#### *Grevillea prostrata*, sp. nov.

Fig. 3, K-P

Frutex parvus prostratus. Rami hirsuti, demum glabri. Folia 2-4.5 cm longa, petiolata, pectinata, lobis linearibus oppositis marginibus revolutis, hirsuta vel supra demum glabra. Flores in racemis densifloris in pedunculosis terminalibus et laterales. Pedunculi hirsuti-pubescentes et parce glandulosi. Bractae spathulatae, 1.5 mm longae, deciduae. Pedicelli 7-8 mm longi, glabri. Perianthium angustatum, 3-4 mm longum, sub limbo revolutum, omnino glabrum. Stylus curvus, glaber; ovario minute glanduloso breviter stipitato; toro recto, glandula hypogyna laterale; disco stigmatico laterale. Folliculus juvenis obovoideus, fere sessilis.

\* Western Australian Herbarium, Perth.

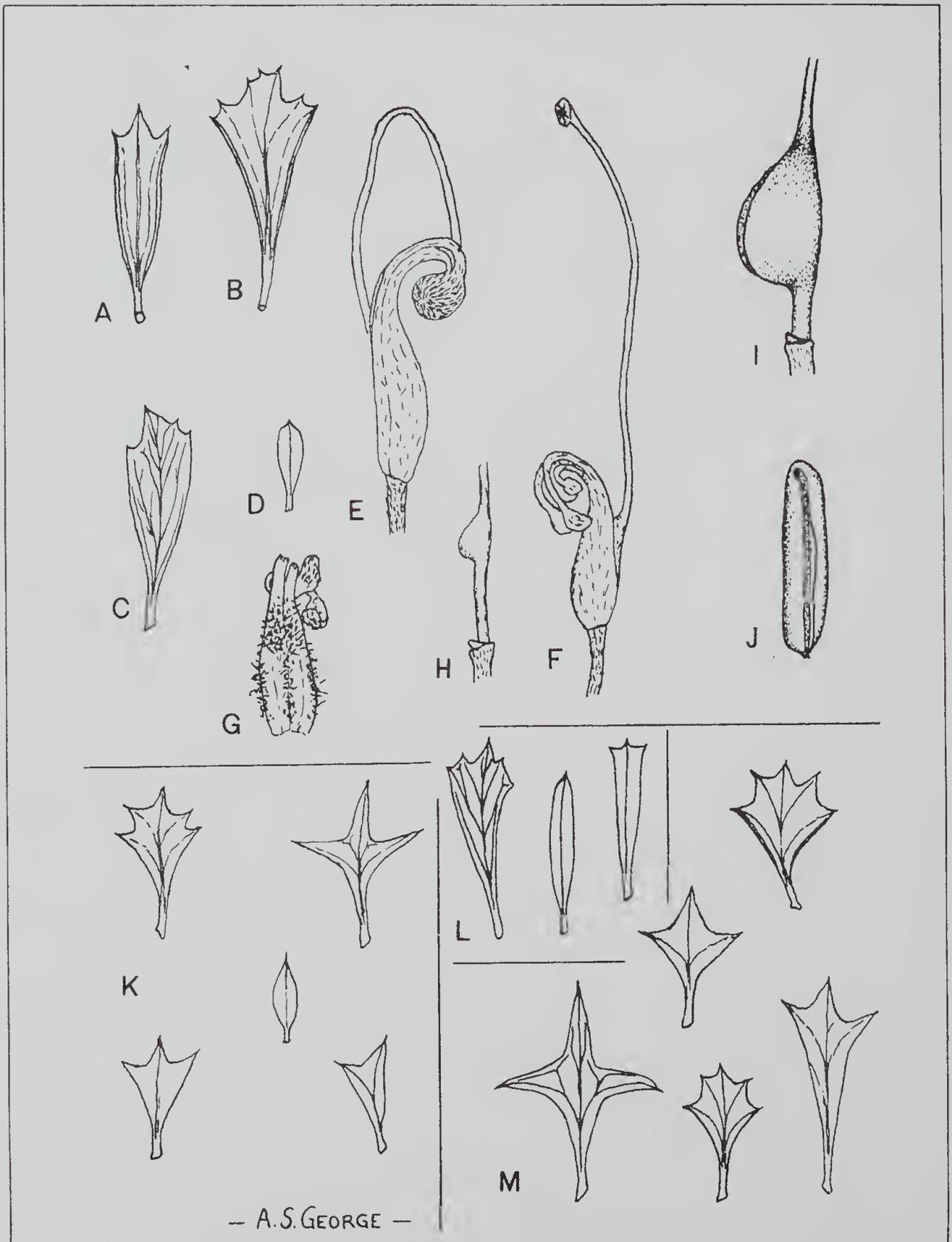


Fig. 1

*Grevillea variifolia*, sp. nov.

A, B, C, D.—Leaves, natural size; E.—Opening flower, 5 X natural size; F.—Open flower, 3 X natural size; G.—Two perianth segments showing inner surface, 4 X natural size; H.—Ovary and torus, 5 X natural size; I.—Fruit, 2 X natural size; J.—Seed, 4 X natural size (A-J from A. S. George 2477); K.—Leaves from A. S. George 3286, natural size; L.—Leaves from A. S. George 2577, natural size; M.—Leaves from A. S. George 2402, natural size.

