COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 21

THE CAPE RANGE STRUCTURE WESTERN AUSTRALIA

Part 1

STRATIGRAPHY AND STRUCTURE

by

M. A. CONDON, D. JOHNSTONE and W. J. PERRY

Part II

MICROPALAEONTOLOGY

by

I. CRESPIN

Issued under the Authority of Senator the Hon. W. H. Spooner,
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Second Edition

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Minister: SENATOR THE HON. W. H. SPOONER

Secretary: H. G. RAGGATT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Part II

MICROPALAEONTOLOGY

BY IRENE CRESPIN

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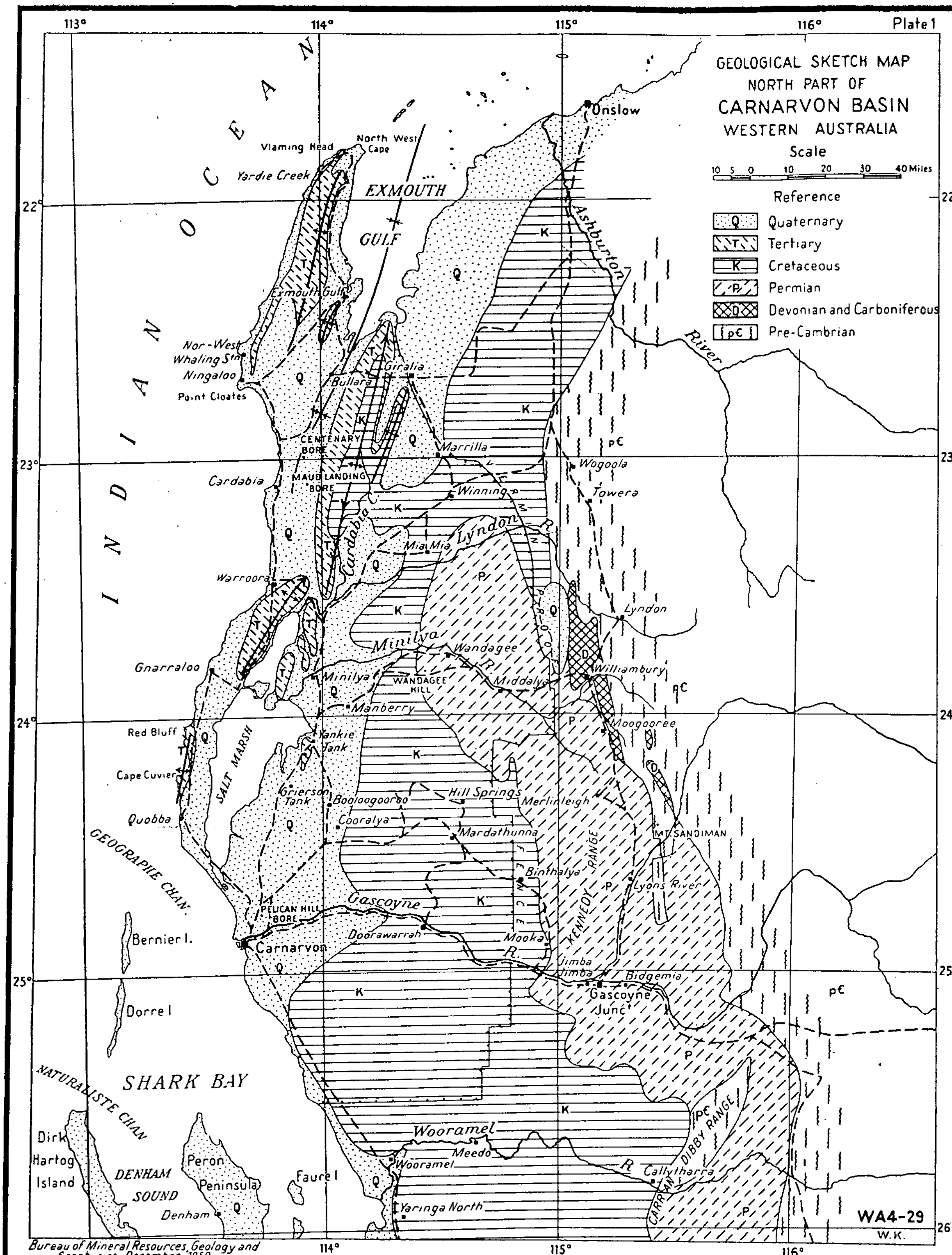
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10 5 0 10 20 30 40 Miles
Reference
Q Quaternary
T Tertiary
K Cretaceous
P Permian
D Devonian and Carboniferous
p€ Pre-Cambrian
INDIAN OCEAN
EXMOUTH GULF
Onslow
Vlaming Head
North West Cape
Yardie Creek
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Nor-West Whaling Stn
Ningaloo
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WA4-29
W.K.
Bureau of Mineral Resources, Geology and Geophysics, December 1950

THE CAPE RANGE STRUCTURE, WESTERN AUSTRALIA

Part I
STRATIGRAPHY AND STRUCTURE

By M. A. CONDON, D. JOHNSTONE and W. J. PERRY

SUMMARY

The Cape Range Structure, which occupies the North-West Cape peninsula, is a closed anticline in Tertiary limestones. The structure is at least eighty miles long and twenty miles wide, and has a vertical closure of 1200 feet and a closed area of 1200 square miles.

The physiography is a reflection of the structure—a young fold mountain with mainly consequent, closely-spaced, drainage.

The Tertiary sediments were laid down in a shelf area of the south-western arm of the Indo-Pacific geosyncline. Because of the stability of the adjoining Western Australian shield, they did not attain the thickness of the sediments laid down elsewhere in the Indonesian geosyncline, nor were they affected to the same extent by subsequent tectonic disturbance.

Five Tertiary formations are exposed on the Cape Range—the lower Miocene ("e-stage") Mandu Calcarenite (265 feet of chalky limestone), the lower Miocene ("f_1-stage") Tulki Limestone (225 to 420 feet of hard crystalline limestone) and the possibly lower Miocene ("f_1" to ?"f_2"-stage) Trealla Limestone (180 feet of white crystalline limestone), constituting the Cape Range Group; and the possibly lower Miocene Pilgramunna Formation and possibly Pliocene Vlaming Formation, forming the Yardie Group (calcareous sandstone and fine conglomerate up to 300 feet thick). Beneath the Miocene limestones are probably at least 3,000 feet of Cretaceous and Eocene marine sediments and possibly up to 18,000 feet of Permian, Carboniferous, and Devonian marine sediments.

In vertical closure and closed area the Cape Range Structure is the largest in the Carnarvon (North-West) Basin. Potential drainage of oil is unrestricted on the west flank and on the northern two-thirds of the east flank. Further geophysical (gravity and seismic) investigations should be carried out so as to try to determine the thickness of sediments and the shape of the structure in depth.

INTRODUCTION

Before 1949, several geologists had inspected the Cape Range Structure, but no detailed work had been done. It was generally believed, chiefly on the physiographical evidence, that the structure was closed, but closure had not been observed on the southern end.

In 1949, as part of the geological investigation of the Carnarvon Basin, which was started in 1948 by agreement between the governments of the Commonwealth and Western Australia, geologists of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics carried out a detailed survey of the Cape Range Structure. The field work was done, under the general direction of M. A. Condon, Senior Geologist, by D. Johnstone and W. J. Perry of the Bureau of Mineral Resources, and J. Sofoulis of the Western Australian Geological Survey.

Situation

The Cape Range Structure is situated on the peninsula between Exmouth Gulf and the Indian Ocean. The Cape Range, which forms the outcropping part of the structure, is about thirteen miles wide from east to west, and extends for sixty miles south from Vlaming Head (from Lat. 21° 48½'S., Long. 114°07' E, to Lat. 22°40'S., Long. 113°45' E.: geographical co-ordinates were taken from military four-mile maps F.50-5 Glenroy and F.50-9 Yanrey).

The area occupied by the structure includes the Yardie Creek Station and parts of Exmouth Gulf and Ningaloo Stations.

Access

The Cape Range Structure is approximately 200 miles by road north of Carnarvon, and 170 miles by road south-west of Onslow. The roads are generally unformed tracks but are trafficable except after heavy rain. Parts of the road from Carnarvon have been formed, but very heavy loads would need to be carried on vehicles similar to the military tank transporter.

Carnarvon and Onslow are the nearest established deep-water ports. Several boat landings in Exmouth Gulf and on the west coast are in use at present. Exmouth Gulf is normally the calmer water area, but the landings here are unprotected to the north, whereas those on the west coast are protected by off-shore reefs. Maud Landing at Cardabia is a deep anchorage, but many of the others are shallow. Sounding surveys of Exmouth Gulf and Maud Landing anchorage have been carried out by survey ships of the Royal Australian Navy.

The former R.A.A.F. airfield at Learmonth (Lat. 22° 13' S., Long. 144° 06' E.) is being maintained; it consists of two intersecting bitumen-sealed gravel strips, each over a mile long, at true bearings 65° and 184°. A regular air service is available from Learmonth to Perth and to Port Hedland. An airfield has been established by the Department of Civil Aviation near Ningaloo Woolshed: this consists of two strips of rolled earth, one bearing about 135° and the other about 15° in a "T" layout. At present there is no regular service to this field, but a plane calls when required to deliver or pick up passengers.

There are no roads or tracks across or into the Cape Range, and the limestone surface with many solution holes makes travel very difficult. Horses cannot be used as the risk of injury is too great. Jeeps were used by the party and, by locating routes on the aerial photographs, access was obtained to the whole of the range. Tyres wear very rapidly and mechanical wear and tear and the risk of damage are considerable. Routes with satisfactory gradients are available so that a first class road could be constructed, although much manual labour and blasting would be necessary. The usual bulldozer technique of road building would be comparatively useless here because of the hardness of the limestone. As the road would have to be built for heavy traffic wherever it may be located, the shortest road which grades will allow is desirable. The shortest route to the apex on the east side runs up the spur which forms the watershed between Badjirrajirra Creek and the creek to the south and is eight miles long, from the mouth of Badjirrajirra Creek (Plate 12). On the west side the shortest practicable route to the apex is seven miles long from the coast, and follows the northern watershed of the creek ¾ mile north of Tulki Well.

Water Supply

The streams in the area flow only for a short period after very heavy rain: water for stock and for domestic use is obtained from the ground water. In the coastal plain, shallow wells or bores (up to 80 feet deep) provide potable but rather hard water. Only one bore ("Pattersons") exists on the range. The water table under the Cape Range is probably very little above sea level. At Pattersons Bore, which is on the south-eastern flank of the structure and 9½ miles from Exmouth Gulf, the static water-level is near sea-level; this is due to the high permeability of the limestone. The supply of ground-water near the apex is likely to be small, but any bore on the flank may be expected to yield 3000 gallons per day continuously. On Cardabia Station, south of the Cape Range Structure, the highly mineralized artesian water is suitable for stock but not for domestic purposes. The aquifer is probably the Cretaceous Birdrong Formation, and may also be present under the Cape Range.

Provision should be made for catching and storing rain water from the roofs of all buildings so that good water for cooking and drinking will be available.

Climate

The climate of the area is warm and dry; the average annual rainfall is about 10 inches, but is erratic and unreliable. Rain falls chiefly in the months from April to September. In this period the days are mild and the nights cool but not frosty. From October to March, the day temperatures are high and often exceed 100° F. in the shade. However, the nights are mild and are only occasionally uncomfortably warm. Winds are very variable. The area lies on the southern edge of the danger area for hurricanes.

Vegetation

The vegetation is very sparse and the species are typical of the semi-arid environment (Gardner, 1942). Spinifex (several species of pungent pointed grass of the genus *Triodia)*, is dominant throughout the peninsula. Stunted shrubs of several species of *Acacia* occupy the stream courses and are scattered over the range. Mangroves grow in some of the tidal creeks on both coasts. There is no timber for construction and very little fire-wood.

Insects

Sandflies are plentiful near the coast and their bites can produce extreme discomfort; flies are numerous in the summer, and blowflies in the cooler months; mosquitoes occur near the coast, but generally not in large numbers. Other insects are not numerous enough to be troublesome.

Game

There is very little wild game in the area—kangaroos, emus, and bustards exist in small numbers. The wild descendants of domestic goats live in the range, and rabbits are found on the western coastal plain. In the water of the Gulf and inside the reef on the ocean shore fish are abundant.

Food Supplies

All food has to be brought into the area with the exception of mutton, which can be obtained from the stations. Fish could be an important source of fresh food. Non-perishable foods are brought overland by motor truck from Carnarvon. Fresh food would need to be brought from Perth by plane or in a ship equipped with refrigeration.

Communications

At present the Learmonth camp may be reached by road or by air; there is an air-mail service to and from Perth twice a week, and surface mail arrives by motor truck once a week, weather permitting. Telegraphic communication is available through the Flying Doctor Service "trans-ceiver" link with Carnarvon.

Health

The health of those who have been working in this area has been very good and, with continued attention to sanitation, fly-proofing, water supply, and diet, should continue so. Heat effect should be guarded against in the summer. Sandfly bites may become infected by scratching. None of the typical tropical diseases is present. The radio contact with the Flying Doctor Service at Carnarvon ensures medical assistance in case of emergency.

Drilling

Very little soil exists on the Cape Range except in sink holes, so that mudtanks would have to be cement-lined excavations in the limestone, or steel tanks.

Bentonitic claystone and nodular barytes are present in outcrop on the Giralia Anticline (Raggatt, 1936, p. 168) north and east of Remarkable Hill, 50 miles southerly from the apex of the Cape Range. These deposits have not been worked to date but may be useful sources of materials for drilling-mud.

Labour is not available locally and would have to be engaged in Perth, Carnarvon, and elsewhere.

SURVEY METHOD

Before systematic mapping was started, a reconnaissance of the whole peninsula was made to establish the stratigraphical sequence and to decide on the features which would be mapped. Of the four outcropping Tertiary formations, only the Tulki Limestone and the Pilgramunna Formation are bounded above and below by other formations. The shape of the structure was defined by mapping the top and bottom of the Tulki Limestone. The top of this formation was identified by a band of hard red-brown pisolitic ferruginous limestone (in some places the lowest of several such bands in a narrow vertical range), the bottom by a lithological change from the hard crystalline Tulki Limestone to the friable chalky Mandu Calcarenite. In addition, dips and strikes were measured wherever observed.

Aerial photographs on a scale of 1 to 31,000 (roughly 2 inches = 1 mile) of most of the Cape Range were available. The northern tip of the peninsula was only covered at the time of the survey by trimetrogon aerial photographs, but this part has since been photographed on a scale of 1 to 50,000, and these photographs were used in compiling the map (Plate 11).

The aerial photographs were examined stereoscopically to determine routes of access into the area being mapped. The position of each observation was fixed on the aerial photograph, marked, and numbered. Altitude was obtained by means of a surveying aneroid or altimeter, and for diurnal correction hourly barometer readings were taken at the Learmonth camp.

Formation boundaries between observed points were traced on the photographs stereoscopically. In some places these had to be checked in the field, because of the poor photographic definition of a boundary.

PHYSIOGRAPHY

The Cape Range is a young fold-mountain forming a peninsula with the Indian Ocean to the west and the synclinal Exmouth Gulf to the east. The range is gently undulating in the centre, with gently sloping flanks and a steep marginal drop to the coastal plain. At the south end the range merges into the high sand-dune-covered ridge which continues southward to Warroora.

The central part of the range is a stripped surface, the Trealla Limestone and the Yardie Group that originally covered the whole range having been eroded away along a surface close to the top of the Tulki Limestone.

At the southern end of the structure this stripping is still in progress. A continuous scarp of Trealla Limestone, facing north-west, extends from a point five miles west-south-west of Learmonth Airfield in a south-westerly direction for thirteen miles. There it crosses the crest of the structure and, facing east, continues in a northerly direction for eight miles; it is here drained by a strike stream. Between the two scarps the top surface of the Tulki Limestone is exposed in a gentle arch. The outcrop of Exmouth Sandstone runs parallel to the scarp facing north-west. Probably the central part of the range was eroded down to the top of the Tulki Limestone while the Exmouth Sandstone was being deposited. An uplift of the order of 600 feet exposed the south end of the structure and the stripping of the Trealla Limestone began there while streams cut deep gorges into the flanks of the central part of the range.

The streams draining the central part of the range are consequent on the shape of the structure and therefore closely spaced. The stream thalweg is sigmoidal in shape with gentle gradients in the upper and lower parts and a very steep gradient in the upper middle part of the course. The larger streams have deepened their valleys faster than the smaller tributaries with the result that many hanging valleys are developed.

Many large sink-holes with characteristic centripetal drainage are found on the flat crest of the range, where the effect of rejuvenation has not been felt. These indicate that a well-developed system of caves almost certainly exists in the Tulki Limestone.

The narrow plain on the west side and the wider plain on the east side, between the hills and the coast, are raised plains of marine deposition with deposits of Recent limestone resting on a bench cut by marine erosion in the Tertiary sediments. At the mouth of Yardie Creek, Recent reef corals up to fifteen feet above high-tide level have been cut through by the creek. Cliffs cut into the Yardie Group by wave-action are still prominent at the eastern edge of the western coastal plain.

Roughly parallel to the western shore-line, and from one-half to one mile off-shore, is a fringing coral reef. The structural section C-D (Plate 15) shows that this reef is probably growing on the seaward edge of the wave-cut platform cut in the Yardie Group. Gaps in the reef, generally opposite the mouths of the larger creeks, are probably caused by the inhibition by fresh water from the creeks of the growth of the organisms that build the reef.

The shore-line of the peninsula is marked by white sand-dunes built up by wind action from the shell-sand brought to the beach by wave and current. Generally there is only a single dune, parallel to the beach. Where the sand has been deposited in large amounts very wide areas of dunes have built up; in such areas the dunes are not parallel to the present beach, but rather to the landward edge of the white sand. The

Nor-West Whaling Company's Station (Lat. 22° 35½′ S., Long. 113° 40¼′ E). is built in such an area of sand-dunes. The beach dune on the shore of Exmouth Gulf is a single dune parallel to the beach.

REGIONAL GEOLOGY

The Cape Range Structure forms part of the large Carnarvon (North-West) Basin (Gentilli and Fairbridge, 1951), the continental part of which extends from Onslow (Lat. 21° 39′ S., Long. 115° 07′ E.) to near the Murchison River (Lat., 27° 45′ S., Long. 115° 00′ E.) and from the coast eastwards to Williambury (Lat. 23° 50′ S., Long. 115° to 10′ E.).

STRATIGRAPHY

Within this depositional basin, a thick sequence of marine sediments has been laid down on a basement of Precambrian sediments, schists, and granite. In the eastern part of the basin the following formations are exposed (Condon, 1954):

PERMIAN

- Kennedy Group (more than 2735 feet thick).
- Baker Formation (200 feet).
- Norton Greywacke (230 feet).
- Wandagee Formation (760 feet).
- Quinnanie Shale (65 to 410 feet).
- Cundlego Formation (1090 feet).

TABLE I.

STRATIGRAPHY OF THE CARNARVON BASIN

Age		Formation	Maximum Thickness (Feet)	Lithology
Quaternary	Recent.			Alluvial clays and sands.
				Evaporites (Salt Marsh)
				Aeolian sand.
		Bundera Calcarenite.	16+	Clastic limestone.
		Mowbowra Conglomerate.	25+	Limestone conglomerate and clastic limestone.
	Pleistocene.	"Joolabroo Formation."	20	Pebbly sand and travertine.
		Exmouth Sandstone.	400	Calcareous sandstone.
		— UNCONFORMITY —		
Tertiary	Pliocene-Miocene.	Yardie Group.	340	Calcareous sandstone.
		Cape Range Group.	1015	Crystalline and clastic limestone.
		— UNCONFORMITY —		
	Eocene.	Giralia Calcarenite.		Crystalline and clastic limestone.
		DISCONFORMITY —		
	Palaeocene.	Jubilee Calcarenite.		
		Cashin Calcarenite.		Fossiliferous calcarenite.
		Pirie Calcarenite.		
		Wadera Calcarenite.		
		Boongerooda Greensand.		Fossiliferous greensand.
		DISCONFORMITY —		

TABLE I. (Continued).
STRATIGRAPHY OF THE CARNARVON BASIN

	Age	Formation	Maximum Thickess (Feet)	Lithology
Mesozoic	Cretaceous.	Miria Marl.		Fossiliferous marl.
		DISCONFORMITY		
		Korojon Calcarenite.		Fossiliferous calcarenite.
		DISCONFORMITY		
		Gearle Siltstone.		Fossiliferous bentonitic siltstone.
		Windalia Radiolarite.		Fossiliferous radiolarite.
		Muderong Shale.		Fossiliferous bentonitic shale.
		Birdrong Formation.	400	Sand, silt, calcareous sandstone.
		UNCONFORMITY		
	Jurassic.	Curdamuda Sandstone.	25+	Calcareous sandstone.
		UNCONFORMITY		
Palaeozoic	Permian	Kennedy Group.	2735+	Quartz greywacke and quartz sandstone.
		Baker Formation.	200	Siltstone and greywacke.
		Norton Greywacke.	230	Quartz greywacke.
		Wandagee Formation.	760	Siltstone and quartz greywacke.
		Quinnanie Shale.	410	Carbonaceous shale.
		Cundlego Formation.	1090	Quartz greywacke, calcareous in part, and siltstone.
		Bulgadoo Shale.	580	Carbonaceous shale.
		Mallens Greywacke.	520	Quartz greywacke.
		Coyrie Formation.	860	Carbonaceous siltstone, quartz greywacke, calcareous beds.
		Wooramel Sandstone.	250	Quartz sandstone.
		Cordalia Greywacke.	180	Quartz greywacke.
		DISCONFORMITY		
		Callytharra Formation.	760	Calcareous greywacke, crystalline limestone and siltstone.
		DISCONFORMITY		
		Lyons Group.	4600	Greywacke, quartz greywacke, siltstone, boulder beds, calcareous greywacke.
		Harris Sandstone.	270	Quartz sandstone.
		UNCONFORMITY		
	Carboniferous.	Yindagindy Formation.	260	Crystalline limestone and greywacke.
		Williambury Formation.	1080	Greywacke, pebbly greywacke, siltstone.
		Moogooree Limestone.	900	Crystalline limestone.
	Devonian.	Willaraddie Formation.	1100	Greywacke, siltstone, conglomerate and limestone.
		Munabia Sandstone.	1900	Quartz sandstone.
		Gneudna Formation.	1720	Calcareous greywacke, crystalline limestone, and siltstone.
		Nannyarra Greywacke.	400	Greywacke and siltstone.
		UNCONFORMITY		
	Precambrian.			Quartzite, slate, limestone; schist, granite, and gneiss.