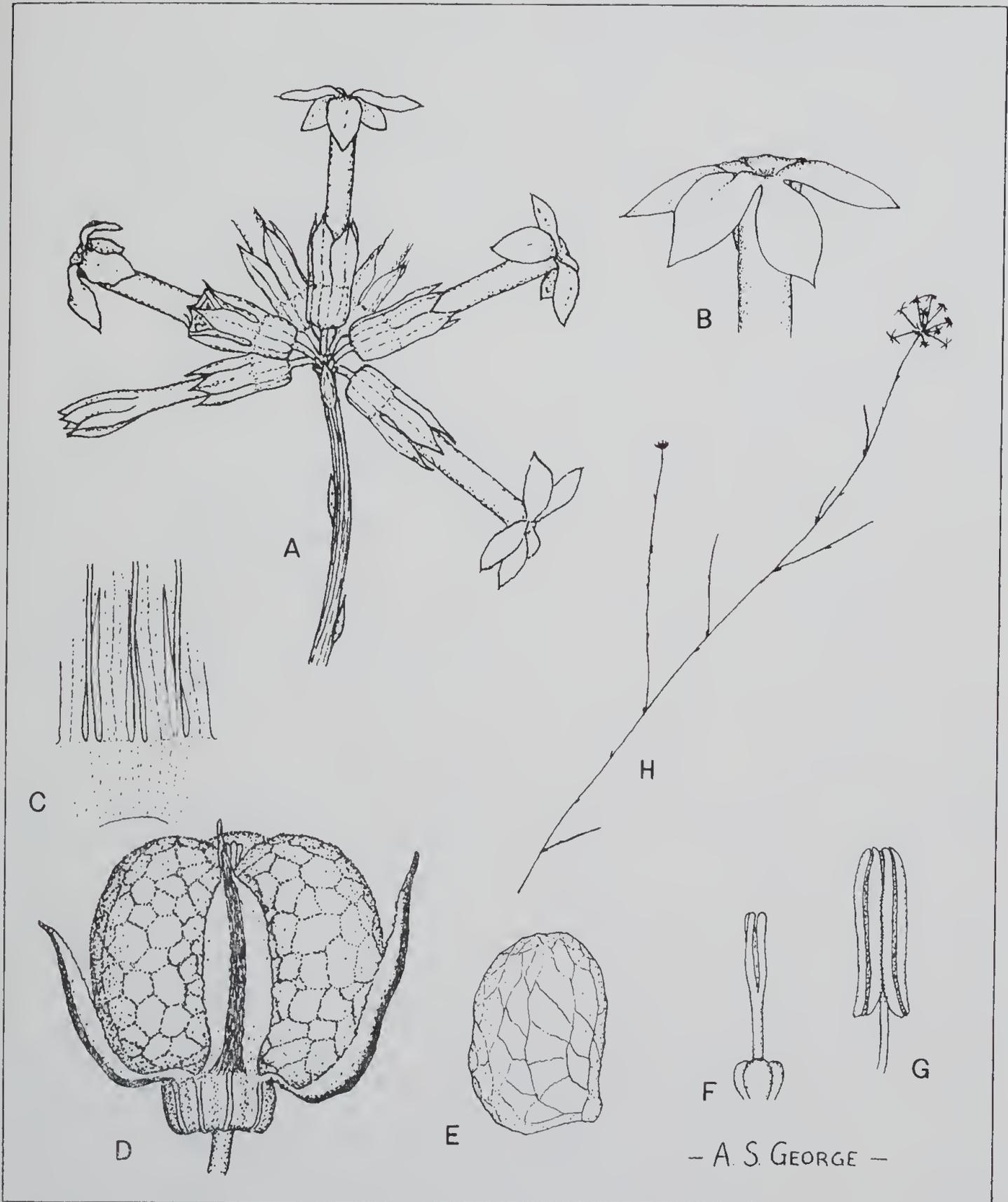


Fig. 2

*Stackhousia umbellata*, sp. nov.

A.—Umbel of flowers, 4 X natural size; B.—Apex of corolla, enlarged; C.—Attachment of staminal filaments and free basal lobes of corolla to calyx tube, enlarged; D.—Fruit, 12 X natural size; E.—Single coccus, 8 X natural size; F.—Style and ovary, 8 X natural size; G.—Anther, much enlarged; H.—Diagram of portion of a branch to show habit, 0.5 X natural size. (A-C, F-H from A. S. George 2585; D, E from A. S. George 1380.)

A prostrate shrub. Stems hirsute, becoming glabrous, not much branched. Leaves 2-4.5 cm long, petiolate, pectinate, lobes linear, opposite, with revolute margins, hirsute, becoming glabrous above. Flowers in short, dense racemes on terminal and lateral branchlets. Rachis hirsute-pubescent, with glandular hairs also. Pedicels 7-8 mm long, glabrous, subtended by deciduous, spatulate bracts 1.5 mm long. Perianth 3-4 mm long, narrow, revolute under the limb, glabrous inside and out, the segments separating when open. Style curved, glabrous; ovary minutely glandular, shortly stipitate; torus straight, hypogynous gland lateral; stigmatic disc lateral. Young fruit obovoid, almost sessile, sparsely glandular.

Holotype and Syntypes: On sandplain outside Pallarup Rocks, S.E. of Lake King, A. S. George 1652, October 14, 1960. "Fls. cream on reddish pedicels".

The species falls in the Section *Lissostylis*, Series *Occidentales*. Although the ovary is minutely glandular, it is never densely hirsute as in the Sections *Hebegyne* and *Eriostylis*. The affinities are with *G. crithmifolia*, R.Br., the differences being the completely prostrate, less crowded habit, the pinnate leaves, smaller floral bracts, the perianth smaller, glabrous inside and out, the shorter ovary stipes, and the smooth fruit.

#### STACKHOUSIACEAE

##### *Stackhousia umbellata*, sp. nov.

Fig. 2

Herba perennis, diffusa, glabra. Rami sulcati. Folia squamata. Flores umbellatae terminales, bracteatae, pedicellis 1-1.5 mm longis. Calyx 4.5 mm longus, 10-nervosus, lobis liberis rhomboideo-oblancoatis, minute denticulatis, quam tubum longioribus. Corolla quam calycem longiora bis, lutea, lobis late lanceolatis acutis patentibus. Stamina inclusa, filamentibus inaequalibus, antheris angustis. Ovarium 3-lobatum. Stylus brevis 3-lobatus. Cocci 3, ovoidei, 2.5 mm longi, reticulati, minute papilloosi.

A diffuse, glabrous perennial herb. Stems slender, sulcate. Leaves reduced to small, scattered scales. Flowers in terminal umbels of up to 14 flowers, each subtended by 2 very small bracts; pedicels 1-1.5 mm long. Calyx 4.5 mm long, 10-nerved in lower half, lobes free, rhomboid-lanceolate, minutely denticulate, acute, longer than tube. Corolla twice as long as calyx, yellow, scented, lobes broadly lanceolate, acute, spreading. Stamens included, filaments unequal, anthers narrow opening in longitudinal slits. Ovary 3-lobed. Style short, 3-lobed. Cocci 3 (often only two developing in fruit), ovoid, 2.5 mm long, reticulate, minutely papillose.

Holotype and Syntypes: Cape Range, near No. 2 Well, in red sand over limestone, A. S. George 2585, June 4, 1961.

*Stackhousia umbellata* differs from all other species in its umbellate inflorescence, and from all except *S. scoparia*, Benth, and *S. dielsii*, Pampanini, in its diffuse, leafless habit. In floral structure it is closest to *S. viminea*, Sm., but the flowers are much larger, the corolla lobes broader, and the cocci less rugose.

The following collections have also been examined: Cape Range (Charles Knife Rd.) in and around spinifex clumps, A. S. George 1336 August 30, 1960: Vlaming Head (Lighthouse Hill) in red sand over limestone, A. S. George 1380, August 31, 1960.

#### MYRTACEAE

##### *Verticordia staminosa*, sp. nov.

Fig. 3, A-J

Frutex ramulosus diffusus. Rami setosi, demum glabri. Folia ad apices ramorum conferta, 7-14 mm longa, linearia-teretia, in basi-bus pulviniformis setosis subpersistentibus inserta. Flores lutei, in pedicellos 4-6 mm longos glandulosos axillares. Bracteoli magni, 5-6 mm longi, ovati, scariosi, subpersistentes. Calycis tubus turbinatus, 1.5-2 mm longus, 2-2.5 mm latus, 10-costatus, glaber. Lobi calycis orbiculares, longe 5-7-pectinato-lobatis, 5 mm longi. Petala ovata, longe 5-7-subulato-lobatis, 5 mm longa. Stamina longe exserta, 9-10 mm longa, in tubum longum connata, filamentibus in dimidio superiore planis, liberis; staminodia subulata in exteriore tubo inserta; antherae basifixae. 2-porosae, glandulis dorsalis prominentibus. Stylus staminis aequalis, stigma parva, pulviniforma. Ovarium 2-ovulatum.

A spreading, much-branched shrub. Branches setose, at length glabrous. Leaves crowded towards the ends of the branches, linear-terete, 7-14 mm long, on short, thick, setose bases which remain on the branch for some time after the leaves have fallen but at length are deciduous. Flowers yellow, on slender glandular pedicels in the upper axils. Bracteoles large, 5-6 mm long, ovate, scarious, red-brown, persistent for some time but deciduous with the flowers. Calyx-tube turbinate, 1.5-2 mm long, 2-2.5 mm wide, 10-ribbed, glabrous; lobes orbicular, deeply divided into 5-7 pectinate-ciliate lobes, the whole 5 mm long. Petals ovate, divided into 5-7 subulate lobes, 5 mm long. Stamens much exceeding the petals, united for about  $\frac{1}{3}$  of their length in a tube, the free portion of the filaments flat; staminodes subulate, inserted on the outside of the tube; anthers basifixed, 2-porose, the dorsal connective gland prominent. Style as long as the stamens (9-10 mm), stigma small, cushion-shaped. Ovary with 2 ovules.