Bulgadoo Shale (580 feet).
Mallens Greywacke (520 feet).
Coyrie Formation (860 feet).
Wooramel Sandstone (130 to 250 feet).
Cordalia Greywacke (0 to 180 feet).
Callytharra Formation (250 to 760 feet).
Lyons Group (4600 feet).
Harris Sandstone (270 feet).

CARBONIFEROUS

Yindagindy Formation (260 feet).
Williambury Formation (1080 feet).
Moogooree Limestone (900 feet).

DEVONIAN

Willaraddie Formation (1100 feet)
Munabia Sandstone (1900 feet).
Gneudna Formation (1720 feet).
Nannyarra Greywacke (150 to 400 feet).

The thicknesses of the Devonian and Carboniferous formations decrease westward, but the Permian, Cretaceous, and Tertiary formations increase in thickness to the west and north. It is possible therefore that the Devonian and Carboniferous sediments are not present under the Cape Range, but the Permian sediments are probably fully developed there. Very little is known of the palaeogeography of the basin, particularly in Palaeozoic time, and for that reason any estimate of the thickness or type of sediments under the Cape Range Structure must be regarded as tentative only. As the exposed strata give some indication of the environment of deposition within the basin, they are briefly described.

PRECAMBRIAN

The basement rocks of the Carnarvon Basin are Precambrian. Schists, granite, and sediments (limestone, quartzite, slate, and tuff) outcrop to the east of the Palaeozoic sediments and in several fault blocks to the west of their eastern boundary, and are assumed to continue westwards as the floor of the basin. These Precambrian rocks are part of the very stable Western Australian shield which controlled the tectonic history of the basin.

DEVONIAN

Resting unconformably on a mature erosion surface of Precambrian rocks in the Williambury area is the Nannyarra Greywacke, comprising 150 to 400 feet of thin-bedded friable felspathic greywacke and siltstone. No fossils have been found in this formation.

The Gneudna Formation rests conformably on the Nannyarra Greywacke. It consists of 1720 feet of interbedded calcareous greywacke, siltstone, and crystalline limestone, and is very fossiliferous. The fauna includes brachiopods (productids, spiriferids, *et. al.)* nautiloids, crinoids (stems), molluscs, stromatoporoids, and corals. Teichert (1950, p. 1790) states that the fauna indicates a late Middle to early Upper Devonian age; this is confirmed by Hill (1954).

Conformably above the Gneudna Formation is the Munabia Sandstone, 1900 feet thick, of permeable, friable, medium-grained to coarse-grained kaolinitic quartz sandstone with plants of *Lepidodendron* type at the base. Conformably above the Munabia Sandstone is the Willaraddie Formation, 1100 feet thick, consisting of interbedded greywacke, siltstone, and pebble conglomerate, with thin limestone near the bottom and sandstone near the top.

CARBONIFEROUS

The Moogooree Limestone rests conformably on the top of the Willaraddie Formation. It consists of 900 feet of thin-bedded crystalline limestone, siliceous in places. Fossils *(Syringothyris, Rhipidomella,* spiriferids and productids) are found in a few beds in the upper part. Teichert (1949*b*, p. 63) states that the abundance of *Syringothyris* suggests a Lower Carboniferous age.

Conformably above the Moogooree Limestone is the Williambury Formation—1080 feet of interbedded greywacke, pebbly greywacke, siltstone, and thin beds of limestone.

The Yindagindy Formation rests conformably on the top of the Williambury Formation. It consists of 260 feet of interbedded thin beds of pebbly crystalline limestone, with brachiopods and ostracods, and medium-grained to coarse-grained greywacke.

PERMIAN

A medium-grained to coarse-grained ferruginous sandstone, 270 feet thick with a rich flora, has been found mainly in small fault blocks. The stratigraphical position of this sandstone, the Harris Sandstone, is between the Yindagindy Formation and the Lyons Group. It rests unconformably on the Yindagindy Formation or older formations. The lower boundary of the Permian is arbitrarily placed at the base of the Harris Sandstone (Condon, 1954) because it is the transgressive sandstone indicating the beginning of sedimentation following an erosive episode; the lowermost marine fossils, about 600 feet above this base, are of Permian (Sakmarian) type.

The Lyons Group comprises many different lithological types, but is characterized by poorly sorted greywacke and other evidence of marine-glacial deposition, including boulder beds, faceted and striated pebbles, fresh felspar grains, and contorted sandstones. The group rests conformably on the Harris Sandstone. The lowermost beds are poorly sorted greywacke, siltstone, boulder beds, thin beds of limestone (fossiliferous in places), and sandstone. Fossils include brachiopods, lamellibranchs, *Calceolispongia,* and corals. The upper part of the group consists of siltstone, greywacke, finely current-bedded sandstone, and few boulder beds. North of the Minilya River the Lyons Group is 4600 feet thick.

Resting disconformably on the top of the Lyons Group is the Callytharra Formation, which consists of interbedded fossiliferous crystalline limestone and calcareous greywacke, and siltstone. Fossils include crinoids, bryozoa, brachiopods (spiriferids and productids), corals, foraminifera, and molluscs (Raggatt and Fletcher, 1937). The thickness of the Callytharra Formation is 300 feet at Callytharra Spring on the Wooramel River, 250 feet at the Arthur River, 420 feet five miles west of Moogooree Homestead, 700 feet one mile east of Moogooloo (K-58), and 760 feet at the Lyndon River. The proportion of clastic sediments increases from south to north.

There is a disconformity at the top of the Callytharra Formation, marked by ferruginization of the uppermost beds of the formation and by the absence of the upper beds of the Callytharra Formation and of the whole of the Cordalia Greywacke in the more easterly outcrops.

In the area north and west of the Minilya River, the Cordalia Greywacke rests disconformably above the Callytharra Formation. It consists of thin-bedded and laminated fine-grained quartz greywacke with lenses of hard calcareous quartz greywacke in the middle third. The maximum thickness measured is 180 feet, 14½ miles east of Mia Mia Homestead.

Conformably above the Cordalia Greywacke or disconformably above the Callytharra Formation is the Wooramel Sandstone. It consists of medium-grained quartz sandstone with beds of coarse-grained quartz sandstone. Cross-bedding, ripple-marking, and invertebrate trails and burrows are common. The Wooramel Sandstone is stated to be 800 feet thick at the Wooramel River, but this thickness may include the Cordalia Greywacke and part of the Coyrie Formation (Raggatt, 1936, p. 130). It is 130 feet thick on the Gascoyne River, 250 feet thick five miles west of Moogooree Homestead, and about 200 feet thick at the Lyndon River.

The Coyrie Formation rests conformably on the Wooramel Sandstone. From the bottom upwards, it consists of 40 feet of micaceous, carbonaceous siltstone, 200 feet of friable medium-grained and fine-grained quartz greywacke with hard calcareous beds containing fossil wood and nautiloids, goniatites, gastropods, pelecypods, *Calceolispongia* plates, and *Dielasma,* 380 feet of soft dark-grey siltstone with thin beds of fine-grained quartz greywacke and many fossil beds containing foraminifera, brachiopods, gastropods, pelecypods, nautiloids, goniatites, *Calceolispongia* plates, trilobites, and *Glossopteris,* and 240 feet of friable laminated and thin-bedded fine-grained quartz greywacke with thin beds of *Chonetes.*

The Mallens Greywacke consists of 520 feet of thin-bedded to laminated quartz greywacke with calcareous beds containing pelecypods, spiriferids, and small gastropods. It conformably overlies the Coyrie Formation.

The Bulgadoo Shale (Teichert, 1941) conformably overlies the Mallens Greywacke. It consists of a thickness of 580 feet of dark carbonaceous shale and siltstone with thin calcareous and sandy beds. Fossils include *Chonetes, Calceolispongia,* foraminifera, corals, and ostracods. The much greater thicknesses previously stated for this formation are in areas where numerous small strike faults cause multiple repetition of small parts of the section.

Overlying the Bulgadoo Shale conformably is the Cundlego Formation (Teichert, 1941), consisting of laminated fine-grained quartz greywacke with calcareous lenses, and soft dark-grey siltstone. Fossils include *Chonetes,* spiriferids, pelecypods, gastropods, *Calceolispongia,* and small corals. The thickness near Cundlego Crossing on the Minilya River is 1090 feet.

The Quinnanie Shale (Teichert, 1950), conformably overlying the Cundlego Formation, consists of 65 to 410 feet of dark carbonaceous shale with ferruginous concretionary beds and few *Lingula,* spiriferids, productids, gastropods, foraminifera, and *Calceolispongia.*

Conformably above the Quinnanie Shale is the Wandagee Formation (Teichert, 1950), consisting of 760 feet of siltstone and thin-bedded to laminated quartz greywacke, calcareous in parts. Some beds are richly fossiliferous. Fossils include large spiriferids and productids, *Calceolispongia, Strophalosia, Linoproductus, Chonetes,* gastropods, pelecypods, corals, foraminifera, and bryozoa.

The Norton Greywacke conformably overlies the Wandagee Formation. It consists of 230 feet of thin-bedded medium-grained quartz greywacke, with several fossil beds including pelecypods, *Strophalosia,* and *Chonetes.*

The Baker Formation, consisting of 200 feet of laminated micaceous, carbonaceous siltstone and laminated fine-grained to medium-grained quartz greywacke, with fossil beds near the middle, is conformable on the Norton Greywacke. Fossils include spiriferids, small productids, *Aulosteges,* and pectinids.

Conformably above the Baker Formation is the very thick Kennedy Group (Raggatt, 1936, p. 142), consisting of alternating formations of quartz greywacke and quartz sandstone. The basal formation of the group is the Coolkilya Greywacke (Teichert, 1950) which includes several richly fossiliferous beds containing *Strophalosia, Calceolispongia,* spiriferids, *Chonetes,* pelecypods, gastropods, and *Cleiothyridina.* The measured thickness of the Kennedy Group is 2735 feet, from the base of the Coolkilya Greywacke to the erosion surface at the top of the uppermost formation exposed (at Venny Peak on the south-western margin of the Kennedy Range).

The uppermost sandstone of the Kennedy Group is the youngest

Permian formation exposed in the Basin; possibly, younger beds of Permian age are preserved under the cover of Cretaceous and Tertiary rocks in the area near the coast.

JURASSIC

The only outcrop of supposedly Jurassic rocks is near Curdamuda Well, Wandagee Station, on the Minilya River. The Curdamuda Sandstone, a calcareous sandstone containing marine fossils possibly of Middle Jurassic age (Teichert, 1940), rests unconformably on Permian gypsiferous shale (?Bulgadoo) and is overlain by Cretaceous glauconitic sandstone of the Birdrong Formation. It may in fact be the lowermost part of the Birdrong Formation.

As Jurassic sediments are present in the Canning Basin to the north-east and at Geraldton to the south, it is possible that Jurassic sediments may be present between the Cretaceous and the Palaeozoic beneath the Cape Range, although bores reaching the Palaeozoic at Cardabia show that it is not present there.

CRETACEOUS

The Cretaceous System in the Carnarvon Basin comprises the basal Birdrong Formation, of quartz sandstone, glauconitic sandstone, quartz greywacke, and siltstone; the Winning Group of fine-grained sediments; and the lower part of the Cardabia Group of calcarenite. The Birdrong Formation is up to 100 feet thick in outcrop on the western side of Kennedy Range and about 400 feet thick in Rough Range bore. It rests unconformably on Palaeozoic sediments.

The Winning Group comprises the lowermost Muderong Shale (fossiliferous bentonitic shale 40 feet thick in outcrop on the west side of Kennedy Range), Windalia Radiolarite (thin-bedded to laminated fossiliferous radiolarite about 200 feet thick), and Gearle Siltstone (fossiliferous bentonitic siltstone 100 feet thick in outcrop west of Kennedy Range and 535 feet in outcrop on Giralia Anticline).

The Cretaceous part of the Cardabia Group consists of the Korojon Calcarenite (calcarenite with large *Inoceramus*) and the Miria Marl (very fossiliferous marl). These are about 120 feet thick at Booloogooroo Station (Grierson's Tank Bore, from 131 to 251 feet), 260 feet in outcrop near Remarkable Hill, Cardabia Station, 296 feet at Warroora No. 1 Bore (from 63 to 359 feet), and 438 feet at Centenary Bore, Cardabia Station (from 124 to 562 feet).

TERTIARY

In the Giralia Anticline the Upper Cretaceous is disconformably overlain by 200 feet of fossiliferous calcarenite belonging to the Palaeocene upper part of the Cardabia Group. This is disconformably overlain by the Eocene Giralia Calcarenite, which is 200 feet thick on the Giralia Anticline.

Eocene marine sandstone crops out at Merlinleigh Station, near the eastern edge of the basin. Fossiliferous sandstone resting unconformably on the Permian in the Moogooree-Williambury area may be correlated with the Merlinleigh Sandstone.

Miocene limestones outcrop in a strip about 30 miles wide along the coast from North-West Cape to Carnarvon. This series is very thin in the southern part of the strip, but in the Cape Range it is more than 1000 feet thick.

STRUCTURE

The Carnarvon Basin is a large epi-continental basin in which sedimentation probably started in the Middle Devonian. A period of erosion, at least in the eastern margin of the basin, occurred during the Upper Carboniferous. During the Upper Carboniferous Epoch, sediments on the eastern margin of the basin were eroded. The first important earth movements to which the Palaeozoic sediments were subjected occurred in epi-Permian time, when large-scale strike faulting broke the sediments into fault blocks. The main faults, with throws of up to 8000 feet, trend west to north, and are probably mainly of the high-angle thrust type and were produced by stress in the basement.

In the time interval between the epi-Permian faulting and the Cretaceous transgression, the surface of the Palaeozoic sediments was reduced to a peneplain.

The main transgression over this surface, in the Lower Cretaceous, reached nearly to the eastern edge of outcrop of the sediments. Regression started in Upper Cretaceous and continued into lower Miocene time: the beds with *Inoceramus*, possibly of Turonian age (Crespin, 1938, p. 395), lens out about 40 miles east of the present coastline, the Eocene limestone lenses out about 20 miles from the coast, and the lower Miocene about 30 miles from the coast. After a minor transgression in the upper part of the lower Miocene, the Trealla Limestone was deposited in a strip which lenses out about 30 miles east of the coast.

Between the Eocene and lower Miocene folding along the Giralia Anticline and erosion of the crestal region took place.

The Tertiary limestones of the coastal strip were folded in late Tertiary time, probably at the same time that minor movements occurred along some of the old faults in the eastern part of the basin (Teichert, 1948).

The western edge of the exposed Palaeozoic sediments is very much faulted and is bounded on the west by a fault-zone with downthrow to the west. Bores indicate that the Cretaceous System is much thicker west of the fault than east of it, but this may be the result of erosion from the upthrown eastern block.

As the Palaeozoic rocks outcrop 100 to 150 miles south-east of the Cape Range Structure, it is to be expected that the sequence beneath the

Cape Range is not the same, either in lithology or thickness, as in the eastern part of the basin.

The Cape Range Structure is one of many anticlines along the coast between North-West Cape and Geraldton. These folds have a marked linear arrangement—the Cape Range Anticline is in line with the Cape Cuvier Anticline, the Rough Range Anticline with the Warroora, the Chargoo Anticline with the Yankie Tank. The Cape Range and Rough Range Anticlines and the smaller Minilya anticlines are nearly symmetrical; the Giralia, Warroora, Chargoo, and Yankie Tank Anticlines and the larger Minilya anticlines are asymmetrical; the Giralia, Warroora, and Yankie Tank Anticlines have the steeper flank on the east, and the others have a steeper western flank.

Faulting in the eastern part of the basin is known to have occurred at two different times: the first probably immediately followed the deposition of the Permian sediments, the second occurred in Upper Tertiary or even in Pleistocene time. In many places later movement occurred along old faults. The Palaeozoic rocks of the eastern part of the basin were faulted and eroded before the deposition of the Mesozoic and Tertiary sediments.

GEOLOGY OF THE CAPE RANGE STRUCTURE

Previous Work

The earliest work published on the geology of the Carnarvon Basin was a section from Carnarvon eastward (F. T. Gregory, 1861, p. 477). This shows the west-dipping Palaeozoic sediments and the unconformable Cretaceous "white chalk-like but non-calcareous rock" [radiolarite]. However, the section is not described in this paper. Hudlestone (1883) listed fossils from "north of the Gascoyne River"; these were thought to "indicate a Lower Carboniferous age".

In 1902 and 1903 a bore was put down by the Mines Department at Pelican Hill near Carnarvon in the search for artesian water. Etheridge (1904) reported on the fossils in the cores. He found foraminifera and small belemnites of Cretaceous type and spiriferids and *Aviculopecten* of "Carboniferous or Permo-Carboniferous" age. Thomas and Dickins (1954) have shown that these fossils *(Cyrtospirifer)* are similar to species found in outcrop in the Devonian Gneudna Formation. The lithology is a likely facies variant of the Gneudna Formation.

Woodward (1907) examined the country north of the Minilya River to estimate its artesian water potential, and noted the limestone of the west flank of the Giralia Anticline.

In 1909 A. Gibb Maitland described the Carboniferous and Permian succession in the area drained by the Gascoyne, Lyons, Minilya and Lyndon Rivers, although he referred the whole sequence to the Carboniferous.

Clapp was the first to describe the Tertiary limestone of the Cape

Range and Giralia Range (1925, p. 64) and to indicate the anticlinal structure of the Cape Range, Rough Range, and Giralia Range (Fig. 4, p. 53). In 1926 he published (Clapp, 1926*a* and *b*) a very pessimistic opinion of oil prospects in Western Australia.

Chapman (1927) described foraminifera from Clapp's samples from "a gorge 25 miles north-west of Exmouth Gulf Homestead", but did not draw any age distinction between the friable and the hard limestones. He ascribed an Oligocene age to the limestone of this locality because of the presence of eulepidines and nummulites.

Woolnough in 1932 flew over the Carnarvon Basin (Woolnough, 1933). He confirmed the anticlinal structure of the coastal ranges and noted folding and faulting in the Permian along the Gascoyne River.

Geologists of Oil Search Ltd., under D. Dale Condit, examined the Carnarvon Basin in 1932, 1934, and 1935. Rudd and Dee named and defined the stratigraphical units of the Permian in the Wooramel River area (first published in Condit, 1935, pp. 869-871). Condit (1935, p. 866) described the Cretaceous and Eocene rocks of the Giralia area and listed fossils determined by Whitehouse and Chapman. He also described (p. 867) the Windalia Radiolarite. Raggatt (1936) described the stratigraphy of the Permian in some detail and subdivided the Cretaceous sequence. Raggatt and Fletcher (1937) examined the fauna of the Carnarvon Basin and re-examined the evidence of the age of the Gondwana rocks generally. They concluded that the beds characterized by the *Eurydesma-Conularia* fauna or the *Gangamopteris-Glossopteris* flora should be assigned to the Permian.

Conrad and Maynard visited the area in 1948 but did not publish any information.

Craig (1950) gave a short account of the stratigraphy and structure of the Cape Range, Rough Range, and Giralia Range He proved closure in Miocene limestone on the Rough Range, but did not have time to investigate the larger structures fully. He regarded these structures as favourable for oil accumulation.