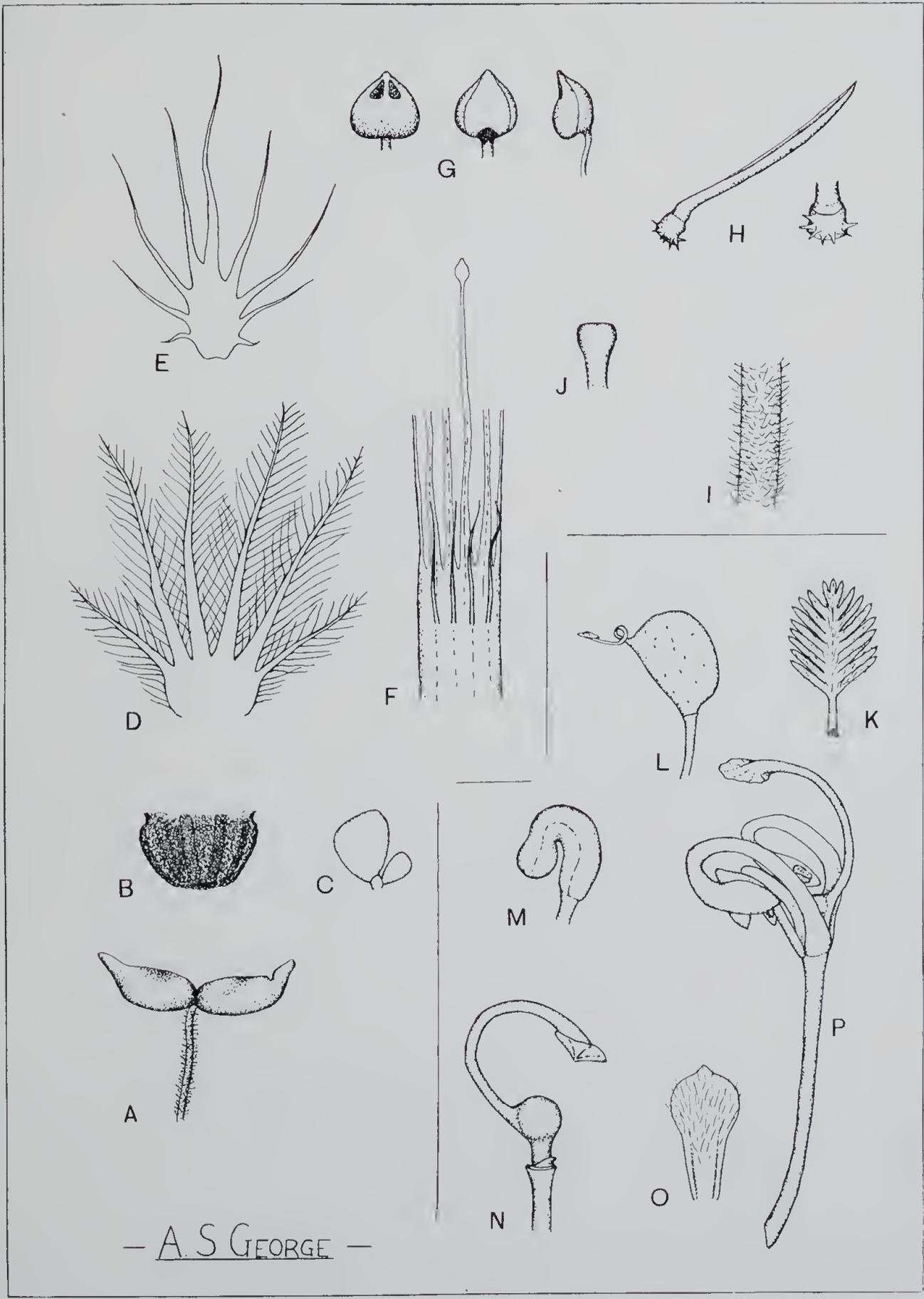
Fig. 3—opposite

##### *Verticordia staminosa*, sp. nov.

A.—Bracteoles and pedicel,  $3\frac{1}{2}$  X natural size; B.—Calyx tube, 6 X natural size; C.—Ovules, enlarged; D.—Calyx lobe, 6 X natural size; E.—Petal, 6 X natural size; F.—Staminal tube, showing staminodes, 6 X natural size; G.—Anthers, much enlarged; H.—Leaf, 3 X natural size, and leaf base, enlarged; I.—Portion of stem, showing setae, enlarged; J.—Style end, much enlarged. (All from W. H. Butler Wongan Hills 12.vi.1961.)

##### *Grevillea prostrata*, sp. nov.

K.—Leaf, natural size; L.—Young fruit, 2 X natural size; M.—Bud, 4 X natural size; N.—Style, ovary, and torus, 8 X natural size; O.—Bract, 14 X natural size; P.—Flower with pedicel, 10 X natural size. (All from A. S. George 1652.)



— A. S. GEORGE —

Fig. 3

Holotype and Syntypes: Wongan Hills, W. H. Butler, June 12, 1961.

*Verticordia staminosa* falls in Bentham's Section 1c of *Euverticordia*, containing *V. grandiflora*, Endl., *V. acerosa*, Lindl., etc., but it differs in the prominently exerted stamens with long tube and external staminodes, the setae on the branches, the crowded, linear leaves, and the long, glandular pedicels.

*Calytrix superba*, sp. nov.

Fig. 4, A-K

Frutex ramis erectis. Folia erecta vel appressa, alterna, oblongo-linear, crassa, concava, 4-8 mm longa, breviter petiolata. Flores ramos terminantes. Bracteoli 10-12 mm longi, fere ad basin liberi, marginibus scariosis, apicibus acutis recurvis. Tubus calycis gracilis, 11-14 mm longus, 10-sulcatus, supra ovario solidus, lobis ad basin orbiculatis in setas minuter scabridas productis, 11-15 mm longis. Petala rosea, quam lobis calycis longiora, late elliptica, acuta. Stamina ca. 30, filamentibus 4-8 mm longis purpureis luteisque, in medio crassis. Anthera oblonga, glandula parva. Stylus gracilis, 5-6 mm longus. Ovuli 2, recti.

A slender shrub with erect branches. Leaves erect or appressed, scattered, oblong-linear, thick, concave, 4-8 mm long, shortly petiolate. Floral leaves similar but with white scarious margins. Flowers terminal. Bracteoles 10-12 mm long, free almost to base, margins broad, scarious, apices acute, recurved. Calyx tube slender, 11-14 mm long, 10-ribbed, solid above the ovary; lobes orbicular at base with slender awns becoming finely scabrous towards the apices, 11-15 mm long. Petals longer than awns, bright pink, broadly elliptical, acute, rather deciduous, the stamens remaining after the petals have fallen. Stamens about 30, filaments 4-8 mm long, purple and yellow, swollen in the middle. Anthers versatile, oblong, opening in longitudinal slits, connective gland small.

Style slender, 5-6 mm long. Ovules 2, erect, attached basally on a short lateral placenta. Holotype and Syntypes: Eneabba, C. Chapman, late December, 1961.

The flowers of *Calytrix superba* are much larger than in any other species. It is also distinguished by the scarious margins of the bracteoles, the swollen, bi-coloured staminal filaments and the extremely small connective of the anther.

*Eremaea rosea*, sp. nov.