STRATIGRAPHY

The stratigraphical columns (Plate 18 and Tables 2 and 3) summarize the stratigraphical succession and its variations in the Cape Range area. The strata outcropping on the Cape Range are Miocene limestone and sandstone, and Quaternary sandstone and limestone. Seven lithological units have been separated as formations. In ascending order these are the lower Miocene Mandu Calcarenite, Tulki Limestone and Trealla Limestone, which constitute the Cape Range Group (Clapp, 1925); the Yardie Group, comprising the lower Miocene Pilgramunna Formation and the possibly Pliocene Vlaming Sandstone; the Pleistocene Exmouth Sandstone; and the Recent Bundera Calcarenite and Mowbowra Conglomerate.

TABLE 3.

STRATIGRAPHY OF THE CAPE RANGE

Period	Age	East Indies Stage	West Flank	North Plunge	East Flank	South Plunge
QUATERNARY	Recent		*Alluvial sand, clay, gravel; aeolian sand.*			
			Bundera Calcarenite		*Mowbowra Calcarenite*	
	Pleistocene					*Exmouth Sandstone*
TERTIARY	? Pliocene		*Vlaming Sandstone*			
	?		FRESH-WATER SANDSTONE	*DISCONFORMITY*		
	Lower Miocene	f_1 - f_2	*Pilgramunna Formation*	*Trealla Limestone*		
			FRESH-WATER LIMESTONE	*DISCONFORMITY*		
	Lower Miocene (? Burdigalian)	f_1	*Tulki Limestone*			
	Lower Miocene (?Aquitanian)	e	*Mandu Calcarenite*	NOT EXPOSED	*Mandu Calcarenite*	NOT EXPOSED

H.E.S.

TABLE 2.

ROCK UNITS OF CAPE RANGE

Group	Formation	Maximum Thickness (in Feet)	Lithology	Guide Fossils
			Alluvial sand, clay, gravel	
			Aeolian sand.	
	Bundera Calcarenite.	16+	Calcarenite.	Corals, molluscs.
	Mowbowra Conglomerate.	25+	Limestone conglomerate, calcarenite.	Oysters, corals.
	Exmouth Sandstone.	400	Calcareous sandstone.	*Marginopora.*
Yardie Group.	Vlaming Sandstone.	240 ?	Calcareous sandstone. Calcareous sandstone.	Calcareous algae. ? Freshwater gastropods.
	Pilgramunna Formation.	96	Calcareous coarse sandstone, calcareous fine conglomerate, sandy limestone.	
Cape Range Group.	Trealla Limestone.	180	Smooth, crystalline foraminiferal limestone.	*Austrotrillina, Flosculinella,* Large molluscs.
		?	Freshwater limestone.	Gastropods.
	Tulki Limestone.	420	Crystalline foraminiferal limestone.	Lepidocyclines, echinoids.
	Mandu Calcarenite.	265+	Foraminiferal calcarenite and coquinite.	Eulepidines (very large).

CAPE RANGE GROUP

Clapp (1925) proposed "for the strata that comprise these anticlines (Cape Range and Giralia) and form the surface between them" the name Cape Range Formation. The Cape Range Formation as defined by Clapp includes Cretaceous limestone, siltstone and greensand, Tertiary limestone, and post-Tertiary sandstone and limestone. As only Cainozoic strata outcrop on the Cape Range, it is proposed to restrict the name to the Tertiary limestones constituting the Cape Range.

The Cape Range Group (comprising the Mandu Calcarenite, Tulki Limestone, and Trealla Limestone) consists of the Tertiary limestone which outcrops on the Cape Range between latitudes 21° 48′ and 22° 35′ South and between longitudes 113° 42′ and 114° 06′ East. It is Miocene in age, ranging from East Indies "e-stage" to "f_1-stage" and possibly up to "f_2-stage". There is evidence of a minor disconformity in the sequence but the micro-faunas indicate that sedimentation was essentially continuous, although evidence of the emergence of the Tulki Limestone may be seen.

Details of the lithology and fossils are given below in the descriptions of the formations constituting the group.

Mandu Calcarenite

The Mandu Calcarenite is the oldest formation exposed on the Cape Range.

The name (pronounced man-doo) is taken from Mandu Mandu Creek, which flows down the western fall of the Cape Range into the Indian Ocean, at about Lat. 22° 09′ S., Long. 113° 52′ E., 20 miles south of Yardie Creek Homestead and 13 miles north of Yardie Creek. The aboriginal name "Mandu Mandu", according to Mr. E. Payne of Yardie Creek Station, means "many stones".

The Mandu Calcarenite is the friable chalky calcarenite at the bottom of the exposed Tertiary section in the Cape Range. As the bottom of the formation is not exposed and has not been recognized in bores, it cannot be defined at present. Its upper limit is the base of the hard crystalline Tulki Limestone.

The only outcrop of the formation on the west side of the range is in the bed of the Mandu Mandu Creek about four miles from its mouth (Plate No. 12). On the east side of the range it outcrops as inliers in the deep gorges 18 to 26 miles southward from North-West Cape.

The type section for the formation is situated in Badjirrajirra Creek, at Lat. 22° 06′ S., Long. 114° 02′ E., on the eastern fall of the range, four miles from the mouth of the creek (Plate No. 12). The Mandu Calcarenite outcrops in the creek bed and in the walls of the valley between three and five miles from the mouth. The strata in this section dip at between three and six degrees to the east.

In the type section the Mandu Calcarenite consists, from the top downwards, of:

95 feet thin-bedded friable white to light-cream foraminiferal chalky calcarenite with beds, up to 18 inches thick, of hard cream crystalline limestone, and with numerous *Cycloclypeus*, *Lepidocyclina*, and small foraminifera (Samples CR.112, CRC.10, CRC.11).

2 feet firm white foraminiferal coquinite, with very large *Lepidocyclina* and numerous small foraminifera (Sample CR.111, CRC.9).

153 feet thin-bedded friable to firm white to cream coquinoid calcarenite with many bryozoa and small foraminifera and few large foraminifera (*Cycloclypeus* and *Operculina*), ostracods, and echinoids (Samples CR.110, CRC.12, CR. 109, CR.108, CR.107,—in descending order).

5 feet firm white chalky calcarenite with nodules of grey flint.

10 feet thin-bedded friable to firm white to buff chalky calcarenite with numerous small and large foraminifera, echinoids, molluscs, ostracods, and crustacean remains (Samples CR.106, CR.123).

Bottom of formation not exposed.

265 feet type thickness of Mandu Calcarenite.

The thickness of the type section, 265 feet, is the greatest thickness of the Mandu Calcarenite exposed in the Cape Range. The total thickness, and the variation in thickness, cannot be determined until well-sampled bores penetrate the subsurface portion of the formation.

The bottom of the Mandu Calcarenite does not outcrop on the Cape Range; and as far as is known the Cape Range is the only place where the formation is exposed at all. It is possible that it rests unconformably on the equivalent of the Eocene Giralia Calcarenite (Condon *et al,* 1955). Overlying the Mandu Calcarenite is the hard crystalline Tulki Limestone; there is a slight angular unconformity between the two formations—up to two degrees—but no evidence of erosional unconformity.

The Mandu Calcarenite is easily recognized in the field because of its friability and the presence of beds of thin discoidal foraminifera from $\frac{1}{2}$ inch to over 2 inches in diameter.

The fossil species identified by Miss Crespin in samples of the Mandu Calcarenite are given in Part II of this Bulletin.

The presence of *Lepidocyclina (Eulepidina)* and the absence of reticulate nummulites suggest that the age of the Mandu Calcarenite is the "e-stage" of the East Indian subdivision of the Tertiary (Umbgrove, 1931). As *Eulepidina* is found to within a few feet of the top of the formation but not above it, the top of the Mandu Calcarenite is probably close to the top of the "e"-stage. The "e"-stage of the East Indies has been correlated with the lower Miocene of Europe (Finlay, 1947), but van der Vlerk (1950) believes that correlation of the Tertiary stratigraphy of the East Indies province with that of Europe and America is not yet possible. Senn (1935) on the other hand indicated large eulepidines and *Miogypsina* as zone fossils for the Aquitanian Stage in both Europe and the East Indies.

Although the Mandu Calcarenite is not known to outcrop anywhere but on the Cape Range, some of the lower beds at Cape Cuvier and Red Bluff may possibly be correlated with it.

Tulki Limestone

The Tulki Limestone is the hard thick-bedded crystalline limestone containing *Lepidocyclina* (subgenera *Nephrolepidina* and *Trybliolepidina*), which conformably overlies the Mandu Calcarenite, and underlies the Trealla Limestone or the Yardie Group, with, in most places, a bed of pisolitic ferruginous limestone at the junction.

The name (which rhymes with "bulky") derives from Tulki Well, Lat. 22° 06′ S., Long. 113° 54′ E., on the western coastal plain, about 16 miles south of Yardie Creek Homestead and 17 miles north of Yardie Creek.

In an unpublished company report (1937) Rudd suggested the name "Yilbiah" for this formation, but as this name is not a published geographical name within the Cape Range area the name "Tulki" published on Lands Department plans is regarded as more suitable.

The Tulki Limestone crops out over the whole of the central part of the Cape Range and in a narrow strip at the foot of the Range on the west side. The type section of the Tulki Limestone is on the southern side of the valley of Badjirrajirra Creek, at Lat. 22° 06′ S., Long. 114° 03′ E., three miles from the mouth of the creek (Plate No. 12).

The type section of the Tulki Limestone in descending order is as follows:

Bottom of Trealla Limestone.

1 foot	hard red-brown ferruginous limestone with angular fragments of cream crystalline limestone with foraminifera (Sample CR.8.)
4 feet	hard, white to cream, fine-grained crystalline limestone.
1 foot	hard red-brown ferruginous sandy limestone.
14 feet	hard, white to cream, fine-grained crystalline limestone.
5 feet	hard light-cream crystalline limestone.
11 feet	hard white crystalline limestone with foraminifera and echinoid spines (Sample CRC.8).
5 feet	hard cream crystalline limestone (Sample CR.7).
31 feet	hard light-yellow fine-grained crystalline limestone with few large foraminifera.
11 feet	hard cream crystalline limestone with foraminifera, bryozoa, and molluscs, and a little glauconite (Sample CRC.7).
11 feet	hard, massive cream fossiliferous limestone. The above 53 feet of thick-bedded hard cream crystalline limestone weathers to a red-brown surface and has many small caves.
10 feet	hard light-yellow crystalline limestone with bryozoa and pectenids.
5 feet	hard light-yellow crystalline limestone with lepidocyclines, pectenids, and corals.
11 feet	hard to medium-hard yellow foraminiferal crystalline limestone and calcarenite with lepidocyclines, pectenids, and bryozoa (Sample CR.6).
15 feet	hard cream crystalline limestone with small lepidocyclines and calcareous algae.
6 feet	hard pink limestone with few fossils.

11 feet hard pink crystalline limestone.
10 feet hard pink crystalline limestone.
33 feet hard cream limestone with foraminifera, bryozoa, and calcareous algae (Sample CRC.5, CRC.4). The above 101 feet of thin-bedded pink and yellow foraminiferal limestone weathers to a yellow and brown nodular surface with a few harder beds weathering to a smooth surface.
5 feet hard pink foraminiferal crystalline limestone (Sample CRC.4).
6 feet hard light-yellow limestone.
8 feet medium-hard pink and cream foraminiferal crystalline limestone (Sample CRC.3).
2 feet hard pink crystalline limestone.
Top of Mandu Limestone.
216 feet type thickness of Tulki Limestone.

A much thicker section crops out in Mandu Mandu Creek, on the west side of the Cape Range, between the bottom of the Yardie Group, one mile from the creek mouth, and the top of the Mandu Calcarenite, four miles from the mouth. The strata in this area dip from three to eight degrees westerly and the complete section from the top to the bottom of the formation is exposed in the gorge of Mandu Mandu Creek. The Tulki Limestone in this section consists, from the top downwards, of:

Bottom of Yardie Group (hard grey calcareous sandstone with well-rounded grains of quartz to 5 mm.).
1 foot hard red-brown pisolitic ferruginous limestone.
210 feet hard grey medium-grained "shimmering" crystalline limestone with molluscs and foraminifera; in beds from 1 to 10 feet thick.
80 feet hard pink medium-grained crystalline limestone with foraminifera, bryozoa, corals, and molluscs; in beds 1 to 3 feet thick, weathering to a nodular surface.
130 feet hard cream medium-grained crystalline limestone with foraminifera, bryozoa, corals, and molluscs; in beds 6 inches to 2 feet thick, weathering to a nodular surface.
Top of Mandu calcarenite (friable cream chalky calcarenite with large foraminifera).
421 feet of Tulki Limestone.

The thickness of the Tulki Limestone increases from 216 to 421 feet from Badjirrajirra Creek to Mandu Mandu Creek (a distance of about nine miles). This is probably due to divergence (actual thickening of beds). The increase in thickness implies that there is an average angular divergence in the Tulki Limestone of 14 minutes in a west-south-west direction; this may not be the direction or amount of maximum divergence.

The fauna identified in the Tulki Limestone belongs to the "f_1"-stage of the East Indies (van der Vlerk, 1950). It contains most of the species characteristic of the East Indies Rembangian Stage (Glaessner, 1943), which has been correlated tentatively with the lower Miocene Burdigalian Stage of Europe. It may be correlated with the upper Ihungia Stage of New Zealand, which contains *Katacycloclypeus*, *Nephrolepidina*, *Trybliolepidina*, *Orbulina*, *Gypsina howchini*, and *Operculina* cf. *victoriensis* (Finlay, 1947). The presence of *Austrotrillina howchini*, *Guttulina (Sigmoidina) silvestrii*, *Gypsina howchini*, *Orbulina universa*, and *Lepidocyclina (Trybliolepidina) gippslandica*, allows a correlation with the Batesford sub-stage of Victoria (Crespin, 1943*b*).

The Tulki Limestone rests with a small angular unconformity on the Mandu Calcarenite. The top of the Tulki Limestone is marked by a thin band of pisolitic ferruginous limestone which appears to have resulted from the weathering of the limestone. In a few places there is evidence of a small amount of erosion on the surface of the formation and, at one place, on the north branch of Yardie Creek, a deposit of fresh-water limestone with gastropods (Sample No. CR.65) rests, apparently in a depression on the surface of the Tulki Limestone. This gives direct evidence of the emergence of the Tulki Limestone before the deposition of the Trealla Limestone and Yardie Group. This emergence must have been very short, because there is no marked faunal break between the top of the Tulki Limestone and the bottom of the Trealla Limestone.

The Trealla Limestone overlies the Tulki Limestone on the east flank, around the southern plunge, at the few outliers near the crest (Mount King, Mount Lefroy) and around the northern plunge. The Yardie Group overlies the Tulki Limestone at many places on the western flank.

The Tulki Limestone occurs as inliers in creek valleys in the central part of the east flank of the Rough Range Anticline; it does not occur on the Giralia Anticline. It outcrops in the Cape Cuvier cliff section, where it is very thin (about 40 feet).

Trealla Limestone

The Trealla Limestone is the hard, white to cream, thin-bedded foraminiferal crystalline limestone, containing many molluscs, which overlies the Tulki Limestone.

The name (pronounced Tree-al′-lā) is taken from the original name of Mount Lefroy (Lat. 22° 13′ S., Long. 114° 00′ E.), which is an outlier of Trealla Limestone, about five miles west of Learmonth airfield. It was suggested by Rudd (1937) in an unpublished company report.

The Trealla Limestone is exposed as outliers capping the spurs between creeks along the lower part of the east side of the Cape Range and the higher part of the west side and in a large area on the south-western flank, and beneath the Yardie Group on the lower part of the west flank and around the northern plunge.

The type section is on the north side of Mount Lefroy, where a continuous section through the formation is exposed. There the Trealla Limestone consists of:

Top of outcrop.

98 feet thin-bedded hard white fine-grained crystalline limestone with numerous small foraminifera and large molluscs. Sample CR.85 at top.

60 feet thin-bedded hard white fine-grained crystalline limestone with foraminifera (some large) and molluscs. Sample CR.84 at top.

15 feet thin-bedded hard pink fine-grained crystalline limestone with foraminifera and molluscs. Sample CR.83.

6 feet hard cream fine-grained crystalline limestone with foraminifera and molluscs. Samples CR.82 and CRC.15.

Top of Tulki Limestone (thin ferruginous limestone).

179 feet Type thickness of Trealla Limestone.

As no reliable marker bed has been found within the formation and the top of the formation is everywhere an erosion surface, the range in the thickness of the Trealla Limestone is not known.

In the East Indies, *Austrotrillina howchini and Flosculinella bontangensis,* which are characteristic of the Trealla Limestone (see Part II), do not occur above the top of the Rembangian Stage (the equivalent of the "f_1-f_2" stage of Leupold and van der Vlerk (1931), and of the "n_2" stage of the Geological Survey of the East Indies). The absence of *Lepidocyclina (Trybliolepidina) rutteni,* which is characteristic of the Preangerian Stage (Tan, 1939), in the upper part of the Trealla Limestone, is perhaps an indication that this formation should be included in the Rembangian Stage.

The Trealla Limestone rests on the surface of the Tulki Limestone with no apparent angular unconformity, although the weathered and eroded surface of the Tulki Limestone and the presence of freshwater limestone between the two (Sample CR.66) indicate that there was a period of emergence between the deposition of these two formations. This is reflected in the faunas on either side of the formation boundary; although many species are common to both formations a sufficient number of species is restricted to one or other of the formations to indicate a faunal break, and therefore a slight disconformity. The Exmouth Sandstone rests with slight angular and erosional unconformity on the Trealla Limestone.

The Trealla Limestone interfingers with the Pilgramunna Formation. On the west flank of the Cape Range Structure, the Trealla Limestone is represented by 20 feet of white crystalline limestone below the base of the Pilgramunna Formation and by a bed of white sandy limestone above the calcareous very coarse sandstone of the bottom part of the Pilgramunna Formation. West of Kuburu Well in the north-eastern part of the range, calcareous very coarse sandstone (Pilgramunna Formation) is interbedded with hard white limestone (Trealla Limestone). Farther south the sandstone is not present. In the Rough Range at least two thin beds of calcareous sandstone are interbedded in the Trealla Limestone.

The Trealla Limestone is also exposed on the Rough Range, on both flanks of the Giralia Anticline and overlapping the Cretaceous in the crestal region near Korojon Pool, on the Warroora, Chargoo, and Minilya Anticlines, on the flanks of the Yankie Tank Anticline, and in the Cape Cuvier cliff sections. The eastern edge of deposition of the Trealla Limestone was probably about thirty miles east of the coast. From the eastern edge it thickens westward; the angular divergence is about four minutes.

Yardie Group

The Yardie Group comprises the Pilgramunna Formation below and the Vlaming Sandstone above; in places it rests disconformably on the top of the Tulki Limestone.

The name is taken from Yardie Creek, which flows into the Indian Ocean at Lat. 22° 20′ S., Long. 113° 48½′ E., about 40 miles S. 30° W. from Vlaming Head Lighthouse.

The Yardie Group outcrops along the western margin of the Cape Range and around the northern end as far as Kuburu Well.

Pilgramunna Formation

The Pilgramunna Formation, the lower formation of the Yardie Group, consists of coarse-grained and medium-grained quartz sandstones, sandy limestone, and limestone, resting disconformably on the Tulki Limestone, or conformably on the Trealla Limestone, and disconformably overlain by the Vlaming Sandstone.

The name is from Pilgramunna Creek, which flows into the Indian Ocean at Lat. 22° 11′ 48″ S., Long. 113° 50′ 36″ E. (Plate 12).

The Pilgramunna Formation crops out along the west flank from ½ mile west of Vlaming Lighthouse to one mile north-north-west of Wealjugoo Hill and around the northern plunge to the vicinity of Kuburu Well.

The type section for the Pilgramunna Formation is at Yardie Creek, above the downstream end of the gorge, 1½ miles from the mouth of the creek and on the south side (Lat. 22° 20′ S., Long. 113° 49½′ E., Plate No. 13).

In the type section, the Pilgramunna Formation consists, from the top downwards, of:

Top of outcrop.

[Stratigraphical position of pale brown calcareous sandstone with ? fresh-water gastropods (Sample CR.63).]

26 feet hard light-grey medium-grained calcareous sandstone with well-rounded coarse sand grains and small foraminifera, in beds from one to four feet thick (Sample No. CR. 77A).

30 feet hard yellow medium-grained sandy limestone with small foraminifera and with thin beds of calcareous very coarse sandstone; in beds up to five feet thick.

20 feet thin-bedded hard greyish-yellow medium-grained sandy limestone with six-inch beds of calcareous coarse sandstone consisting of well-rounded quartz grains, and calcareous algae, foraminifera, and bryozoa; cross-bedded in places (Sample No. CR.77).

25 feet thin-bedded hard grey fine-grained to medium-grained crystalline limestone with foraminifera and sandy crystalline limestone in beds from ½ inch to 2 inches (Sample No. C.R.76).

52 feet hard light-red-brown calcareous coarse sandstone and calcareous fine conglomerate (with well-rounded quartz grains about 5 mm. diameter).

Top of Tulki Limestone (hard, grey to pale pink, medium-grained "shimmering" crystalline limestone with flat echinoids, gastropods, and foraminifera).

153 feet Type thickness of Pilgramunna Formation.

The lithology throughout the Pilgramunna Formation is reasonably uniform, with variations from limestone with laminae of quartz sand to calcareous fine conglomerate.

The Pilgramunna Formation contains two different foraminiferal assemblages: one, present mainly in the limestone beds, characterized by *Marginopora;* the other, present in some of the limestone beds but more commonly in the calcareous sandstone or fine conglomerate, consisting almost entirely of fossil fragments. Almost all the species found in the Pilgramunna Formation are also found in the Trealla Limestone; but all, except fragments of *Lepidocyclina,* are long-ranging forms. The guide fossils of the Trealla Limestone—*Austrotrillina howchini* and *Flosculinella bontangensis*—have not been found in the Pilgramunna Formation.

The sandy limestone beds in the Pilgramunna Formation have been correlated in the field, on lithology, structural and stratigraphical position, and megafossils, with the Trealla Limestone. These sandy limestones are white smooth-fracturing very-fine-grained crystalline limestones with clear quartz sand either in laminae or disseminated. Apart from the presence of the sand, the limestone is very similar to the less fossiliferous parts of the Trealla Limestone, which have a quite distinctive appearance. Similar colonial corals and gastropods are present in these limestone beds and in the Trealla Limestone, but the poor preservation makes identification impossible. The corals are probably long-ranging forms and like most of the microfossils serve only to show that in general the limestone beds of the Pilgramunna Formation are similar to the Trealla Limestone. The main outcrop area of thick Trealla Limestone is low on the east flank and of the Pilgramunna Formation low on the west flank. On the northern plunge, thin calcareous fine conglomerate (Pilgramunna Formation) rests on thin Trealla Limestone with a gradational, interbedded contact. Nowhere is there continuity of outcrop between thick Trealla Limestone and thick Pilgramunna Formation, but structurally and stratigraphically the Pilgramunna Formation occupies the position on the west flank equivalent to the Trealla Limestone on the east flank. Both show angular conformity with the underlying Tulki Limestone but also show evidence of disconformity—a bed of limestone with fresh-water gastropods and beds of pisolitic ferruginous limestone between the Trealla Limestone and Tulki Limestone and, below the Pilgramunna Formation, a ferruginous surface on the Tulki and extension of the calcareous fine conglomerate into joint cracks in the topmost Tulki Limestone.

The scarcity of diagnostic fossils and the lack of continuity of outcrop raises a doubt as to the relative ages of the Trealla Limestone and the Pilgramunna Formation. The fragments of *Lepidocyclina* could indicate erosion of the Trealla Limestone; but the fragments are enclosed in the calcite cement of the calcareous sandstone in which they are found, and not in fragments of Trealla Limestone as would be expected if they were derived from the Trealla Limestone by erosion. Fossils (apart from mollusc casts and colonial corals) do not weather out of the Trealla Limestone at the present surface. There is no evidence of an erosion surface between the base of the Pilgramunna Formation and the lowermost beds of the Trealla where they are in contact, and one mile north-west of Kuburu Well the contact is gradational.

Non-deposition of the Trealla Limestone on the west flank and later deposition of the Pilgramunna Formation is unlikely because of the *Lepidocyclina* fragments in the Pilgramunna Formation and the gradational contact between the low Trealla and lowermost Pilgramunna Formation on the north plunge.

The evidence for contemporaneity of deposition of Trealla Limestone and Pilgramunna Formation—similarity of lithology of Trealla Limestone and limestone beds of the Pilgramunna Formation; presence of *Lepidocyclina* and other similar foraminifera, and of corals and gastropods in both formations; similarity of structural and stratigraphical position of both formations relative to the top of the Tulki Limestone; and absence of evidence of erosion or disconformity and presence of gradational contact where the two are in contact—is sufficiently positive to make any other interpretation untenable.

The contemporaneous deposition of the Trealla Limestone and the Pilgramunna Formation may be interpreted as being caused by a strong marine current which brought sand into the seaward edge of a dominantly lime-rich environment; this, in the still clear water inshore from the current, resulted in the deposition of the richly fossiliferous very-fine-grained crystalline Trealla Limestone. The strong current and the sand carried by it reduced the number of fossils deposited and broke up those which did reach the bottom. Fluctuations in the strength of the current affected the coarseness and amount of sand deposited so that the resulting deposit varies from friable fine quartz conglomerate to an almost sand-free limestone containing unbroken fossils.

The age of the Pilgramunna Formation is that of the Trealla Limestone, namely "f_1—f_2"-stage of the East Indies.

Vlaming Sandstone

The upper formation of the Yardie Group, the Vlaming Sandstone, consists of thin-bedded calcareous sandstone resting disconformably on the Pilgramunna Formation. It is bounded above by an erosion surface.

The Vlaming Sandstone crops out along the lower western flank of the Cape Range Structure from Vlaming Head Lighthouse to near the road between Ningaloo and Exmouth Gulf. The name is from Vlaming Head (Lat. 21° 48′ 15″ S., Long. 114° 06′ 24″ E.).

The type section of the formation is one mile south-south-east of Tulki Well at Lat. 22° 06′ S., Long. 113° 54′ E., (plate 12), where the sequence in descending order is:

90 feet sandstone, calcareous, bedded, reddish-brown, medium grained, with coarse sand grains (Vlaming Sandstone).

9 feet quartz conglomerate, hard, calcareous, fine-grained (top of Pilgramunna Formation).

The measured thickness of the Vlaming Sandstone ranges up to 240 feet, but as the thickness is limited by an erosion surface the variations are not indicative of the original thickness variations of the formation.

The Vlaming Sandstone has no fossils which give any precise age determination. *Amphistegina,* small rotalines, and molluscs *(Natica)*, are the only fossils seen. The presence of the land snail *Rhagada (Tunegada) convicta* Cox,* a form still extant, may indicate that the formation is younger than Pliocene. However, as it is reasonably certain, on structural grounds, that the Vlaming Sandstone is older than the Exmouth Sandstone, which has been referred, mainly on physiographical evidence,

*Determined by B. C. Cotton, South Australian Museum.

to the Pleistocene, for the present the Vlaming Sandstone is referred tentatively to the Pliocene.

On the geological plans, the top limestone bed of the Pilgramunna Formation has been used as the boundary between the upper and lower formations of the Yardie Group. This is not quite correct, as the boundary is actually a variable thickness above this member—up to about 20 feet at Yardie Creek.

QUATERNARY

Exmouth Sandstone

The Exmouth Sandstone is the brown calcareous quartz sandstone that overlies the Tertiary formations of the Cape Range with slight angular and marked erosional unconformity.

The name (first used by Craig in 1950 as Exmouth Formation) is taken from Exmouth Gulf, the large gulf to the east of the Cape Range peninsula.

The Exmouth Sandstone covers most of the synclinal area between the Cape Range and Rough Range Anticlines, and overlaps the flanks of these structures. The tentative type section is on the eastern slope of trig. hill 458′ at Lat. 22° 21′ S., Long. 114° 00′ E., and in the gully to the north-east of that hill.

The section of the Exmouth Sandstone in that locality is as follows, from top to bottom:

Top of outcrop at Trig. Hill 458′.

24 feet	medium-hard, light red-brown, cross-bedded calcareous medium-grained sandstone (CRC.23).
5 feet	hard, light grey, limestone with corals.
10 feet	friable, light red-brown, cross-bedded calcareous medium-grained quartz sandstone (Sample CRC.22).
1 foot	medium-hard, fine-grained to coarse-grained limestone conglomerate with light red-brown sandy matrix (Sample CRC.21).

Trealla Limestone.

40 feet Tentative type thickness of Exmouth Sandstone.

This section is regarded as a tentative type section, because much thicker sections are available, especially on the flanks of the Rough Range; but they have not been measured.

A bore put down by the Seismic Party of the Geophysical Section of the Bureau on the beach dune about 2 miles north of the runway intersection, Learmonth Airfield, passed through Exmouth Sandstone from 27 feet (about 15 feet below sea level) to the bottom of the bore at 480 feet. The lithology is dominantly brown calcareous sandstone with beds of limestone conglomerate (pebbles of Tulki Limestone) and shell fragments. This location is within the synclinal area of Exmouth Gulf and gives an indication of the maximum thickness of the Exmouth Sandstone.

Foraminifera from the Exmouth Sandstone, identified by Miss Crespin, include:

Amphistegina sp.
Anomalina glabrata Cushman.
Elphidium craticulatum (F. and M.).
Elphidium crispum (Linné).
Globigerinoides trilobus (d'Orb.).
Marginopora vertebralis (Blainville).
Peneroplis planatus (F. and M.).
Rotalia beccarii d'Orb.

These species are all found in the Recent shore sands along the west coast of Western Australia. The stratigraphical, structural, and physiographical position of the Exmouth Sandstone suggests that it is Pleistocene in age.

The Exmouth Sandstone is very permeable and somewhat soluble. Where it forms the surface it weathers into small loose rough blocks of hard calcareous sandstone. Sink-holes are common on its surface. This formation has weathered to give much of the fine red sand which has been blown into long dunes.

The Exmouth Sandstone unconformably overlaps the Trealla Limestone and the Yardie Group. It outcrops around the south-western, southern, and south-eastern margin of the Cape Range Structure and was involved in the later stages of the folding movement. It also outcrops on all sides of the Rough Range Structure and almost certainly covered the whole area of this structure before it was eroded from the crestal region. Along the coast, south of the Cape Range, this formation outcrops at least as far as Cape Cuvier but has not been seen on the east flank of the Giralia Anticline or on the Minilya Anticlines, east of the Salt Marsh. This indicates that the Pleistocene transgression in this area covered the strip west of a line from the head of Exmouth Gulf to the north end of the Salt Marsh.

The Exmouth Sandstone may be correlated with the Coastal Limestone of the west coast of Western Australia (Fairbridge, 1950), although it is probably entirely marine and not aeolian.

Bundera Calcarenite

The Bundera Calcarenite is the Recent thin-bedded calcarenite, which unconformably overlies the Tertiary rocks on the western coastal plain between the foothills of the Cape Range and the sea.

The name (pronounced Bun-deră) is taken from Bundera Well, which is 6½ miles south-south-west from the mouth of Yardie Creek, at Lat. 22° 25′ S., Long. 113° 46′ E.

The type section is exposed in the large sink-hole about one half mile west-north-west of Bundera Well. The section from top to bottom is as follows:

[5 feet light red-brown sand (not included in the formation).]

4 feet friable cream shelly limestone (coquinoid calcarenite) with molluscs, bryozoa, corals, and foraminifera.

2 feet firm to friable laminated calcarenite with some cross-bedding.

10 feet firm to friable white cross-bedded chalky calcarenite with many shell fragments.

Water level in sink-hole.

16 feet Type thickness (incomplete) of Bundera Calcarenite.

This section is incomplete at the bottom and the formation may include an appreciable thickness between this measured section and the surface of the Tertiary rocks.

The Bundera Calcarenite probably overlies the Tulki Limestone with a slight angular and a marked erosional unconformity. It outcrops between low-tide level on the shore and about 20 feet above that level. It is deposited on a wave-cut bench in the Tertiary rocks and is in places actively eroded by wave action. This formation, with a thin cover of wind-blown sand, forms the surface of the coastal plain on the west side of the peninsula. It is possible that the Bundera Calcarenite was deposited when the sea was at the level at which the "ten-foot bench" of the coast south of Geraldton was eroded; the difference in elevation, some ten feet, may be due to continuing fold movement in the Cape Range Structure.

The appearance of the fossils and field relations suggest that this formation is of Recent age. Near the mouth of Yardie Creek the formation includes reef corals probably of living species.

Mowbowra Conglomerate

The Mowbowra Conglomerate consists of the Recent limestone conglomerate and calcarenite which outcrop on the eastern coastal plain, between the Cape Range and Exmouth Gulf, in the vicinity of Mowbowra Well (Lat. 22° 00′ S., Long. 114° 07′ E.).

The type section of the formation is in the tidal creek (at Lat. 22° 01′ S., Long. 114° 07′ E.), 15 miles south of North-West Cape. At that place, the formation comprises, from top to bottom:

Top of outcrop.

20 feet medium-hard limestone conglomerate consisting of well-rounded pebbles, up to three inches in diameter, of Tertiary limestone in a matrix of friable light red-brown calcarenite. The conglomerate is in beds from one to five feet thick, with a few thin beds of current-bedded calcarenite. The conglomerate contains a few oysters.

5 feet friable light red-brown calcarenite with many colonial corals and some molluscs.

The base is not exposed.

25 feet Type thickness of Mowbowra Conglomerate.

The formation probably rests on a bench eroded in the Tertiary limestone. Its position relative to sea level is the same as that of the Bundera Calcarenite with which it is correlated. Its physiographical position and fossil content make it probable that the Mowbowra Conglomerate is Recent in age.

STRUCTURE

The Cape Range Structure is a closed anticline in Tertiary limestone. It is somewhat asymmetrical both across and along the structure, with a slightly steeper limb on the east side and a slightly steeper plunge to the north. Flank dips generally do not exceed five degrees on the west side and seven degrees on the east. Plunge to the north is up to three degrees but to the south is generally below one degree. In cross section, the fold has a relatively steep region near the middle part of the flanks, a broad flat crest, and probably very broad flat synclines, although these are not exposed. Along the crest there is a flattening (or slight reversal) east of the mouth of Yardie Creek. There are several minor depositional undulations on the flanks. No faulting has been seen on this structure.

The vertical closure is determined by the highest point of the "Dingo Syncline" between the Cape Range and Rough Range Structures. The difference in elevation of the top of the Tulki Limestone in the Dingo Syncline and at the apex of the Cape Range Structure is about 1000 feet. The Rough Range Structure has only a minor effect on the vertical closure of the Cape Range Structure because it is merely a small fold on the flank of the larger structure. Taking the two structures together, the structural feature determining closure is the reversal of plunge on the Cape Range axis to the south. The Cape Cuvier Anticline is on the same axial line as the Cape Range Structure, so the reversal of plunge is probably in the vicinity of Cardabia Homestead. The Centenary Bore 11 miles east-north-east of Cardabia Homestead went through "hard limestone"—probably Trealla Limestone—at a depth of 306 feet (200 feet below sea level). As the dips are very gentle in this region, the reversal would be at about this level so that the total vertical closure on the Cape Range Structure, on the top of the Tulki Limestone, is about 1200 feet.

The Exmouth Gulf is synclinal and indicates the limit of the drainage area to the east. On the ocean side, bathymetric data available indicate that there is probably no reversal of the westerly regional dip for at least 30 miles. The drainage area to the east of the axis is about 1200 square miles and that to the west is very much more. The area of closure on the top of the Tulki Limestone (including the Rough Range Structure) is 1230 square miles.

ORIGIN OF FOLDING

The dimensions and shape of the Cape Range Structure are such that an examination of the origin of the folding is warranted. In outcrop the Cape Range Structure is 66 miles long and 11 miles wide. In a cross section through the apex, the radius of curvature of the broad crestal part of the fold ($3\frac{1}{2}$ miles wide) is of the order of 70 miles. The east limb of the structure, from anticlinal to synclinal axis, is at least 10 and may be 20 miles wide. When folding took place there was no cover over the Tertiary limestone. No evidence of faulting in the Tertiary rocks of the Cape Range Structure has been found.

The Cape Range Anticline, which has limbs dipping at an average of about three degrees, obviously could not have been produced by lateral compression of the Tertiary strata. It may have been produced in one of the following ways:

(a) By differential compaction. The difference in compaction between a large bioherm and adjoining fine muds could produce such a compaction fold, although the dimensions of the Cape Range Structure make it unlikely. In the Giralia Anticline the exposed Cretaceous rocks do not include large bioherms. It is unlikely that a bioherm older than Cretaceous would have produced the differential compaction necessary to cause the folding of the Tertiary strata.

(b) By deposition over pre-existing hills. This type of depositional fold (Powers, 1922) is marked by noticeable thinning over the crestal region: no evidence of such thinning was found on the Cape Range Structure. In addition it is unlikely that a range of hills of the required height could have survived the peneplanation which, between the Permian and Cretaceous, planed down fault-blocks with a throw of 8000 feet.

(c) By vertical uplift produced by fold or fault movement in subjacent strata or by fault movement in basement rocks (Clark, 1932). In the outcropping Palaeozoic rocks at the eastern edge of the basin, folding, except that due to drag along faults, is rare. Evidence exists of high-angle thrust faults of large throw in the Palaeozoic and basement rocks in that area; and movement along these faults is known to have occurred in epi-Permian and late Tertiary times.

It is possible that the folds of the coastal region of the Carnarvon Basin were formed above upthrust wedges of Precambrian basement rocks in the case of symmetrical folds like the Cape Range Structure, and above single thrust faults in the case of asymmetrical folds like the Giralia Structure.

The absence of faulting and of steep dips on the Cape Range Structure indicates that the structure in the Palaeozoic rocks is more likely to be a fold structure than a fault structure.

Relation To Adjoining Structures

The Rough Range Structure is a relatively small symmetrical fold to the south-east of the Cape Range Structure: in depth this fold may be merely a terrace on the limb of the main Cape Range fold. Farther to the south-east, the large Giralia Structure is about the same length as the Cape Range Structure but is physiographically older and structurally higher. Erosion of the Tertiary Limestone from the crest of this structure has exposed Cretaceous limestone, siltstone, and radiolarite. To the south-south-west, the Cape Cuvier Anticline is in line with the Cape Range Structure. The Warroora Anticline is an asymmetrical anticline between the Cape Range—Cape Cuvier line and the Giralia Structure.

POSSIBILITY OF OIL ACCUMULATION

Source Beds

Palaeozoic marine limestones, crowded with fossils and interbedded with fossiliferous greywacke and siltstone, are exposed in the eastern part of the basin. The fossils indicate an environment favourable to marine organisms. The benthonic type of fossils indicates that the water was shallow, and the absence of current bedding in the clastic sediments indicates that deposition was sufficiently rapid to prevent the sorting and cleaning of the sediments by wave action. The rapid sedimentation would be favourable to the preservation of organic matter. The limestones are recrystallized by diagenetic processes and show no trace of organic residues except a foetid odour in parts of the Permian Callytharra Formation.

Several formations of Permian marine siltstone and shale containing rich faunas of both benthonic and pelagic forms are exposed in a large area between Mia Mia Station and Gascoyne Junction. They are generally carbonaceous and in a few places bituminous. Pyrite, which is regarded as indicating anaerobic, reducing, conditions of sedimentation and diagenesis—one of the probable requirements for the accumulation of petroleum—is a characteristic component of these fine-grained sediments, and gives rise to much secondary gypsum in the weathered surface-zone of these rocks.

Cretaceous radiolarite, bentonitic siltstone, and greensand contain a mainly pelagic fauna—radiolaria and foraminifera—and much pyrite.

Although the facies under the Cape Range is possibly different from that seen in outcrop, it is probable that the conditions favouring an abundant marine life and the preservation of organic matter would have extended at least as far as the Cape Range area, and that the equivalents there of the limestones and carbonaceous shales of the eastern part of the basin may be effective source beds of petroleum.

The primary evaporites which are exposed in the Permian on Wandagee Station may have some significance, as the occurrence of evaporites and oil in the same sequence is not uncommon, e.g. Permian of Texas, Permian of north-western Germany. It is not suggested that the evaporites are source beds: but they do occur in some oil-bearing sequences.

The Carnarvon Basin may be classed as an unstable shelf area of deposition. This is evidenced by and reflected in the lithology and stratigraphy. The clastic sediments include arkose, greywacke, and quartz sandstone, indicating rapid to very slow sedimentation related to the varying stability of the shelf. Formations may be traced over very large areas with only minor variations in lithology and thickness. Variations are more pronounced in the greywacke than in the quartz sandstone formations. The unstable shelf provided the varying environment in which were possible both the rapid sedimentation required for the preservation of organic matter (Illing, 1938) and the slow sedimentation necessary for the development of quartz sandstone reservoir beds.

Reservoir Beds

Because of the structural environment, potential reservoirs must be looked for among the permeable sediments: the amount of jointing is not likely to have produced important reservoirs in hard brittle impervious rocks such as the crystalline limestone of the Callytharra Formation or the Moogooree Limestone. The Mandu Calcarenite of the Cape Range and the Upper Cretaceous and Eocene clastic limestone of the Giralia Anticline are permeable enough for reservoir rocks but lack cap rocks.

Cretaceous sandstone resting on the eroded surface of the Permian is probably the main artesian aquifer in the northern part of the Carnarvon Basin. It is the reservoir bed in the Rough Range Structure. Artesian bores which have tapped this bed, e.g. Pelican Hill Bore, have produced very large flows of water (up to two million gallons per day) but no sign of petroleum. The large flow of water indicates high permeability, and a hydraulic pressure sufficient to bring the water to the surface. The two artesian bores on Cardabia Station (Raggatt, 1936, Plate 3, Bores No. 2 and 3) are well down on the west flank of the Giralia Anticline, in a structural position where petroleum would not occur in the presence of water. No. 2 Bore, Cardabia Station (Raggatt, 1936, Bore No. 4), is near the crest of the Giralia Anticline but in a structural saddle. Water was obtained in a sandstone possibly of Cretaceous age, but no sign of petroleum was reported. As this bore is at a position which structurally is only about 300 feet below the apex of the structure, it constitutes an important negative test of the Cretaceous radiolarite and sandstone and the Permian strata for perhaps 1000 feet below the Permian-Cretaceous unconformity.