Fig. 4, L-V

Frutex ramosus erecto-diffusus, 30-50 cm altus. Rami juvenes setosi, mox pubescentes, demum glabri. Folia 6-9 mm longa, alterna,

breviter petiolata, lineare-lanceolata, concava, carinata, 1-3-nervosa, glabra nisi marginibus setosis. Flores ramos terminantes, sessiles, solitarii vel raro geminis. Bracteae plures, ovatae, obtusae, imbricatae, breviter pubescentes, marginibus ciliatis. Calyx ab bracteis fere occultus, 5-8 mm longus, pubescens, lobis marginibus scariosis ciliatis quam tubum brevioribus. Petala rosea, quam sepala longiora, spathulata, patentia. Stamina in phalangibus petalis oppositis conjuncta, filamentis roseis, antheris luteis. Stylus glaber, staminibus aequalis. Ovarium 3-loculatum, apice convexo dense hirsuto. Fructus sessilis, urceolatus, valvis inclusis, lobis calycis deciduis.

A spreading shrub with several stems 30-50 cm high. Branches setose when young, later pubescent and finally glabrous. Leaves 6-9 mm long, scattered, shortly petiolate, linear-lanceolate, obtuse, concave, keeled, 1-3-nerved, glabrous except for setae along the margins which become glabrous with age. Flowers terminal sessile, solitary or rarely two within the one series of bracts. Bracts numerous, ovate, obtuse, imbricate, shortly pubescent with ciliate margins, somewhat scarious and striate. Calyx almost concealed by the bracts, 5-8 mm long, pubescent, lobes shorter than tube with scarious ciliate margins. Petals pink, longer than the calyx-lobes, spathulate, spreading. Stamens united in bundles of 12-15 opposite the petals, filaments pink, anthers yellow. Style glabrous, as long as the stamens. Ovary 3-locular, apex convex and densely hirsute. Fruit sessile, smooth, urceolate, 6-7 mm long, 7-8 mm wide when young, 10 mm long, 10-11 mm wide when mature, valves included, calyx-lobes deciduous.

Holotype and Syntypes: Maida Vale, in sand, A. S. George, 4161, September 10, 1962.

*Eremaea rosea* differs from *E. acutifolia*, F. Muell., in the flat, obtuse leaves, the pubescent calyx with lobes deciduous in fruit, the deep pink flowers and the ovary convex on top. It differs from *E. pauciflora*, (Endl.) Druce in the broader, flat leaves, the bracts almost completely covering the calyx, the stamens in 5 definite bundles, the deep pink colour, the ovary convex on top and the fruit larger with a wider orifice.

GOODENIACEAE

*Leschenaultia subcymosa*, sp. nov.

Fig. 5

Herba perennis usque ad 30 cm alta, ramis erectis floridis et ramis diffusis foliolatis. Rami striati. Folia linearia, usque ad 10 mm longa, triquetra, recta. Flores sessiles paniculati ramis cymosis. Bracteae lineares. Calycis lobi lineares, 1.5-2 mm longi, acuti. Corolla alba,

Fig. 4—opposite

*Calytrix superba*, sp. nov.

A.—Flowering branch, natural size; B.—Corolla,  $1\frac{1}{2}$  X natural size; C.—Calyx lobe,  $3\frac{1}{2}$  X natural size; D.—Calyx tube, 3 X natural size; E.—Ovary in vertical section, enlarged; F.—Bracteoles, 3 X natural size; G.—Floral leaf,  $3\frac{1}{2}$  X natural size; H.—Leaves,  $3\frac{1}{2}$  X natural size; I.—Style end, enlarged; J.—Stamen, 10 X natural size; K.—Anthers, enlarged. (All from C. Chapman, Eneabba, late December 1961.)

*Eremaea rosea*, sp. nov.

L.—Bracts surrounding flower, 3 X natural size; M.—Flower with bracts removed, 3 X natural size; N.—Staminal bundle,  $3\frac{1}{2}$  X natural size; O.—Anthers, much enlarged; P.—Vertical section of ovary, with style, enlarged; Q.—Young fruit, 2 X natural size; R.—Mature fruit, 2 X natural size; S.—Leaf,  $2\frac{1}{2}$  X natural size; T.—Flowering branch, 2 X natural size; U.—Fertile seed, 4 X natural size; V.—Sterile seeds, 4 X natural size. (All from A. S. George 4161.)