Although many pervious sandstones, conglomerates, and greywackes outcrop in the Palaeozoic succession in the eastern part of the basin, it is possible that individual formations of this type would not continue out into the basin as far as the Cape Range. However, medium-grained to coarse-grained sandstone occurs in the Pelican Hill Bore, eight miles north of Carnarvon. Quartz sandstone formations such as the Devonian Munabia Sandstone, the Permian Wooramel Sandstone and the Permian Kennedy Group sandstone, deposited on a stable shelf, may extend as a thin sheet over very large areas. The area of the Wooramel Sandstone known from outcrop is about 3000 square miles, with very little variation in thickness or lithology. The main aquifer of the Great Artesian Basin of Australia, the Bundamba-Doologarah Sandstone, extends for at least 150 miles from its outcrop. It is therefore possible that these sandstones do extend under the Cape Range area, where they would constitute important and effective reservoir beds.

Cap Rock

The presence of artesian water at Cardabia Station assures that above that aquifer (probably the Cretaceous sandstone) the seal provided by the overlying rocks is sufficiently effective to prevent the escape of water under pressure. The Cretaceous radiolarite and bentonitic siltstone that form the cap rock for this aquifer are probably competent to retain any petroleum that may have accumulated in the underlying rocks. The complete absence of major faulting at the surface suggests that this seal has not been broken. Furthermore, the absence of oil or gas seepages may be a favourable rather than unfavourable indication—it may mean, as it does in many fields in U.S.A., England and elsewhere, that the seal is complete and tight, and that none of the accumulated oil is escaping. In many cases of overlap the basal members of the overlapping formation contain either oil or oil residues. No sign of such residues has been observed at the unconformity between the Permian and the Mesozoic, but, as the unconformity is exposed in few places, this could be due to the chances of observation. The presence of oil in the overlapping formation is dependent on seepage from the underlying rocks, and if the pools were not breached, by erosion or faulting, no seepage would occur.

Many of the formations that outcrop as siltstones at the eastern edge of the basin will probably be represented under the Cape Range by shales which could act as either source or cap rocks.

It is unlikely that any good cap rock occurs above the Lower Cretaceous bentonitic siltstone, so that, although some of the Upper Cretaceous and Tertiary formations could have been source and reservoir rocks, the absence of a cap rock precludes the possibility of production from this part of the sequence.

STRUCTURE

The Cape Range Structure is a very large anticline with a vertical closure of 1200 feet, a closed area of 1230 square miles, and a drainage area of at least 2400 square miles and probably very much more than that. This indicates that the structural conditions for retaining oil are almost perfect. It is expected that the Cape Range fold (in Tertiary limestone) will be continued in the underlying Cretaceous, and in the Palaeozoic rocks below them the fold may be more pronounced because of pre-Cretaceous folding. It is to be noted, however, that a regional convergence of three degrees in an easterly or westerly direction would eliminate the closure on this structure, and as the convergence in the Tulki Limestone is of the order of 14 minutes to the east, it is quite possible that closure may be eliminated at no great depth.

The structure in the Palaeozoic sediments beneath the Cape Range, on the other hand, may be a fault horst and much less favourable for oil accumulation. The cross-sectional shape of the fold in the Tertiary limestone, however, is such that the radius of curvature of the anticlinal bends on the flanks is of the order of 20,000 feet. If the fold is caused by the vertical movement of a fault wedge of the basement, this radius may approximate to the depth at which the faults originating in the basement pass upwards into folds in the sediments.

Closure in the Palaeozoic depends on the regional dip under the Cape Range. If the Palaeozoic strata are sub-horizontal the structure in the Palaeozoic would be similar to that in the Tertiary limestones. If the regional dip is to the west, the anticline in the Palaeozoic strata will be under the east flank, at about the edge of outcrop. If the regional dip is to the east, the anticline in the Palaeozoic strata will be under the west flank, at about the edge of outcrop. Seismic evidence on the Giralia Anticline (Vale, 1951) and a reconnaissance gravity survey (Thyer, 1951) indicate that the regional dip in the Palaeozoic under the Cape Range may be to the east.

IGNEOUS ACTIVITY

The only evidence of igneous activity in this region so far discovered is the formation of bentonitic siltstone in the Cretaceous rocks of the Giralia Anticline. This material may derive from volcanic ash erupted from distant volcanoes. There is no evidence of volcanic activity within the Carnarvon Basin, nor is there any indication of intrusive igneous activity which could have metamorphosed the sediments and destroyed any accumulated oil.

POSITION IN THE BASIN

The apex of the Cape Range Structure is situated about 60 miles west of the eastern edge of the outcrop of Palaeozoic sedimentary rocks. The original edge of the basin was much farther east—as indicated by the

Devonian sediments in a fault block some six miles east of the main eastern edge of outcrop of the Palaeozoic sediments. It is probable that the Mesozoic and Tertiary sediments were deposited on the continental shelf at the edge of the stable Western Australian Precambrian shield. The exposed Palaeozoic rocks were deposited on a sinking continental shelf that bore information indicates to have probably extended at least as far westward as Cardabia Station and Carnarvon.

THICKNESS OF SEDIMENTS

Most of the possibilities of oil accumulation are based on the assumption that the Palaeozoic sediments exposed in the eastern part of the basin extend, with only minor changes in thickness and lithology, under the Cape Range. This assumption is founded on the following stratigraphical and structural evidence.

Both Palaeozoic and post-Jurassic formations increase in thickness in a north-westerly direction. The thickest outcrop of the Permian formations is exposed along the Lyndon River at the northern and western limit of outcrop; and bore logs indicate a thickening of Cretaceous and Tertiary sediments in the north-westerly direction. The Lyndon River outcrop is 100 miles south-east of the apex of the Cape Range Structure, and the nearest bore penetrating the Cretaceous sediments is the Centenary Bore, 60 miles south of the apex. It is most probable that the Cretaceous-Tertiary sediments continue to thicken between this bore and the apex, because the exposed part of the Tertiary sediments is much thicker in the Cape Range Structure than elsewhere to the south and east.

In the Pelican Hill Bore, Carnarvon, a thickness of 1605 feet of Devonian sediments was penetrated. This includes a sandstone formation, possibly the equivalent of the Nannyarra Greywacke, and an overlying formation of shale and limestone which is the equivalent of the Gneudna Formation and contains the same *Cyrtospirifer* (Thomas and Dickins, 1954). The sandstone formation, deposited on a stable shelf in shallow water, indicates that the shelf environment of deposition extended at least as far west as Carnarvon: this eliminates the possibility that the fault zone at the western edge of outcrop of Permian sediments was located at the western edge of the Permian shelf area. No. 1 Deep Bore, Cardabia Station (on the east flank of the Giralia Anticline, 80 miles south-south-east of the Cape Range apex and 30 miles west-north-west of the western edge of outcrop of Permian sediments), penetrated a thickness of 3200 feet of Permian shale and sandstone (Goldfields Diamond Drilling Company's Driller's Log).

All the available stratigraphical evidence indicates the extension of the Permian sediments from their outcrop to the Cape Range area with probably an increase in thickness and no change in lithology.

Little can be deduced about the extension of the Devonian and Carboniferous sediments. The lithology of the Munabia Sandstone and of the Moogooree Limestone indicates that they were deposited on a stable shelf. It is possible that that shelf had an extent similar to the Permian shelf, in which case the Devonian and Carboniferous sediments may extend under the Cape Range area.

In each flank of the Cape Range Anticline the region of steeper dips forms an anticlinal bend the radius of curvature of which is about 20,000 feet. The radius of curvature of the crestal arch, between these anticlinal bends, is of the order of 70 miles.

Assuming (see p. 38) that the stress producing the fold in the sediments was mainly vertical, the folding would be of the concentric type, and the centre of curvature of the fold would indicate the depth at which folding originated. Below this depth the differential movement would take place along a fault. It is probable that folded sediments extend at least to this depth (20,000 feet below the top of the Tulki Limestone) and sediments may continue below this depth.

If the total thickness of sediments is more than 20,000 feet, it is probable that the Devonian and Carboniferous Systems would be included, because the maximum known thickness of the Permian, Cretaceous, and Tertiary Systems combined is about 14,000 feet, and thickening of the Permian System between the Lyndon River and the Cape Range is not likely to account for the whole of the difference.

Reconnaissance gravity surveys done in 1950 showed a high positive gravity anomaly—of the order of 40 milligals—in the Cape Range area (Thyer, 1951). This could be taken to indicate that the sediments under the Cape Range are very thin. The stratigraphical and especially the structural evidence indicate that the high positive gravity anomaly may require some other explanation.

Seismic investigations were started in April 1951, but reliable reflections were not obtained. A seismic survey of Rough Range Anticline was carried out by Seismograph Services Ltd. for West Australian Pty. Ltd. in 1953, but results are not available.

LOCATION OF TEST BORE

Because of the gentle dips and large size of this structure, the location of a test bore to test the Tertiary and Mesozoic strata does not require such close control as is required in a steeply-dipping structure. The indication from the surface structure is that the sites may be anywhere within the zero contour (Plate 17), although early test bores should probably be placed near the apex, rather than far from it.

Location of a test bore should await geophysical survey, for the following reasons:

(i) There may be a displacement of the crest at depth within the Mesozoic-Tertiary strata: the slight asymmetry of the surface structure may be increased with a consequent shift of the crest to the west; convergence would cause a shift of the crest in the direction of convergence.

(ii) The anticlinal axis in the Palaeozoic is likely to be under the western anticlinal bend (near the western edge of outcrop of Tertiary limestone). Seismic survey will be required to confirm this and to determine closure.

(iii) The total thickness of sediments may be determined by seismic survey and, as oil may have accumulated at any part of the section, the drill used should be capable of exploring the full sedimentary sequence or as much of it as possible. A larger rig may make the difference between a complete test and an unfinished and therefore unsatisfactory one. The geophysical estimate of the total thickness of sediments will be a check on the presence of Palaeozoic sediments under the structure.

CONCLUSIONS

It is considered that adequate testing of the Cape Range Structure for petroleum is justified for the following reasons:

(i) The surface structure, a very large simple anticline, is one of the largest in the world. The surface structure probably continues through the Tertiary and Mesozoic strata.

(ii) Palaeozoic sediments similar to those outcropping in the eastern part of the basin, and including typical source, reservoir, and cap rocks, probably extend under the Tertiary sediments of the Cape Range.

(iii) The folding has probably been produced by vertical uplift—by the upthrusting of a fault wedge of the Pre-Cambrian basement—and therefore the folding in the Palaeozoic rocks is likely to be more pronounced than at the surface.

The Cape Range Structure has greater vertical closure, closed area and area of drainage than the Giralia Structure. The Palaeozoic sediments are probably faulted under the Giralia but not under the Cape Range. About 1000 feet of extra depth, which is unlikely to be productive, would have to be drilled on the Cape Range, as compared with the Giralia. A larger part of the stratigraphical column could be tested on the Giralia as the formations are probably thinner there than on the Cape Range Structure. Geologically the Cape Range Structure is preferable for a first deep test bore, but the practical difficulties connected with that location may make the Giralia Structure a more desirable area for the first deep test; field work on this structure has been completed and plans and a report on it are published (Condon, Johnstone, Pritchard, and Johnstone, 1955).

No production of oil is likely above the base of the Tertiary sediments, because of the lack of cap rocks, but oil accumulations are possible in the Boongerooda Greensand at the base of the Tertiary, at a depth of about 1500 feet from the top of the Tulki Limestone; in the Birdrong Formation at the base of the Cretaceous at about 4000 feet; in Permian sandstone; in Devonian sandstone; and in Devonian greywacke on basement. As the Palaeozoic sediments were probably folded in the epi-Permian tectonic movements and eroded to near peneplanation in the Permian-Jurassic interval, it is probable that the upper part of the Permian is missing.

Seismic investigation should precede drilling in order to estimate total thickness of sediments, to check the position of the apex in the Palaeozoic sediments, and to determine the nature of the folding in the Palaeozoic sediments.

If possible a rig capable of exploring the full thicknesses of sediments should be used and located above the apex in the Palaeozoic sediments. If drilling starts before a seismic survey is done, the bore should be located near the apex of the structure and should be capable of drilling to at least 10,000 feet, and preferably to 15,000 feet.

Should an oil accumulation be found on this structure, the other structures along the coastal strip—the Giralia, Rough Range, Warroora, Yankie Tank, Chargoo and Minilya Anticlines—should also be drilled.

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THE CAPE RANGE STRUCTURE, WESTERN AUSTRALIA

Part II
MICROPALAEONTOLOGY

By Irene Crespin

SUMMARY

Eight post-Mesozoic Formations have been recognized by geologists in the Cape Range area, namely the Mandu Calcarenite, Tulki Limestone, Trealla Limestone, Pilgramunna Formation, Vlaming Sandstone, Exmouth Sandstone, Bundera Calcarenite, and Mowbowra Conglomerate. Foraminifera have been recognized in all sediments except those of the Mowbowra Conglomerate.

The larger foraminifera in the assemblages from the Mandu Calcarenite, Tulki Limestone, and Trealla Limestone are characteristic of assemblages elsewhere in the Indo-Pacific region. Comparisons have been made with these, and the age of the Formations is based on this evidence. The "letter" classification used in Tertiary Indo-Pacific stratigraphy is applied to the Mandu Calcarenite, Tulki Limestone, Trealla Limestone, and Yardie Group, the Mandu Calcarenite being referred to "e" stage and the Tulki and Trealla Limestone and the Pilgramunna Formation to "f_1" stage.

The species of smaller foraminifera present have been previously described from Miocene deposits in Java, Sumatra, and south-eastern Australia. The species recognized in the beds of the Vlaming Sandstone, Exmouth Sandstone, and Bundera Calcarenite are all Recent forms. Stratigraphical positions of these Formations suggest that the Vlaming Sandstone is probably Pliocene, the Exmouth Sandstone Pleistocene, and the Bundera Calcarenite and Mowbowra Conglomerate Recent.

INTRODUCTION

The presence of foraminiferal limestones of Tertiary age in the Cape Range has been known since 1924, when F. G. Clapp (1925) discovered them at a locality "south of North West Cape, 25 miles N.W. of Exmouth Gulf Station Homestead, in a deep gorge". This locality is now known to be in Badjirrajirra Creek. F. Chapman (1927) described the foraminiferal content of these limestones and gave the age as Oligocene.

Since that date many geologists, carrying out investigations on behalf of companies in the search for oil, have made collections of foraminifera-bearing rocks from Badjirrajirra Creek and other localities in Cape Range. Few of these collections were made systematically, but all were

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submitted to the late F. Chapman or to the writer for micropalaeontological examination.

The writer, in two recent publications (Crespin, 1948, 1950*b*), showed the possible correlation of the Tertiary rocks in the Carnarvon Basin with others elsewhere in the Indo-Pacific region. The stratigraphical sequence worked out from observations of the occurrence of larger foraminifera in these early collections has been proved substantially correct by detailed investigations in the Cape Range by geologists of the Bureau of Mineral Resources, Geology and Geophysics during 1949. In these recent surveys, collections have been made from stratigraphical sections which can now be regarded as types for the area; and any further work will be made comparatively simple by the results obtained from this micropalaeontological examination, which are set out in this Bulletin.

Twelve foraminiferal assemblages have been recognized; and it is now possible to correlate samples from many of the localities from which the early collections were made with those collected during 1949 and 1950.

A complete list of foraminifera, with their distribution in five of the formations recognized by the geologists, is given in pages 75 to 80.

HISTORICAL REVIEW OF PREVIOUS COLLECTIONS

Several collections have been made by geologists, and all have been examined for microfaunas by the writer or the late F. Chapman.

(a) F. G. Clapp, 1924

Clapp collected material from what is now known as the Mandu Calcarenite at Badjirrajirra Creek, four miles upstream from its mouth.

Chapman's tentative age determination as Oligocene cannot be revised on this collection because there appears to be no record of the whereabouts of his foraminiferal slides. (Clapp, 1925.)

(b) E. A. Rudd and D. Dale Condit, 1934

Rudd and Condit collected fossiliferous limestones on behalf of Oil Search Ltd. Both Mandu and Tulki Limestones are represented in the collection, mostly taken from Badjirrajirra Creek. (Condit, Raggatt, and Rudd, 1936.)

(c) H. G. Raggatt, 1935

Among the rocks collected by Raggatt in the Carnarvon Basin, on behalf of Oil Search Ltd., were two specimens from Yardie Creek and one from Dingo Well, Exmouth Gulf Station. All were of Trealla Limestone. (Raggatt, 1936; Condit, Raggatt, and Rudd, 1936.)

(d) E. A. Rudd, 1936

Rudd made a further, systematic, collection in 1936 (for Oil Search Ltd.), and suggested a stratigraphical classification for the rocks. His work was unpublished, but the collection has been re-examined and referred to by the writer in recent papers. (Crespin, 1948, 1950, 1950*a*.)

(e) Caltex (Australia) Ltd., 1941

A small collection was made by W. H. Maddox and H. G. Higgins on behalf of Caltex (Australia) Oil Development Pty. Ltd.; it proved to consist of specimens of Tulki and Trealla Limestones.

(f) E. K. Craig, 1948

Craig collected a few specimens on behalf of Australian Motorists Petrol Co. Ltd. They included rocks from the Tulki and Trealla Limestones.

(g) Bureau of Mineral Resources Collections, 1949-50

In 1949 N. H. Fisher collected a series of specimens in stratigraphical sequence from Mt. Lefroy, which included the first specimen of the reddish sandy limestone that marks the break between the Tulki and the Trealla Limestone. Also in 1949, M. A. Condon, D. Johnstone, and W. J. Perry, of the Bureau of Mineral Resources, and J. Sofoulis of the Geological Survey of Western Australia, made collections in the course of the field-work described in Part I of this Bulletin, and these were supplemented in 1950 by I. Crespin and H. S. Edgell.

These collections are the main. sources for the descriptions which follow.

MICROFAUNAS OF THE TYPE SECTIONS FOR THE FORMATIONS

The stratigraphical sequence of the Tertiary rocks in the Cape Range area recently suggested by the writer (Crespin, 1948, 1950), which was based on micropalaeontological evidence, especially on the larger foraminifera in the rock samples from isolated localities, has been confirmed by recent detailed field investigations. These investigations have proved the existence of eight mappable units which are listed below in descending stratigraphical sequence:

Bundera Calcarenite and Mowbowra Conglomerate.

Exmouth Sandstone.

Vlaming Sandstone.

Trealla Limestone, and Pilgramunna Formation.

Tulki Limestone.

Mandu Calcarenite.

Foraminifera have been found in rocks of all formations present in the Cape Range except the Mowbowra Conglomerate. The restricted vertical range of certain species of the larger foraminifera and the incoming and outgoing of certain smaller species permit the age of the rocks to be traced upwards from "e" stage of Indo-Pacific Tertiary stratigraphy to Recent. The foraminiferal assemblages found in the rocks of each formations are discussed in detail in this section, but a complete list of foraminifera in all samples examined is given in pages 67 to 73.

MANDU CALCARENITE

The type locality for the Mandu Calcarenite (see Part I, page 21) is in Badjirrajirra Creek, on the eastern side of Cape Range, at Lat. 22° 06′ S., Long. 114° 02′ E., between 3 and 5 miles from the mouth of the creek, and 20.5 miles south of Vlaming Head Lighthouse. The rock samples collected by Johnstone, Perry, and Sofoulis, with a supplementary collection made by Johnstone, Edgell, and the writer from the section, are regarded as types for the formation and include CRC.11, CR.112, CR.111, CRC.9, CR.110, CR.109, CR.108, CR.107, CR.106, CR.123, in descending stratigraphical order.

Two hundred and sixty-five feet of white to cream chalky limestones of the Mandu Calcarenite were measured by Johnstone and Perry underlying the Tulki Limestone. They contain large and small foraminifera, cidaroid fragments, mollusca, ostracoda, and a shark's tooth. Except for the shark's tooth, which was found in sample CR.111, 95 feet below the top of the formation, the megafossils occur only near the base.

The writer found that it was possible to zone the formation in the field by means of the foraminifera. The zoning shown in Table 4 is the result of these observations.

TABLE 4.

SECTION OF MANDU LIMESTONE
Base of Tulki Limestone
19 feet of white chalky limestone, with small foraminifera.
75 feet of *Lepidocyclina* limestone in which megalospheric and microspheric tests of *Lepidocyclina (Eulepidina) manduensis* are very common, average diameter of microspheric form being 20 mm.; *Cycloclypeus* and smaller species also present.
2 feet of *Lepidocyclina* coquinite consisting almost entirely of horizontally bedded tests of *Lepidocyclina (Eulepidina) badjirraensis*, some microspheric tests measuring up to 65 mm. in diameter; also *Cycloclypeus eidae* and small species.
30 feet of cream chalky limestone with abundant *Cycloclypeus (C. eidae* and *C. posteidae)*, and microspheric and megalospheric tests of *Operculina victoriensis* and some small species.
139 feet of white chalky limestone containing chert nodules and abundant small foraminifera with a few tests of *Cycloclypeus*.
Bottom of Section.

The downward stratigraphical sequence of samples in the type section of the Mandu Calcarenite as collected by Johnstone and Perry and supplemented by the writer is given below, together with the foraminiferal content of each sample.

Type Section—Badjirrajirra Creek on east fall of Cape Range about 11 miles north of Learmonth

CRC.11. (17 feet below top of Mandu Calcarenite);
Moderately hard cream calcarenite with numerous *Cycloclypeus*, *Lepidocyclina*, and small foraminifera.

Amphistegina lessonii
Anomalina subnonionoides
Anomalina sp.
Anomalinella rostrata var. nov.
Cibicides foxi
Cibicides sp.
Cycloclypeus posteidae
Lepidocyclina (Eulepidina) manduensis
Lepidocyclina (Nephrolepidina) sp.
Operculina victoriensis (form B)
Osangularia bengalensis.

CR.112. (24 feet below top of formation):
White calcarenite with *Cycloclypeus* and *Lepidocyclina* and numerous small foraminifera.

Amphistegina lessonii
Amphistegina radiata
Anomalina glabrata
Anomalina subnonionoides
Anomalina sp.
Anomalinella rostrata var. nov.
Bolivina fastigia
Cassidulina sp.
Cibicides victoriensis
Cibicides sp.
Cycloclypeus posteidae
Discorbis turbo
Gypsina howchini
Lepidocyclina (Eulepidina) badjirraensis
Lepidocyclina (Eulepidina) manduensis
Operculina victoriensis.

CR.111. (97 feet below top of formation):
Cream coquinite composed almost entirely of bedded megalospheric and microspheric tests of *Lepidocyclina (Eulepidina) badjirraensis* with numerous small foraminifera in the chalky material.

Alabamina sp.
Amphistegina lessonii
Anomalina glabrata
Anomalina subnonionoides
Anomalinella rostrata var. nov.
Bolivina fastigia
Cassidulina subglobosa
Cibicides foxi
Cibicides lobatulus
Cibicides victoriensis
Cibicides spp.
Cycloclypeus posteidae (forms A and B)
Discorbis patelliformis
Gaudryina (Pseudogaudryina) crespinae
Globigerina baroemoenensis
Globigerinoides trilobus
Globigerinoides trilocularis
Lepidocyclina (Eulepidina) badjirraensis (forms A and B)
Lepidocyclina (Nephrolepidina) sp.
Operculina victoriensis (forms A and B)
Osangularia bengalensis
Robulus cf. *inornatus*
Robulus nigriseptus
Robulus pseudolimbosus
Siphonodosaria scalaris.

CRC.9. (99 feet below top of formation):

Cream chalky coquinite composed almost entirely of bedded megalospheric and microspheric tests of *Lepidocyclina (Eulepidina) badjirraensis*, one microspheric test measuring 65 mm. in diameter; also abundant small foraminifera in chalky material.

Alabamina sp. nov.
Amphistegina lessonii
Amphistegina radiata
Anomalina ammonoides
Anomalina glabrata
Anomalina subnonionoides
Anomalinella rostrata var. nov.
Anomalina sp.
Bolivina fastigia
Bolivina cf. *victoriana*
Carpenteria proteiformis
Cassidulina subglobosa
Cibicides doropustulosus
Cibicides foxi
Cibicides victoriensis
Cibicides spp.
Clavulinoides szaboi var. *victoriensis*
Cycloclypeus eidae
Cycloclypeus posteidae
Discorbis patellifromis
Eponides repandus
Gaudryina (Pseudogaudryina) crespinae
Globigerinoides trilocularis
Globulina gibba
Lepidocyclina (Eulepidina) badjirraensis (forms A and B)
Lepidocyclina (Nephrolepidina) parva
Loxostomum hentyanum
Nodosaria raphanus
Operculina victoriensis (forms A and B)
Osangularia bengalensis
Planulina cf. *ariminensis*
Reussella spinulosa
Robulus nikobarensis
Robulus pseudolimbosus
Trifarina bradyi
Vaginulinopsis infrapapillata.

CR.110. (103 feet below top of formation):

Friable to hard cream calcarenite with small foraminifera.

Alabamina cf. *hardyi*
Angulogerina australe
Anomalina subnonionoides
Anomalina sp. nov.
Anomalinella rostrata var. nov.
Cibicides sp.
Dyocibicides biserialis
Frondicularia sp. nov.
Globigerina tripartita
Globigerinoides trilobus
Globigerinoides trilocularis
Gypsina globulus
Lagena cf. *acuticosta*
Loxostomum hentyanum
Reussella spinulosa
Robulus cf. *inornatus*
Sphaeroidina bulloides
Spiroplectammina sp.
Virgulina schreibersiana.

CR.109. (132 feet below top of formation):

Friable to moderately hard calcarenite with *Cycloclypeus* and *Operculina* and many small foraminifera.

Anomalina ammonoides
Anomalina subnonionoides
Anomalinella rostrata var. nov.
Cibicides victoriensis
Cibicides sp.
Cycloclypeus posteidae

Gaudryina (Pseudogaudryina) crespinae
Globigerinoides trilocularis
Loxostomum hentyanum
Operculina victoriensis (forms A and and B)
Osangularia bengalensis.

CR.108. (210 feet below top of formation):
Friable to moderately hard cream calcarenite with small foraminifera.

Amphistegina lessonii
Anomalina spp.
Anomalinella rostrata var. nov.
Cassidulina margaritea
Cibicides lobatulus
Cibicides cf. *foxi*
Globigerina bulloides
Globigerinoides trilocularis
Gyroidina soldanii var. *altiformis*
Osangularia cf. *bengalensis*
Sphaeroidina bulloides.

CR.107. (223 feet below top of formation):
Friable cream calcarenite with small foraminifera.

Anomalina glabrata
Anomalinella rostrata var. nov.
Bolivina fastigia
Bolivina cf. *hebes* var. *victoriensis*
Bolivina spp.
Buliminella elegantissima
Cibicides lobatulus
Cassidulina sp.
Cibicides victoriensis
Cibicides spp.
Cycloclypeus eidae
Gyroidina soldanii
Gyroidina soldanii var. *altiformis*
Heronallenia sp. nov.
Loxostomum hentyanum
Operculina victoriensis
Parrella bengalensis.

CR.106. (257 feet below top of formation):
Friable buff calcarenite with numerous tests of large and small foraminifera, *Cycloclypeus* and *Operculina* being very common.

Alabamina sp. nov.
Angulogerina sp. nov.
Anomalina ammonoides
Anomalina glabrata
Anomalina subnonionoides
Bolivina acerosa
Bolivina fastigia
Bolivina girardensis
Bolivina spp.
Bolivinita quadrilatera
Cancris saga var. *communis*
Carpenteria rotaliformis
Cassidulina margaritea
Cibicides lobatulus
Cibicides soendaensis
Cibicides cf. *ungerianus*
Cibicides victoriensis
Clavulinoides szaboi var. *victoriensis*
Cycloclypeus eidae (forms and B)
Dentalina soluta
Discorbis bertheloti var. *papillata*
Discorbis turbo
Elphidium sp.
Eponides sp.
Frondicularia sp. nov.
Glandulina sp.
Globigerina bulloides
Globigerinoides sacculiferus var. *irregularis*
Globigerinoides trilocularis
Globorotalites sp. nov.
Gypsina globulus

Gyroidina soldanii
Haplophragmoides sp.
Lagena laevis
Lepidocyclina (Nephrolepidina) borneënsis
Loxostomum hentyanum
Marginulina cf. *glabra*
Nonionella sp.
Operculina victoriensis (forms A and B)
Pullenia cf. *quinqueloba*
Reussella ensiformis
Reussella spinulosa
Robulus cf. inornatus
Robulus cf. politus
Spiroplectammina arenacea
Sphaeroidinella multiloba
Textularia cf. *semilata*
Uvigerina cf. *peregrina*
Vaginulinopsis subaculeata var. *glabrata.*

CR.123. (Base of section, in stream bed, 265 feet below top of formation): White calcarenite with numerous small foraminifera, cidaroid plates, mollusca, ostracoda, and chela of crab.

Angulogerina australe
Anomalina glabrata
Anomalina sp.
Anomalinella rostrata var. nov.
Bolivina cf. *arta*
Bolivina fastigia
Bolivina hebes
Bolivina spp. nov.
Bolivina spp.
Cassidulina laevigata
Cibicides dorsopustulosus
Cibicides lobatulus
Cibicides soendaensis
Cibicides telisaensis
Cibicides cf. *ungerianus*
Cibicides sp. cf. *discus*
Cibicides spp.
Clavulinoides szaboi var. *victoriensis*
Discorbis patelliformis
Elphidium sp.
Globigerinoides trilocularis
Globoratalites sp.
Gyroidina soldanii
Loxostomum hentyanum
Osangularia cf. *bengalensis*
Reussella ensiformis
Reussella cf. *spinulosa*
Robulus cf. inornatus.

A further thickness of approximately 150 feet of the Mandu Calcarenite was indicated by a hole put down for geophysical information by a seismic party in the bed of a gully immediately north of Badjirrajirra Creek. About 10 feet of Mandu Calcarenite is exposed at the base of the cliff in this gully and the bed containing abundant tests of *L. (E.) badjirraensis* in Badjirrajirra Creek can be recognized. A sample of cream limestone was taken from the hole at the depth of 390 feet (about 485 feet below the top of the Mandu Calcarenite) and the following foraminifera were determined:

Amphistegina lessonii
Anomalina ammonoides
Anomalina subnonionoides
Anomalina rostrata var. nov.
Bolivina cf. *antiqua*
Bolivina scalprata var. retiformis
Bulimina ovata
Buliminella madagascarensis var. *spicata*
Carpenteria proteiformis
Cassidulina margaritea
Chilostoma ovoidea

Cibicides cf. *telisaensis*	*Loxostomum hentyanum*
Cibicides victoriensis	*Nodosaria longiscata*
Clavulinoides szaboi var. *victoriensis*	*Nonion* cf. *grateloupii*
Cycloclypeus eidae	*Operculina victoriensis*
Discorbis bertheloti var. *papillata*	*Osangularia bengalensis*
Dyocibicides biserialis	*Reussella decorata*
Eponides repandus	*Reussella ensiformis*
Globigerina bulloides	*Reussella spinulosa*
Globigerina dubia	*Robulus nigriseptus*
Globigerina baroemoenensis	*Robulus submammilligerus*
Globigerinoides trilobus	*Siphonina* sp. nov.
Gypsina globulus	*Sphaeroidina bulloides*
Gyroidina soldanii	*Spiroplectammina arenacea*
Lagena marginata	*Uvigerina sparsicostata*
Lepidocyclina (Eulepidina) badjirraensis	*Vaginulinopsis gemmata.*

Three outstanding features of the microfaunal assemblage in Mandu Calcarenite are:

(1) The bed two feet thick (from 97 feet to 99 feet below the top of the type section), which is crowded with flatly-lying tests of the large form *Lepidocyclina (Eulepidina) badjirraensis* Crespin.

(2) The abundance of the smaller species *Lepidocyclina (Eulepidina) manduensis* Crespin in the chalky limestones above the bed referred to in No. 1 (this form persists almost to the top of the formation).

(3) The abundance of small species of foraminifera in the chalky limestones throughout the formation.

(1) The most striking feature in the calcarenite is the coquinite bed two feet thick crowded with megalospheric and microspheric tests of *L. (E.) badjirraensis* which give the coquinite a bedded appearance. One of the microspheric tests has a diameter of 65 mm. This species has always been referred to as L. *(E.) dilatata* Michelotti, but the wafer-like thinness of the tests, the unusually large nucleoconch, and the thickness of the walls of the chambers which, in vertical section, give the internal structure a stratified appearance, clearly distinguish it from that form and have led the writer to describe it as a new species (Crespin, 1952). Samples from this bed have been collected by most geologists who have visited Badjirrajirra Creek.

(2) In the calcarenite overlying those containing the large Eulepidine *L. (E.) badjirraensis* are numerous tests of a smaller species *L. (E.) manduensis* (Crespin, 1952). This form has the same stratified structure and the wafer-like thinness of the test as in *L. (E.) badjirraensis*

but the nucleoconch is smaller and the largest microspheric tests are only 25 mm., which is equivalent to the diameter of the megalospheric test of *L. (E.) badjirraensis.*

(3) Small foraminifera are very common in the calcarenite, but at times are difficult to determine specifically because of the encrusted condition of the tests. However, many species have been determined, and the largest number recognized in any one sample was sixty-one in a sample collected by Rudd and Condit. Most of the smaller species have been described from the Miocene deposits of the Indo-Pacific region and of south-eastern Australia. It will be shown later that many of them range upwards into the overlying Tulki Limestone and even into the Trealla Limestone and consequently are of little value as zonal forms.

Amongst the smaller foraminifera described from the Indo-Pacific region are *Cibicides delicatulus* Le Roy, *C. dorsopustulosus* Le Roy, *C. soendaensis* Le Roy, *C. telisaensis* Le Roy, *Globigerina tripartita* Koch, *Robulus nikobarensis* (Schwager), *Robulus nigriseptus* (Koch), *Osangularia bengalensis* (Schwager), and *Spiroplectammina arenacea* Le Roy. South-eastern Australian species include *Loxostomum hentyanum* (Chapman), *Angulogerina australe* (Heron-Allen and Earland), *Bolivina hebes* Macfadyen var. *victoriensis* Cushman, *Carpenteria rotaliformis* Chapman and Crespin, *Cibicides victoriensis* Chapman, Parr and Collins, *Clavulinoides szaboi* (Hantken) var. *victoriensis* Cushman, *Listerella victoriensis* Cushman, and *Tubulogenerina mooraboolensis* (Cushman).

Associated with the smaller foraminifera are larger forms such as *Cycloclypeus* and *Operculina,* and small species of *Lepidocyclina. Cycloclypeus* is represented by *C. eidae* Tan, *C. posteidae* Tan, and *C. indopacificus* Tan. The microspheric form of *C. indopacificus* is common in a sample from the west fall of Cape Range, some of the tests having a diameter of 25mm. Small species of *Lepidocyclina* include *L. (N.) borneënsis* Provale, *L. (N.) parva* Oppenorth, and *L. (T.) gippslandica* Crespin.

Operculina is very common in certain beds, especially below those containing *L. (E.) badjirraensis.* It is represented by both the megalospheric and microspheric generations of *O. victoriensis* Chapman and Parr.

TULKI LIMESTONE

The type section for the Tulki Limestone is at Lat. 22° 06′ S., Long. 114° 03′ E., 4 miles N. 76° W. from mouth of Badjirrajirra Creek, and is represented by samples (arranged in descending stratigraphical sequence) CRC.8, CR.7, CRC.7, CR.6, CRC.6, CRC.5, CRC.4, and CRC.3, collected by Crespin, Johnstone, and Perry. Only 210 feet of Tulki Limestone are represented at the type locality, but the contacts at the base of the section with the Mandu Limestone and at the top of the section with the Trealla Limestone are clearly marked.

The Tulki Limestone consists of hard cream crystalline concretionary foraminiferal limestone at the base of the section, passing upwards into pink to reddish ferruginous limestone towards the top. This pink limestone is one of the most distinctive beds within the formation on the eastern side of Cape Range. The most prominent mega-fossil is *Conoclypus westralensis* Crespin, which is apparently restricted to this formation in the Carnarvon Basin. Another striking rock type in exposures of the formation other than at the type locality is a hard recrystallized limestone in which the internal structures of the foraminifera and other fossils have been almost completely dissolved out, leaving only the external shell.

The foraminiferal content of the samples from the type section for the Tulki Limestone is given below, the specimens being arranged in descending stratigraphical sequence.

Type Section—4 miles N. 76° W. from mouth of Badjirrajirra Creek

CRC.8. (352 feet above stream bed and 187 feet above base of formation):

Pink to cream crystalline limestone with foraminifera and echinoid spines; the majority of the foraminiferal tests being too altered for determination.

Cycloclypeus indopacificus
Lepidocyclina (Nephrolepidina) cf. *sumatrensis*
Lepidocyclina (Trybliolepidina) cf. *martini*
Lepidocyclina (Trybliolepidina) cf. *pilifera*
Operculina victoriensis.

CR.7. (335 feet above stream bed and 176 feet above base of formation): Hard cream recrystallized limestone with poorly preserved foraminifera.

Amphistegina lessonii
Cycloclypeus sp.
Lepidocyclina (Nephrolepidina) cf. *sumatrensis*
Operculina victoriensis

CRC.7. (306 feet above stream bed and 141 feet above base of formation): Cream crystalline foraminiferal limestone with poorly preserved calcareous algae, foraminifera (chiefly small forms), bryozoa, echinoid spines, molluscan shell fragments, and glauconite infillings of many tests.

Amphistegina lessonii
Bolivina sp.
Lepidocyclina (Nephrolepidina) cf. *sumatrensis*
Lepidocyclina (Trybliolepidina) pilifera (form B)
Nodosaria radicula
Operculina cf. *victoriensis*
Orbulina universa
Planorbulina mediterranensis
Quinqueloculina sp.
Rotalia cf. *schroeteriana*
Spiroloculina excavata
Textularia cf. *sagittula*
Triloculina tricarinata
Small indeterminate rotalines.

CR.6. (260 feet above stream bed, and 101 feet above base of formation): Hard cream foraminiferal limestone with calcareous algae and foraminifera, many tests being iron-stained.

Amphistegina lessonii
Austrotrillina howchini
Cycloclypeus indopacificus
Elphidium hispidulum
Globigerina bulloides
Gypsina globulus
Lepidocyclina (Nephrolepidina) ferreroi
Lepidocyclina (Trybliolepidina) pilifera
Reussella sp.
Spiroloculina sp.
Textularia sp.

CRC.6. (259 feet above stream bed, and 100 feet above base of formation): Pale pink to cream foraminiferal limestone with calcareous algae and abundant small *Lepidocyclinae.*

Amphistegina lessonii
Anomalinella rostrata var. nov.
Cibicides victoriensis
Cibicides sp.
Cycloclypeus indopacificus
Discorbis patelliformis
Elphidium crespinae
Elphidium hispidulum
Globigerina baroemoenensis
Guttulina (Sigmoidina) silvestrii
Gypsina howchini
Gypsina globulus
Lepidocyclina (Nephrolepidina) borneënsis
Lepidocyclina (Nephrolepidina) sumatrensis
Lepidocyclina (Nephrolepidina) sumatrensis var. *inornata*
Lepidocyclina (Nephrolepidina) verrucosa
Lepidocyclina (Trybliolepidina) martini
Lepidocyclina (Trybliolepidina) cf. *rutteni* forma *globosa*
Lepidocyclina (Trybliolepidina) transiens
Miogypsina polymorpha
Operculina victoriensis
Peneroplis sp.
Reussella spinulosa
Rotorbinella cycloclypeus
Rotorbinella balcombensis
Valvulina chapmani
Valvulina davidiana.

CRC.5. (219 feet above stream bed, and 54 feet above base of formation): Cream crystalline foraminiferal limestone with calcareous algae and abundant small *Lepidocyclinae.*

Amphistegina lessonii
Anomalina glabrata
Cycloclypeus indopacificus (forms A and B)
Gypsina howchini
Gypsina globulus
Lepidocyclina (Nephrolepidina) borneënsis
Lepidocyclina (Trybliolepidina) martini
Miogypsina excentrica
Miogypsina polymorpha
Miogypsina thecidaeformis
Spiroloculina sp.

CRC.4. (189 feet above stream bed, and 24 feet above base formation): Hard pink crystalline foraminiferal limestone with numerous *Amphistegina, Cycoclypeus,* and *Lepidocyclina.*

Amphistegina lessonii
Amphistegina radiata
Austrotrillina howchini
Cycloclypeus indopacificus
Cycloclypeus indopacificus var. *terhaarii*
Elphidium cf. *hispidulum*
Gypsina globulus
Gypsina howchini
Lepidocyclina (Trybliolepidina) martini
Lepidocyclina (Trybliolepidina) pilifera
Lepidocyclina (Trybliolepidina) rutteni forma *globosa*
Lepidocyclina (Trybliolepidina) transiens
Lepidocyclina sp. (form B)
Miogypsina excentrica
Miogypsina polymorpha
Planorbulinella inaequilateralis.

CRC.3. (170 feet above stream bed, and 5 feet above base of formation): Hard to moderately hard cream crystalline foraminiferal limestone with numerous small and large species.