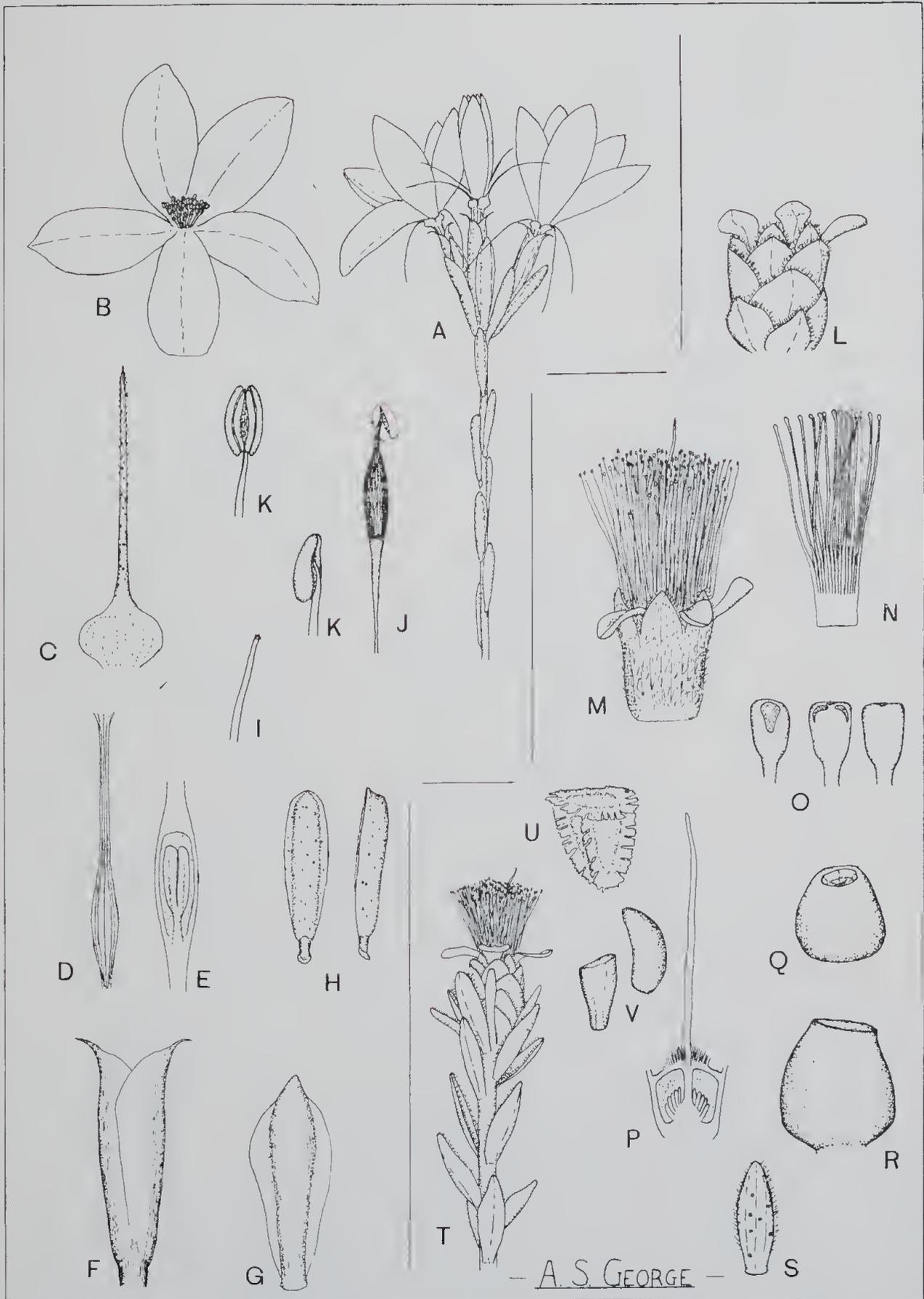


Fig. 4

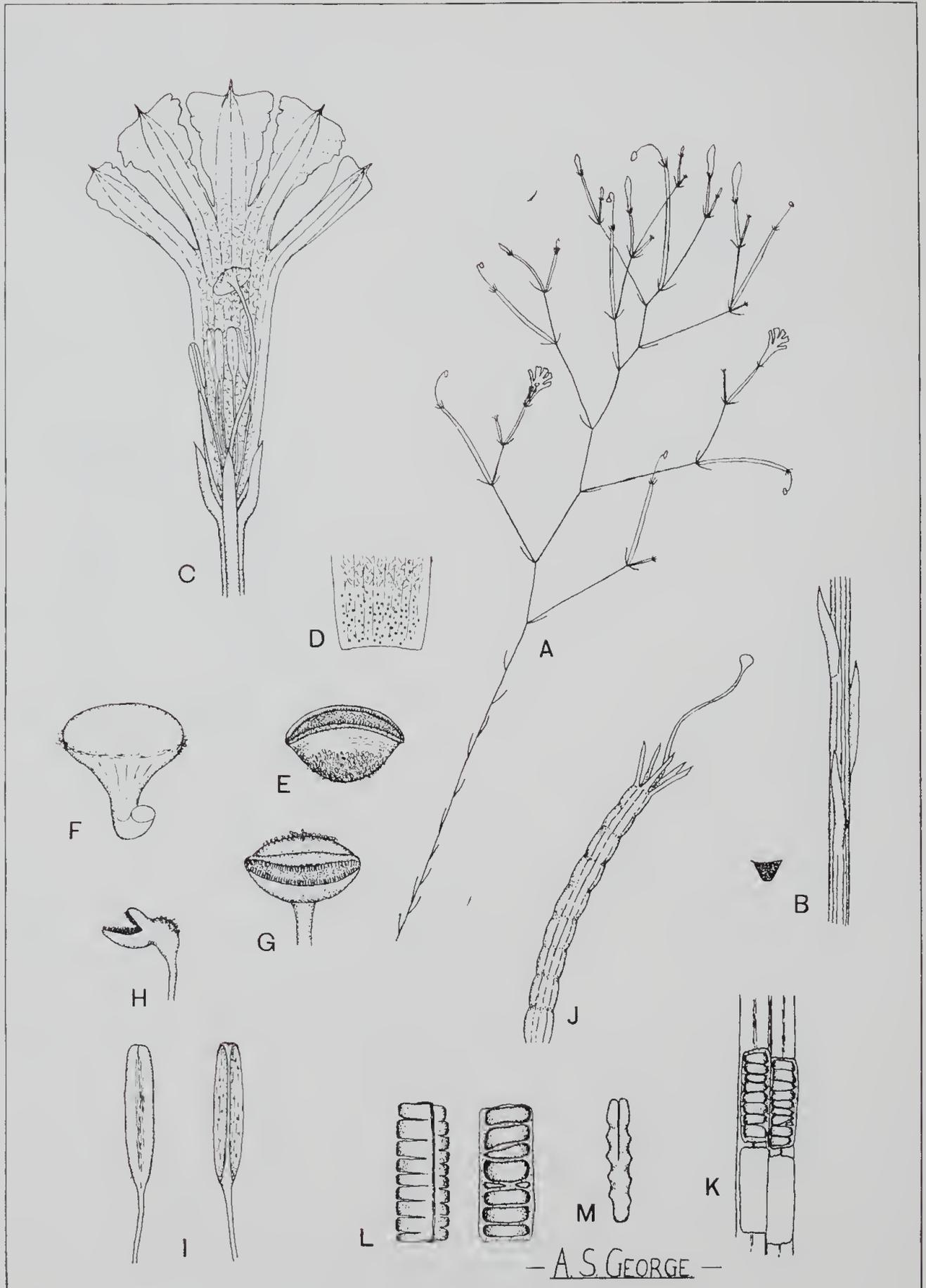


Fig. 5

*Leschenaultia subcymosa*, sp. nov.