Alabamina sp.
Amphistegina lessonii
Anomalina subnonionoides
Anomalinella rostrata var. nov.
Bdelloidina aggregata
Bolivina cf. *arta*
Bolivina cf. *uniforminata*
Carpenteria proteiformis
Cibicides dorsopustulosus
Cibicides refulgens
Cibicides victoriensis
Cycloclypeus indopacificus
Elphidium pseudonodosum
Elphidium sp.
Gaudryina (Pseudogaudryina) crespinae
Globigerina bulloides
Globorotalites sp.
Guttulina sp.
Gypsina globulus
Lepidocyclina (Nephrolepidina) borneënsis
Lepidocyclina (Nephrolepidina) cf. *nipponica*
Lepidocyclina (Nephrolepidina) sumatrensis
Lepidocyclina (Trybliolepidina) martini
Lepidocyclina (Trybliolepidina) transiens
Lepidocyclina sp. (form B)
Nonion sp.
Operculina victoriensis
cf. *Osangularia bengalensis*
Polystomellina miocenica
Sigmoidella elegantissima
Robulus sp.
Textularia sagittula
Verneuilina triquetra.

In discussing the microfauna of the Tulki Limestone, it is necessary to include evidence from the foraminiferal assemblages in limestones other than those from the type area, as certain species of zonal importance have not been found at that locality. Five notable features distinguish the fauna of the Tulki Limestone from the underlying Mandu Calcarenite.

(1) The abrupt disappearance of the zonal "e"-stage genus, *Lepidocyclina (Eulepidina)*.
(2) The incoming of many species of larger foraminifera which are typical of "f"-stage throughout the Indo-Pacific region and of lower Miocene deposits in south-eastern Australia.
(3) The occurrence of *Katacycloclypeus annulatus*.
(4) The presence in the rocks near the base of the formation of numerous small species of foraminifera which occurred in the Mandu Calcarenite.
(5) The presence of a large irregular echinoid *Conoclypus westraliensis* in the limestones throughout the formation.

(1) The change from the Mandu Calcarenite to the overlying Tulki Limestone is not only a lithological but also a palaeontological one. The most striking feature is the abrupt disappearance of *Lepidocyclina (Eulepidina)*, which is represented by the species *L. (E.) badjirraensis* and *L. (E.) manduensis* and which occurs in such abundance towards the top of the Mandu Calcarenite. This abrupt disappearance of *Eulepidina* marks the change from "e"-stage to "f"-stage in Indo-Pacific Tertiary stratigraphy.

(2) The incoming in abundance of the smaller Lepidocyclinae, especially species belonging to the subgenus *Trybliolepidina*, and of the typical "f"-stage genera *Austrotrillina, Cycloclypeus, Flosculinella, Miogypsina,* and *Operculina,* is well illustrated in the rocks of the Tulki Limestone. Both the subgenera of the smaller Lepidocyclinae, *Nephrolepidina* and *Trybliolepidina,* are present. *Nephrolepidina* is represented by *L. (N.) angulosa* Provale, *L. (N.) borneënsis* Provale, *L. (N.) ferreroi* Provale, *L. (N.) inflata* Provale, *L. (N.) sumatrensis* (Brady), *L. (N.) sumatrensis* (Brady) var. *inornata* Rutten, and *L. (N.) verrucosa* (Scheffen). *Trybliolepidina* is represented by *L. (T.) gippslandica* Crespin, *L. (T.) pilifera* Scheffen, *L. (T.) martini* (Schlumberger), and *L. (T.) transiens* Umbgrove. Another large species of the subgenus *Trybliolepidina* is a persistent form in the lower part of the Tulki Limestone and is tentatively referred to *L.* cf. *verbeeki* (Newton and Holland).

The earliest record of *Austrotrillina howchini* (Schlumberger) in the rocks of the Cape Range area is in the Tulki Limestone. In other localities in the Indo-Pacific this species makes its earliest appearance in "e"-stage rocks. However, it was originally described from rocks at Hamilton, western Victoria, which are considered to be equivalent to "f_1" stage.

Cycloclypeus is very common in some of the limestones, where it is represented almost exclusively by *C. indopacificus* Tan. Both the microspheric and megalospheric forms are usually present.

Flosculinella bontangensis (Rutten) is not common in the Tulki Limestone, but *Miogypsina* occurs more frequently, the characteristic species being *M. kotoi* Hanzawa, *M. musperi* Tan, *M. excentrica* Tan, *M. polymorpha* Rutten, and *M. thecidaeformis* Rutten. *Operculina victoriensis* Chapman and Parr is very common in some of the limestones. *Amphistegina* is represented by two species, *A. radiata* d'Orb., which is abundant in the lower part of the formation, and *A. lessonii* d'Orb., which increases in abundance towards the top of the section. *Gypsina howchini* Chapman, characteristic of the lower Miocene deposits of south-eastern Australia, is frequently present.

(3) The earliest record of *Katacycloclypeus* (Martin) in the Tertiary deposits of the Cape Range is in the pink limestones 2 miles S. 87° E. from the mouth of Mandu Mandu Creek. This form is of zonal importance in the lower part of "f" stage.

(4) In some of the samples from the lower part of the formation small species of foraminifera are common; many of them have also been recorded from the Mandu Calcarenite. Such species as *Cibicides victoriensis* Chapman, Parr, and Collins, *Rotorbinella balcombensis* (Chapman, Parr, and Collins), *Guttulina (Sigmoidina) silvestrii* Chapman and Ozawa, and *Polystomellina miocenica* Cushman have been described from the lower Miocene of Victoria; and such species as *Cibicides dorsopustulosus* Le Roy, and *Globigerina baroemoenensis* Le Roy were described from the Miocene of Java.

(5) A characteristic megafossil in the pink and cream limestones in a gorge on the east flank of Cape Range, west of Exmouth Gulf Outcamp (now Trealla Well), and at a locality 4 miles upstream from the mouth of Badjirrajirra Creek, is *Conoclypus westraliensis* Crespin, which was described from the first locality mentioned above (Crespin, 1941). This species is apparently restricted to the Tulki Limestone.

TREALLA LIMESTONE

The type section for the Trealla Limestone is at Mt. Lefroy (Trealla Hill), Lat. 22° 13′ S., Long. 114° 00′ E., and is represented by samples CR.85, CR.84, CR.83, CRC.15, and CR.82 (arranged in descending stratigraphical sequence), collected by Crespin, Johnstone, and Perry. The relationship of the Trealla Limestone with the underlying Tulki Limestone is an obvious one in the field. The break is marked by the lowest of several bands of red-brown ferruginous limestone. However there is no evidence of a sharp microfaunal break and the persistent upward range of certain zonal species from the Tulki Limestone up to the Trealla Limestone indicates only a gradual change of existing faunal conditions. Certain species such as *Austrotrillina howchini* which are characteristically "f_1"-stage have not been found in formations later than the Trealla.

The microfaunal content of the samples from the type section for the Trealla Limestone is given below, the samples being arranged in descending stratigraphical sequence.

Type Section—Mt. Lefroy.

CR.85. (Top of Mt. Lefroy, 179 feet above base of formation):
White crystalline limestone with numerous small foraminifera and indeterminate corals.

Marginopora vertebralis
Triloculina tricarinata
Numerous small miliolidae.

CR.84. (82 feet above base of formation):
White crystalline limestone with foraminifera.

Austrotrillina howchini
Lepidocyclina sp.
Valvulina davidiana.

CR.83. (22 feet above base of formation):
White crystalline limestone with foraminifera.

Amphistegina sp.
Anomalinella rostrata var. nov.
Cycloclypeus indopacificus
Globigerinoides trilobus
Gypsina globulus
Lepidocyclina (Trybliolepidina) martini
Nodosaria radicula
Operculina victoriensis
Spiroculina excavata
Valvulina sp.

CR.15. (6 feet above base of formation):
Cream crystalline limestone with numerous foraminifera.

Amphistegina lessonii
Austrotrillina howchini
Elphidium hispidulum
Globigerinoides trilobus
Gypsina globulus
Lepidocyclina (Nephrolepidina) ferreroi
Lepidocyclina (Trybliolepidina) martini
Lepidocyclina (Trybliolepidina) cf. *rutteni* forma *globosa*
Operculina victoriensis
Operculinella venosa
Orbulina universa
Planorbulina mediterranensis
Numerous small miliolidae.

CR.82. (5 feet above base of formation):
Cream crystalline limestone with foraminifera.

Cycloclypeus sp.
Lepidocyclina (Nephrolepidina) sumatrensis
Lepidocyclina (Trybliolepidina) martini
Lepidocyclina sp. (form B).

In previous work on the Tertiary stratigraphy of the Carnarvon Basin the writer recognized two foraminiferal assemblages of "f"-stage species in the limestones (Crespin, 1948, 1950*b*). These assemblages have been shown by this detailed investigation in the Cape Range area to be characteristic of the rocks composing the Trealla Limestone. The two assemblages are:

(1) *Austrotrillina, Flosculinella, Marginopora, Peneroplis, Sorites, Valvulina,* and numerous small miliolidae, in the upper part of the formation.

(2) Small *Lepidocyclina* together with *Austrotrillina, Cycloclypeus, Flosculinella, Marginopora,* and *Operculina,* in the lower part.

Assemblage 1. This assemblage usually contains one of the zonal species *Austrotrillina howchini* and *Flosculinella bontangensis,* together with *Marginopora vertebralis, Sorites* aff. *martini, Valvulina davidiana,* and *V. fusca,* and many small miliolidae such as *Spiroloculina excavata* and *Triloculina tricarinata.*

Assemblage 2. In the lower part of the formation, similarity with the top part of the underlying Tulki Limestone is shown by the presence of numerous tests of *Lepidocyclina,* including such species as *L. (N.) angulosa, L. (T.) gippslandica,* and *L. (T.) martini.* The difference, however, lies in the numerous tests of *Austrotrillina howchini, Flosculinella bontangensis, Gypsina howchini,* and *Marginopora vertebralis,* which are found associated with them.

YARDIE GROUP

The type section for the Yardie Group is at Lat. 22° 20′ S., Long. 113° 50′ E., 1½ miles S. 57° E. from the mouth of Yardie Creek, 40 miles southward from Vlaming Head Lighthouse. The rocks composing the Group are primarily arenaceous and are represented by samples CR.77A, 77, and 76, collected by Johnstone and Perry. At the type locality the Group overlies the Tulki Limestone.

The Yardie Group is divided into two formations, the upper one, Vlaming Sandstone, being a calcareous sandstone formation, the lower one, Pilgramunna Formation, consisting of calcareous fine conglomerate, calcareous sandstone, and sandy limestone. The rocks of the sandstone Formation consist of medium-grained angular quartz grains in a calcareous groundmass. Calcareous algae and foraminifera are present in some of the samples but are usually poorly preserved.

The limestone beds consist of sandy limestone containing angular quartz grains. Calcareous algae and foraminifera are fairly common.

The microfaunal content of samples from the type locality for the Group is given below, the samples being arranged in descending stratigraphical sequence.

Type Section—1½ miles S. 57° E. from mouth of Yardie Creek.

CR.77A. (150 feet above base of Group, and 233 feet above base of section):

Hard yellowish calcareous sandstone with large rounded to oval quartz grains, calcareous algae, and poorly preserved foraminifera.

CR.77. (95 feet above base of Group):

Hard cream to yellowish sandy limestone with numerous fine angular to rounded quartz grains, calcareous algae, and foraminifera.

Cibicides refulgens	*Spiroloculina* sp.
Marginopora vertebralis	*Textularia* sp.
Planorbulina mediterranensis	

CR.76. (56 feet above base of Group, and 139 feet above base of section):

Grey to pink sandy limestone with numerous angular quartz grains and poorly preserved foraminifera.

Anomalina glabrata	*Spiroloculina* sp.

A specimen (CRC-18) of hard calcareous sandstone and hard crystalline limestone was collected by Johnstone and the writer at a locality $1\frac{1}{2}$ miles S.S.W. of Vlaming Head Lighthouse. This interesting specimen when examined in thin section shows the relationship between the base of the Pilgramunna Formation and the underlying Tulki Limestone. The erosional surface of the Tulki Limestone is marked by broken tests of foraminifera, and the foraminiferal assemblage in this portion of the rock is similar to that described in Assemblage 2 on page 65. The upper portion of the thin section shows the typical lithology of the Pilgramunna Formation with its angular to rounded quartz grains.

A specimen of calcareous sandstone from south-east of Milyering Well and belonging to the Vlaming Sandstone (NWC.12) contains a few small foraminifera including *Amphistegina* and indeterminate rotalines.

EXMOUTH SANDSTONE

The type locality for the Exmouth Sandstone is at Trig. Point 458′ Lat. 22° 21′ S., Long. 114° 00′ E., seven and a half miles west-north-west of Exmouth Gulf Homestead. The formation here is 40 feet thick and immediately overlies the Trealla Limestone. The rocks consist of hard to moderately friable pinkish calcareous sandstone with small foraminifera and with irregular veins of travertinized sandstone. The following samples, CRC.23, CRC.22, CRC.21, are regarded as types and were collected by Johnstone and the writer.

The microfaunal content of the samples, which are arranged in descending stratigraphical sequence, is given below.

Type Section—Exmouth Sandstone

CRC.23. (27 feet above base of section):

Pinkish calcareous sandstone with numerous angular to rounded quartz grains, fragments of calcareous algae and small foraminifera chiefly indeterminate; also with veins of travertinized material.

Amphistegina sp.	*Discorbis* sp.
Anomalina glabrata	*Rotalia* cf. *beccarii*.

CRC.22. (10 feet above base of section):

Hard pinkish calcareous sandstone, containing algae, a few small, poorly preserved, foraminifera and fragments of molluscan shells, and with veins of limonitic material containing numerous fine angular quartz grains.

Anomalina sp.	*Elphidium crispum*
Bolivina sp.	*Globigerinoides trilobus.*

CRC.21. (1 foot above base of section):

Hard pinkish calcareous sandstone, with angular to rounded quartz grains, small foraminifera, and molluscan shell fragments.

Anomalina cf. *glabrata*	*Elphidium* cf. *craticulatum.*
Discorbis sp.	

The foraminifera in the rocks of the Exmouth Sandstone are fragmentary, but the determinable ones are referable to Recent species. At a locality one mile S. 85° W. from Patterson's Bore, Exmouth Gulf Station, *Marginopora vertebralis* and *Rotalia beccarii* are present. The assemblage generally is typical of that found in the Recent shore sands along the west coast of Western Australia.

Bundera Calcarenite

The type locality for the Bundera Calcarenite is in a sink-hole about one-half mile west-north-west of Bundera Well, which is 5½ miles south from the mouth of Yardie Creek, at about Lat. 22° 25′ S., Long. 113° 46′ E. The calcarenite contains calcareous algae, recent species of molluscan shells, and large fragments of corals. Foraminifera are scarce, the only recognizable form being *Rotalia beccarii.*

MICROFAUNAL ASSEMBLAGES AND AGE OF THE FORMATIONS

The similarity of the microfaunas of the Tertiary rocks of the Cape Range with others in the Indo-Pacific region makes it convenient to refer to the special nomenclature used in Indonesia by the Dutch palaeontologists. Van der Vlerk and Umbgrove (1927) proposed a simple but useful "letter" classification for the stratigraphical sequence of the rocks in the Indo-Pacific region, based on the presence or absence of the larger foraminifera. This classification has been modified from time to time (Tan, 1939; Glaessner, 1943), and Crespin (1948) suggested a simplified form for the rocks in the Carnarvon Basin, Western Australia, and south-eastern Australia. Van der Vlerk (1950) suggested a scheme which is most adaptable to the Tertiary stratigraphy of the Cape Range area and his final statement in his short paper is worthy of repetition . . . "The fact that genera and subgenera such as *Biplanispira, Austrotrillina, Flosculinella, Miogypsinoides, Trybliolepidina, Katacycloclypeus, Radiocycloclypeus* and a number of species of other genera are restricted to the Far East is too important to doubt of the autochthony of this district." Other comments on Indo-Pacific stratigraphy and its relation to the Cape Range sequence have been made recently by Schneeberger (1952).

At this point, the writer desires to correct an error in determination given in the paper "Indo-Pacific Influences in Australian Tertiary Foraminiferal Assemblages" (Crespin, 1948), in which reference was made to some rocks in Badjirrajirra Creek being of Oligocene age. Further examination of thin sections of limestones and of actual specimens of foraminifera reveal that the reference to "reticulate nummulites" is incorrect. This determination should have been "*Amphistegina*". This correction means that, up to the present, beds of definite Oligocene age have not been discovered in the Cape Range area.

The foraminifera found in the sediments of the type sections for the different formations are listed in pages 75 to 80. Twelve different assemblages have been recognized in the sequence and these together with their age equivalents are shown in Table 5.

Five foraminiferal assemblages can be recognized in the Mandu Calcarenite, four of them in the section at the type locality at Badjirrajirra Creek on the eastern fall of Cape Range and a fifth in the bed of Mandu Mandu Creek on the western fall of the Range. The assemblages on the eastern fall, which are dominated by species of *Eulepidina,* are regarded as representing "e" stage of Indo-Pacific Tertiary stratigraphy (van der Vlerk, 1950). The assemblage on the western fall of Cape Range is dominated by *Cycloclypeus indopacificus,* which is associated with Lepidocyclinae chiefly of the subgenus *Nephrolepidina* and is referred to basal "f_1" stage.

Seven other assemblages have been recognized in the formations above the Mandu Calcarenite, one in the Tulki Limestone containing numerous tests of *Cycloclypeus* and *Lepidocyclina,* two in the Trealla Limestone with *Austrotrillina howchini, Flosculinella bontangensis,* and *Marginopora vertebralis* amongst the prominent species, one in the Pilgramunna Formation, one in the Vlaming Sandstone, one in the Exmouth Sandstone, and one in the Bundera Calcarenite. These twelve assemblages are described in detail below.

Assemblage 1 (Mandu Calcarenite). This assemblage, which is found in the Calcarenite throughout the type section of the Mandu Calcarenite in Badjirrajirra Creek, is composed almost entirely of small species of foraminifera, the majority being characteristic of the Miocene deposits of the Indo-Pacific region. Some species such as *Loxostomum hentyanum, Cibicides victoriensis, Carpenteria rotaliformis,* and *Tubulogenerina mooraboolensis,* have been described from Miocene deposits of south-eastern Australia, and others such as *Cibicides dorsopustulosus, C. soendaensis,* and *Spiroplectammina arenacea,* have been described from

TABLE 5.

FORAMINIFERAL ASSEMBLAGES IN THE FORMATIONS IN THE CAPE RANGE AREA

Assemblages	Formation	Stage (East Indies)	Epoch
12. Small Recent species	Bundera Calcarenite	—	Recent
11. Small Recent species	Exmouth Sandstone	—	? Pleistocene
10. *Amphistegina* and small rotalines	Vlaming Sandstone	—	? Pliocene
9. *Marginopora vertebralis* and small species	Pilgramunna Formation	Upper "f_1" to ? "f_2"	lower Miocene
8. *Austrotrillina howchini, Flosculinella bontangensis, M. vertebralis, Sorites* aff. *martini, Valvulina fusca, V. davidiana,* numerous small miliolidae	Trealla Limestone	Upper "f_1" to ? "f_2"	lower Miocene
7. *Lepidocyclina (Trybliolepidina* common), *Cycloclypeus indopacificus, Austrotrillina howchini, Flosculinella bontangensis, Marginopora,* small miliolidae	Trealla Limestone	Upper "f_1" to ? "f_2"	lower Miocene
6. *Lepidocyclina (Nephrolepidina, Trybliolepidina), Cycloclypeus indopacificus, Katacycloclypeus annulatus, Miogypsina polymorpha, M. excentrica, Operculina victoriensis, Austrotrillina howchini,* small foraminifera	Tulki Limestone	Lower "f_1"	lower Miocene
5. *Cycloclypeus indopacificus,* very common, *Nephrolepidina, Trybliolepidina,* small foraminifera.	Mandu Calcarenite	Lower "f_1"	lower Miocene
4. *Lepidocyclina (Eulepidina) manduensis* common, numerous foraminifera	Mandu Calcarenite	"e"	lower Miocene
3. *L.(E.) badjirraensis* abundant, numerous small foraminifera	Mandu Calcarenite	"e"	lower Miocene
2. *Cycloclypeus eidae, C. posteidae, Operculina victoriensis* (A & B), numerous small foraminifera	Mandu Calcarenite	"e"	lower Miocene
1. *L. (E.) badjirraensis,* abundant small foraminifera	Mandu Calcarenite	"e"	lower Miocene

the Miocene of Java and Sumatra. An occasional test of *Lepidocyclina (Eulepidina) badjirraensis* indicates an "e"-stage age for the beds.

Assemblage 2 (Mandu Calcarenite). This assemblage is dominated by abundant tests of *Cycloclypeus* and *Operculina: Cycloclypeus* is represented by the "e"-stage species *C. eidae* Tan and *Operculina* by a large form which is referred to the microspheric generation of *O. victoriensis* Chapman and Parr. Small foraminifera are present.