A.—Diagram of flowering stem, less than natural size; B.—Portion of stem, with T.S. of a leaf, enlarged; C.—Flower, 7 X natural size; D.—Base of corolla spread open, enlarged; E.—Indusium from above, much enlarged; F.—Indusium from below, much enlarged; G.—Indusium from front, much enlarged; H.—Indusium from side, much enlarged; I.—Anthers, 10 X natural size; J.—Fruit 4 X natural size; K.—Seeds before falling, 9 X natural size; L.—Seeds, 14 X natural size; M.—Embryo, 14 X natural size. (All from A. S. George 2433.)

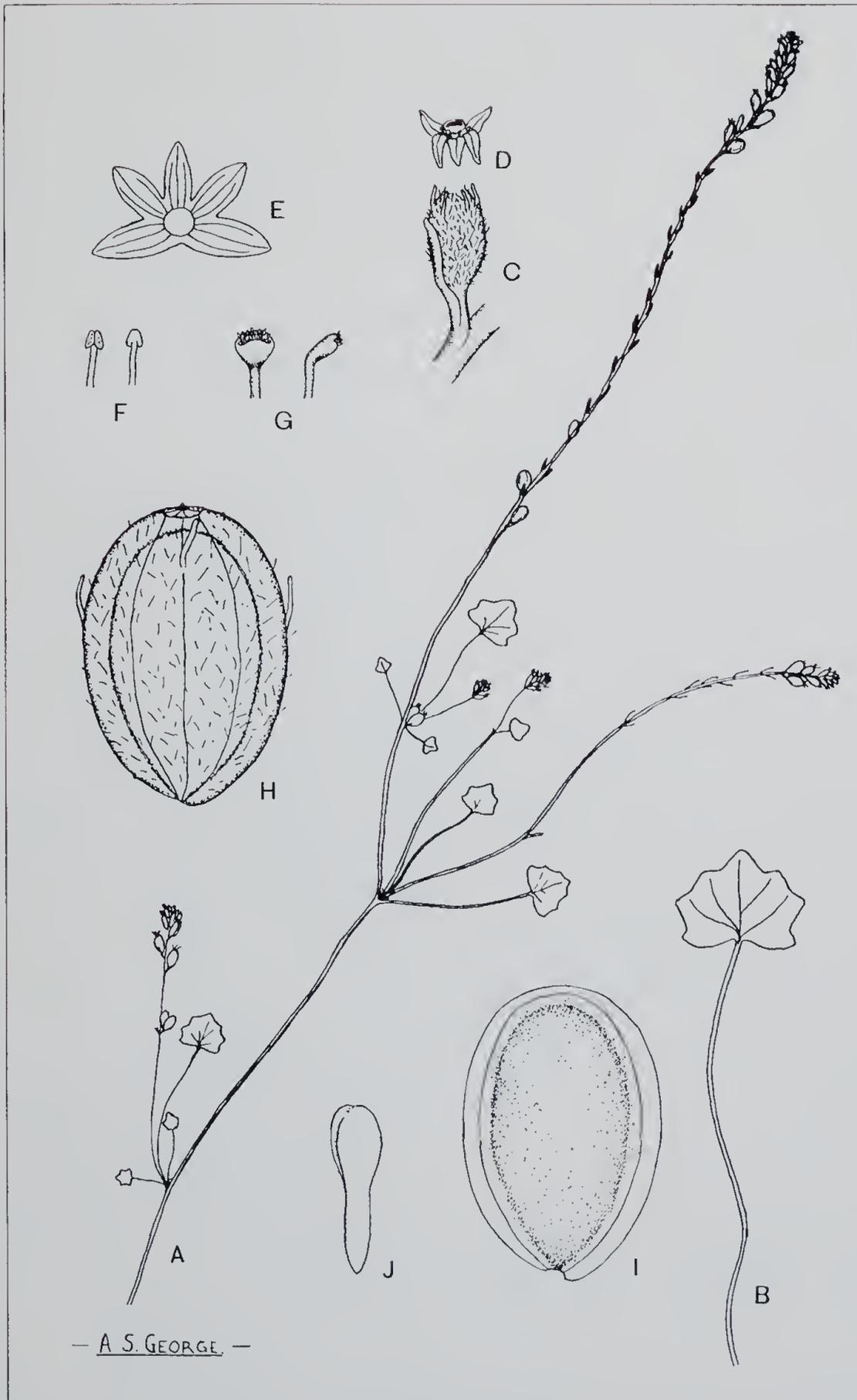


Fig. 6

*Neogoodenia minutiflora*, gen. et sp. nov.

A.—Branch and floral scape,  $\frac{2}{3}$  X natural size; B.—Leaf, 2 X natural size; C.—Calyx with bract, 9 X natural size; D.—Corolla, 6 X natural size; E.—Corolla spread open, 11 X natural size; F.—Stamens, 18 X natural size; G.—Style and indusium, 18 X natural size; H.—Fruit, 10 X natural size; I.—Seed, 10 X natural size; J.—Embryo, 12 X natural size. (All from A. S. George 910.)

15-17 mm longa, lobis subaequalibus alatis patentibus, tubo intus pubescente, ad basin minute glanduloso. Stamina plus minusve libera, quam stylo breviora. Stylus glaber, 10-11 mm longus, indusio in dorso pubescente, labiis ciliatis. Ovarium lineare cylindricum 12-15 mm longum. Ovuli usque ad 15 per loculum. Capsula 25-30 mm longa, erostrata. Semina cylindrica, 1.5-2 mm longa, testa dura horizontaliter tuberculata.

A perennial herb to 30 cm high, with a short, thick basal stem and numerous erect or spreading flowering stems and shorter, spreading leafy ones. Stems striate. Leaves linear, to 10 mm long, triquetrous, erect. Flowers sessile, in panicles with cymose branches, bracts linear. Calyx-lobes linear, 1.5-2 mm long, acute. Corolla white, 15-17 mm long, lobes subequal, winged, spreading, tube pubescent within, minutely glandular towards the base. Stamens more or less free in the open flower, shorter than the style. Style glabrous, 10-11 mm long, indusium pubescent on the back, lips ciliate. Ovary linear, cylindrical, 12-15 mm long. Ovules up to 15 per locule. Capsule 25-30 mm long, not beaked. Seeds cylindrical, 1.5-2 mm long, testa hard with large horizontal tubercles. Old fruit persistent for some time.

Holotype and Syntypes: 56 miles S. of Learmonth, in red sand with spinifex and low shrubs, A. S. George 2433, June 2, 1961.

Other collections: Learmonth rd., 22 miles N. of Warroora turnoff, in red sand. A. S. George 3288, February 22, 1962. Learmonth rd., 18 miles S. of Bullara turnoff, in red sand, A. S. George 3293, February 22, 1962.

The species is closest to *L. stenosepala*, Pritzl, differing in the habit, the shorter calyx-lobes, the white corolla, and the longer ovary and fruit.

#### Genus *Neogoodenia*, gen. nov.

Calycis tubus ovario adnatus, lobis liberis. Corolla minima glabra bilabiata, lobis subaequalibus exalatis trinervis. Stamina libera. Stylus glaber, indusium labiis ciliatis. Ovarium uniloculatum. Ovulus 1, basifixus. Fructus multo compressus, indehiscens. Semen magnum, anguste alatum. Embryo in endospermo copioso rectum.

Herba prostrata annua. Folia alterna plana. Flores racemosi.

Type species: *N. minutiflora*, sp. nov.

#### *Neogoodenia minutiflora*, sp. nov.

Fig. 6

Herba annua prostrata, glabra calycum nodorumque exceptione. Rami 20-40 cm longi, plures, racemis terminantes. Folia alterna,

cordato-rhomboidea, plana, obtuse 5-7-lobata, longe petiolata, capillis albis in axilibus. Racemae aphyllae, multiflorae. Flores breviter pedicellatae bracteis linearibus bracteolatis nullis. Calyx ad ovarium adnatus, compressus, ovalis, 6-nervosus, pubescens vel breviter hispidus, lobae breves. Corolla minima, 1 mm longa, glabra, bilabiata, mox decidua; lobae subaequales, exalatae, trinervae. Stamina libera, 0.4 mm longa. Stylus 0.5 mm longus, glaber; indusium glabrum, labiis ciliatis. Ovarium 1-loculatum, 1-ovulatum. Fructus compressus, ovalis-obovatus, pubescens, 3.5-4 mm longus, 2.5-3 mm latus, pericarpium tenue. Semen ovalis-obovatum, marginatum sed etiam anguste alatum. Embryo 2 mm longum in endospermo copioso rectum.

A prostrate annual, glabrous apart from the flowers and leaf nodes. Stems 20-40 cm long, slender with one or more branches from each node, all ending in racemes. Leaves alternate, cordate-rhomboid, flat, obtusely 5-7-lobed, on long petioles, with a tuft of white hairs in the axils. Racemes leafless, many-flowered, elongating as flowering progresses. Deciduous white hairs around young buds. Flowers each subtended by a linear bract, bracteoles none. Pedicels short. Calyx about 1.5 mm long, adnate to ovary, compressed, ovate, each face 3-nerved, pubescent or shortly hispid, lobes linear, short. Corolla very small, about 1 mm long, 5-lobed almost to base, bilabiate, lobes subequal, without wings, 3-nerved. Stamens free, 0.4 mm long, filaments flattened. Style 0.5 mm long, glabrous; indusium glabrous, lips ciliate; stigma strap-shaped, protruding in older flowers. Ovary 1-celled, 1-ovulate. Fruit much enlarged as flower matures and falls, much compressed, oval, 3.5-4 mm long, 2.5-3 mm wide, pubescent; calyx-lobes persistent; seed rim apparent through thin pericarp. Seed basifixed, with a thickened rim, narrowly winged, similar to fruit in shape and size. Embryo straight, erect, embedded in endosperm.

Holotype: 10 miles south of Mt. Magnet, in red loam, A. S. George 910, August 20, 1960.

This extraordinary plant falls in the section including *Scaevola*, *Dampiera*, *Verreauxia* and *Diaspasis*. It differs from them all in its annual habit, the minute wingless corolla and the flat thin-walled fruit. Other differences from individual genera will be apparent from the description. The epithet "Neo-" in the generic name has two shades of meaning. It refers to the unusual characteristics, observed in this plant, which have not been seen in the family Goodeniaceae before; and in a lesser sense it indicates that it is the most recently discovered genus in this family.





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