Assemblage 3 (Mandu Calcarenite). Overlying the bed containing Assemblage 2 is a bed two feet thick which is composed almost entirely of flatly-lying microspheric and megalospheric tests of *L. (E.) badjirraensis.* Some of the microspheric tests have a diameter measuring up to 65 mm. This should be a distinct marker bed within the Mandu Calcarenite.

Assemblage 4 (Mandu Calcarenite). Overlying the bed with Assemblage 3 and extending to the top of the formation are chalky limestones containing abundant microspheric and megalospheric tests of *L. (E.) manduensis* with tests of *Cycloclypeus,* chiefly *C. posteidae,* and many small foraminifera. At the type locality for the formation, where the limestone has been subject to weathering, the test of *L. (E.) manduensis* can be readily collected.

Assemblage 5 (Mandu Calcarenite). In the bed of Mandu Mandu Creek on the western fall of Cape Range, another assemblage is present in which small foraminifera characteristic of the formation on the eastern fall are common, but *Eulepidina* and *Cycloclypeus eidae* are not present. Instead, "f"-stage forms such as species of *Nephrolepidina* and *Trybliolepidina, Cycloclypeus indopacificus,* and *Miogypsina* are common. Tests of the microspheric form of *C. indopacificus* are much larger than those of the megalospheric form, and Tan (1932) noted that the microspheric form of species younger than *C. eidae* have this characteristic feature. He showed that the ratio of sizes of megalospheric to microspheric test in *C. eidae* is 1: 1 to 1: 2, whereas in the younger species, as in *C. indopacificus,* the range is from 1: 2 up to 1: 5. The variation in the size of the two generations in *C. indopacificus* is a feature of the calcarenite from the western fall of Cape Range in which this species is so common.

Assemblage 6. This assemblage is found in the Tulki Limestone and is typically basal "f_1"-stage. It includes the genera *Lepidocyclina (Nephrolepidina* and *Trybliolepidina), Cycloclypeus, Katacycloclypeus, Miogypsina, Operculina, Amphistegina,* and *Austrotrillina,* together with numerous small foraminifera, also recorded from the underlying Mandu Calcarenite, in the lower part of the formation. Lepidocyclinae with the trybliolepidine type of embryonic apparatus are prominent and *Cycloclypeus (C. indopacificus)* and *Operculina (O. victoriensis)* are very common in some beds.

Two important forms make their first appearance in this assemblage in the Cape Range microfaunas, namely *Austrotrillina howchini* and *Katacycloclypeus annulatus*. *A. howchini* makes its first appearance in the Cape Range area is the basal "f_1" stage, whereas elsewhere in the Indo-Pacific region its first record is from "e"-stage beds. Tan regarded the incoming of the genus *Katacycloclypeus* as of stratigraphical importance and as being characteristic of the lower part of "f" stage.

Assemblage 7. This assemblage is found in the lower part of the Trealla Limestone and is represented by *Lepidocyclina* (chiefly *Trybliolepidina*), *Cycloclypeus indopacificus, Flosculinella bontangensis, Austrotrillina howchini,* and *Marginopora vertebralis.*

Assemblage 8. This distinctive assemblage is found in the upper portion of the Trealla Limestone. *Lepidocyclina* is very rarely present and the assemblage is dominated by *Austrotrillina, Flosculinella, Sorites,* and *Valvulina.* Numerous small miliolidae are usually associated with them. This assemblage is not mentioned in the stratigraphical sequence given by van der Vlerk (1950), but it is a typical one at the top of the Trealla Limestone in the Carnarvon Basin and in south-eastern Australia (Crespin, 1948, 1950*b*). However, no evidence has been found in the Carnarvon Basin to indicate that *Austrotrillina howchini occurs* in "e" stage. This species was originally described from beds considered to be equivalent in age to "f_1" stage in western Victoria.

Assemblage 9. The only distinctive species in the Pilgramunna Formation is *Marginopora vertebralis.* It is associated with a form of *Sorites* which seems to be related to *Sorites martini* Verbeek, and small foraminifera probably referable to Recent species. In interbedded calcareous sandstones, a few small fragments of *Lepidocyclina* sp. are found. For the present the assemblage is correlated with Assemblage 8.

Assemblage 10. Very few foraminifera are present in the Vlaming Sandstone. The forms are represented by *Amphistegina* and a few small rotalines. The age of the beds is tentatively regarded as Pliocene.

Assemblage 11. Only small species of foraminifera are present in the Exmouth Sandstone. All are found living in Recent seas. It is suggested that the assemblage is Pleistocene in age.

Assemblage 12. Few foraminifera have been recognized in the Bundera Calcarenite. The Formation is most probably Recent in age.

NOTES ON SOME OF THE FORAMINIFERA AND DISTRIBUTION OF THE LARGER FORMS IN THE CAPE RANGE AREA

The majority of the larger foraminifera recognized in the Cape Range limestones have been discussed at different times by various Dutch micropalaeontologists and the writer, and there is little doubt that such forms are of the utmost importance in the determination of age in the Indo-Pacific

TABLE 6.

DISTRIBUTION OF LARGER FORAMINIFERA IN THE CAPE RANGE FORMATIONS.

Foraminifera	Mandu Calcarenite	Tulki Limestone	Trealla Limestone	
			Lr.	Up.
Lepidocyclina (E.) badjirraensis Crespin	——			
Lepidocyclina (E.) manduensis Crespin	——			
Lepidocyclina (N.) verbeeki (Newt. & Holl.)	——			
Cycloclypeus eidae Tan	——	——		
Cycloclypeus posteidae Tan	——	——		
Lepidocyclina (N.) parva Oppenoorth	——	——		
Lepidocyclina (N.) borneënsis Provale	——	——		
Lepidocyclina (N.) sumatrensis (Brady)	——	——		
Lepidocyclina (T.) pilifera Scheffen	——	——	——	
Lepidocyclina (T.) martini (Schlumberger)	——	——	——	
Operculina victoriensis Chapman & Parr	——	——	——	
Cycloclypeus indopacificus Tan	——	——	——	
Lepidocyclina (N.) acuta Rutten		——		
Lepidocyclina (N.) ferreroi Provale		——		
Lepidocyclina (N.) angulosa Provale		——		
Lepidocyclina (T.) gippslandica Crespin		——		
Lepidocyclina (T) howchini Chapman & Crespin		——		
Lepidocyclina (T.) transiens Umbgrove		——		
Lepidocyclina (T.) sumatrensis var. *inornata* Rutten		——		
Miogypsina excentrica Tan		——		
Miogypsina kotoi Hanzawa		——		
Miogypsina kotoi var. *digitata* Tan		——		
Miogypsina musperi Tan		——		
Miogypsina polymorpha Rutten		——	——	
Lepidocyclina (N.) inflata Provale		——		
Lepidocyclina (T.) rutteni v. d. Vlerk forma *globosa* Scheffen		——	——	
Austrotrillina howchini (Schlumberger)		——	——	——
Flosculinella bontangensis (Rutten)		——	——	——

region. The stratigraphical ranges of many forms have been illustrated by van der Vlerk (1950) and by Möhler (1949).

Lepidocyclinae such as *L. (N.) angulosa, L. (N.) ferreroi, L. (N.) borneënsis, L. (N.) sumatrensis, L. (N.) sumatrensis* var. *inornata, L. (N.) inflata,* and *L. (T.) martini,* are common species in Indo-Pacific stratigraphy. However, the distribution of such forms as *L. (N.) verrucosa, L. (T.) gippslandica, L. (T.) howchini, L. (T.) pilifera,* and *L. (T.) transiens,* is not so widely known, and *L. (E.) badjirraensis* and *L. (E.) manduensis* are new species.

Lepidocyclina (Eulepidina) badjirraensis (pl. 7, figs. 2, 3; pl. 8, fig. 4; pl. 10, fig. 3) has been described by Crespin (1952) from the type section for the Mandu Calcarenite in Badjirrajirra Creek. All previous references to *L. (E.) dilatata* Michelotti in the limestones from the Carnarvon Basin pass into the synonymy of this new species. It is easily recognizable by its large size and its thin, wafer-like tests with a small central boss. The megalospheric tests are approximately 25 mm. in diameter and are very abundant. The microspheric form is less common and is very large, some tests measuring up to 65 mm. in diameter. *L. (E.) badjirraensis* is amongst the largest Lepidocyclinae found in the Indo-Pacific region. It has recently been determined by the writer from Cebu Island, Philippines (Crespin, 1955) where its field occurrence is similar to that at Cape Range. The tests are flatly lying and closely matted together and similar species of small foraminifera, together with *Cycloclypeus eidae*, are associated. The writer also has little doubt that *L. (E.) saipanensis* Cole (Cole and Bridge, 1953) is synonomous with *L. (E.) badjirraensis*.

Lepidocyclina (Eulepidina) manduensis (pl. 8, figs. 2, 3) has also been described recently (Crespin, 1952) from the Mandu Calcarenite at Badjirrajirra Creek. The general shape and internal structure are similar to *L. (E.) badjirraensis*, but both the megalospheric and microspheric generations are much smaller than in that species.

Well preserved tests of *Lepidocyclina (N.) verrucosa* (pl. 7, fig. 1) occur on the surface of the pink limestone of the Tulki Formation. The species has also been recognized in thin sections. It was described by Scheffen (1932) from chalky sandstones from South Bantam, West Java.

Lepidocyclina (T.) pilifera, described by Scheffen (1932) from "f"-stage rocks in Java, is common in the Tulki Limestone in which both the megalospheric and microspheric generations are found. It also occurs in some of the rocks in the lower part of the Trealla Limestone. This species, according to Van Eek (1937), is a common one in the Lower Palembang beds of South Sumatra, which belong approximately to "f_2-f_3".

Figure 2, Plate 8, is compared with *Lepidocyclina (T.) sondaica* Yabe and Hanzawa (1929). Professor Hanzawa in a personal communication (1950) remarked on the close resemblance of this species from Badjirrajirra Creek to *L. (T.) sondaica* which occurs in British North Borneo, the Philippines and Formosa.

Lepidocyclina (Trybliolepidina) transiens was described by Umbgrove (1929) from "f"-stage beds in southern Sumatra, and the species is common in the lower samples collected from the type section for the Tulki Limestone. Caudri (1939) places this in the synonymy of *L. (N.) borneënsis*. However, the characteristic large and frequently irregularly shaped nucleoconch of *L. (T.) transiens*, which has both nephrolepidine and trybliolepidine features, distinguish it from *borneensis*, which always shows a typical small nephrolepidine-shaped nucleoconch.

Lepidocyclina (Trybliolepidina) gippslandica occurs in the top beds of the Mandu Calcarenite and in the lower part of the Tulki Limestone. The appearance of this species in the Cape Range rocks is interesting as it was described by Crespin (1943) from Gippsland, Victoria, from limestones which until recently were regarded as equivalent in age to "f_2-f_3", but are now assigned to "f_1".

Lepidocyclina (Trybliolepidina) howchini is present in the Tulki Limestone. This species was described by Chapman and Crespin (1932) from the rich *Lepidocyclina* limestones in the Hamilton Bore, Parish of Yulecart, western Victoria, and was later discussed by Crespin (1943). The site of the Hamilton Bore was close to the locality from which *Austrotrillina howchini* was originally described by Schlumberger (1893).

Cycloclypeus is very common in the Mandu Calcarenite and Tulki Limestone and is represented by species such as *C. eidae* Tan (Pl. 9, fig. 1; pl. 10, fig. 3), *C. posteidae* Tan, and *C. indopacificus* Tan (pl. 9, fig. 2, 3). The last named species is most abundant in the exposures of Mandu Calcarenite on the western fall of Cape Range, well preserved tests of both the microspheric and megalospheric generations being present. Some of the samples from the Tulki Limestone are composed almost entirely of C. *indopacificus,* which is characteristic of "f"-stage rocks. It is interesting to note that similar *Cycloclypeus*-bearing rocks are found in Formosa, where they are of similar age to the Tulki Limestone (Yabe and Hanzawa, 1930).

Katacycloclypeus annulatus (Martin) makes its first appearance in the Cape Range area in the Tulki Limestone and it ranges up to basal Trealla Limestone. The genus is important in the "f" stage in Indo-Pacific assemblages.

Large tests of *Operculina* are present both in the Mandu Calcarenite and in the lower part of the Tulki Limestone; they have been determined as the microspheric form of *O. victoriensis* Chapman and Parr, described from the lower Miocene beds of Victoria. Yabe and Hanzawa (1930) described a large varietal form of *O. bartschi* Cushman as *multiseptata,* but there seems little doubt that the present form is the microspheric generation of *O. victoriensis,* which is so common in the Mandu Calcarenite and Tulki Limestone.

Flosculinella bontangensis (Rutten) (pl. 9, fig. 5) is a characteristic "f"-stage species and is common in the Trealla Limestone. An interesting discovery in a specimen of the Trealla Limestone was a test of *F. cucumoides,* described by Chapman as *Alveolina cucumoides* from the Tertiary rocks of Malekula, New Hebrides (Chapman, 1908). It is a rare species in Indo-Pacific assemblages.

Miogypsina is not a common genus in the Cape Range rocks, but several species are recorded, the commonest being *M. polymorpha* Rutten. One of the most striking species is *M. excentrica* (pl. 9, fig. 6) described by Tan from Middle Madoera (Tan, 1937).

An interesting feature of the foraminiferal assemblages in the Miocene rocks of the Cape Range area is the presence of a number of smaller species originally described from south-eastern Australia (Chapman, 1910; Chapman, Parr and Collins, 1934; Heron-Allen and Earland, 1924), especially from the *Lepidocyclina* horizon of Victoria, which is now regarded as being equivalent to "f_1" stage (Crespin, 1936). These species include *Austrotrillina howchini* (Schlumberger), *Loxostomum hentyanum* Chapman, *Carpenteria alternata* Chapman and Crespin, *Carpenteria rotaliformis* Chapman and Crespin, *Gypsina howchini* Chapman, *Cibicides victoriensis* Chapman, Parr, and Collins, *Operculina victoriensis* Chapman and Parr, *Planorbulinella inaequilateralis* (Heron-Allen and Earland), *Tubulogenerina mooraboolensis* (Cushman), *Reussella decorata* (Heron-Allen and Earland), and *Reussella ensiformis* (Chapman). Comments have already been made on the occurrence of *Austrotrillina howchini* (pl. 9, fig. 4), which has only been found in "f_1"-stage rocks on the Cape Range; but many of the other species are associated with "e"-stage limestones in that area.

Associated with these small species described from south-eastern Australia are those described from Java, Sumatra, and elsewhere in the Indo-Pacific. Species such as *Cibicides dorsopustulosus, C. soendaensis, C. telisaensis, Globigerina baroemoenensis,* and *Spiroplectammina arenacea,* have been described by Le Roy (1944), and others such as *Robulus nikobarensis* and *Osangularia bengalensis* by Schwager (1886) and *Globigerina tripartita* and *Robulus nigriseptus* by Koch (1926).

COMPLETE LIST OF FORAMINIFERA WITH THEIR DISTRIBUTION IN THE ROCKS OF THE DIFFERENT FORMATIONS

A complete list of foraminifera recorded from the various collections is given below. Chapman's determinations from Clapp's material are included.* The distribution of species in the five formations is also shown. (No foraminifera are listed from the Bundera Calcarenite). The abbreviations given for the formation names correspond to those shown on the maps and are as follows:

Tmm=Mandu Calcarenite.
Tmk=Tulki Limestone.
Tmt=Trealla Limestone.
Ty=Yardie Group.
Qpe=Exmouth Sandstone.

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Acervulina inhaerens Schultz	—	—	x	x	—
Alabamina sp. nov.	x	—	—	—	—
Alabamina cf. *hardyi* Le Roy	x	—	—	—	—
Alabamina sp.	x	x	—	—	—
Amphistegina lessonii d'Orb	x	x	x	—	—
Amphistegina radiata (F. & M.)	x	x	—	—	—
Amphistegina sp.	—	—	—	x	x

*Species not recognised in the present collection are indicated by *.

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Angulogerina australe (Heron-Allen & Earland)	x	—	—	—	—
Angulogerina sp. nov.	x	—	—	—	—
Anomalina ammonoides (Reuss)	x	—	x	—	—
Anomalina glabrata Cushman	x	x	x	x	x
Anomalina grosserugosa (Gümbel)	x	—	—	—	—
Anomalina subnonionoides Finlay	x	x	—	—	—
Anomalina sp. nov.	x	—	—	—	—
Anomalinella rostrata var. nov.	x	x	—	—	—
Austrotrillina howchini (Schlumberger)	—	x	x	—	—
**Baculogypsina sphaerulata* (Parker & Jones) ..	x	—	—	—	—
Baggina cf. philippinensis Cushman	x	—	—	—	—
Bdelloidina aggregata Carter	x	x	—	—	—
Bolivina acerosa Cushman	x	—	—	—	—
Bolivina cf. *antiqua* d'Orb	x	—	—	—	—
Bolivina cf. *arta* Macfadyen	x	—	—	—	—
Bolivina dilatata Reuss	x	—	—	—	—
Bolivina fastigia Cushman	x	—	—	—	—
Bolivina girardensis Cushman	x	—	—	—	—
Bolivina hebes Macfadyen var. *victoriensis*. Cushman	x	—	—	—	—
Bolivina cf. *limbata* Brady	x	—	—	—	—
Bolivina limbata Brady var. *costulata* Cushman	x	—	—	—	—
Bolivina cf. *lobata* Brady	x	—	—	—	—
Bolivina cf. *mississippiensis* Cushman	x	—	—	—	—
Bolivina nobilis Hantken	x	—	—	—	—
Bolivina cf. paula Cushman	x	—	—	—	—
**Bolivina punctata* Brady	x	—	—	—	—
Bolivina scalprata Schwager	x	—	—	—	—
Bolivina scalprata Schw. var. *miocenica* Macfadyen	x	—	—	—	—
**Bolivina spiroplectiformis* Chapman	x	—	—	—	—
Bolivina cf. *sumatrensis* Le Roy	x	—	—	—	—
**Bolivina textularioides* Reuss	x	—	—	—	—
Bolivina cf. uniforminata Le Roy	—	x	—	—	—
Bolivina victoriana Cushman	x	—	—	—	—
Bolivina spp. nov.	x	—	—	—	—
Bolivinella cf. folia (Parker & Jones)	x	—	—	—	—
Bolivinella folia (P. & J.) var. *ornata* Cushman ..	x	—	—	—	—
Bolivinata quadrilatera (Schwager)	x	—	—	—	—
**Bulimina elegans* (d'Orb.)	x	—	—	—	—
Buliminella elegantissima (d'Orb.)	x	—	—	—	—
Calcarina verriculata (Howchin & Parr)	x	x	x	—	—
Calcarina sp.	x	—	—	—	—
Cancris saga (d'Orb). var. *communis* Cushman & Todd	x	—	—	—	—
Carpenteria alternata Chapman & Crespin ..	x	—	—	—	—
Carpenteria capitata Jones & Chapman	—	—	x	—	—
Carpenteria conoidea Rutten	—	x	—	—	—
Carpenteria proteiformis Goes	x	x	—	—	—
Carpenteria rotaliformis Chapman & Crespin ..	x	x	—	—	—
**Cassidulina calabra* (Seg.)	x	—	—	—	—
Cassidulina cf. *delicata* Cushman	x	—	—	—	—
Cassidulina laevigata d'Orb.	x	—	—	—	—
Cassidulina margaritea Karrer	x	—	—	—	—
Cassidulina subglobosa Brady	x	—	—	—	—
Cibicides delicatulus Le Roy	x	—	—	—	—
Cibicides cf. discus (Roemer)	x	—	—	—	—
Cibicides dorsopustulosus Le Roy	x	x	—	—	—
Cibicides foxi Le Roy	x	—	—	—	—
Cibicides lobatulus (Walker & Jacobs)	x	x	—	—	—
Cibicides refulgens (Montf.)	x	—	—	x	—
Cibicides soendaensis Le Roy	x	—	—	—	—
Cibicides sorrentae Chapman, Parr & Collins ..	x	—	—	—	—

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Cibicides telisaensis Le Roy	x	—	x	—	x
Cibicides ungerianus (d'Orb.)	x	—	—	—	—
Cibicides cf. ungerianus (D'Orb.)	x	—	—	—	—
Cibicides sp. nov.	x	—	—	—	—
Cibicides victoriensis Chapman, Parr & Collins ..	x	x	—	—	—
Cibicides sp. nov.	x	—	—	—	—
Clavulinoides szaboi (Hantken) var. *victoriensis* Cushman	x	—	—	—	—
Cyclammina incisa Stache	x	—	—	—	—
Cycloclypeus cf. *carpenteri* Williamson	—	x	—	—	—
Cycloclypeus eidae Tan	x	—	—	—	—
Cycloclypeus indopacificus Tan	x	x	x	—	—
Cycloclypeus indopacificus var. *terhaarii* Tan ..	—	x	—	—	—
Cycloclypeus posteidae Tan	x	x	—	—	—
Cycloclypeus sp.	—	—	—	x	—
Dentalina communis d'Orb	x	—	—	—	—
Dentalina consobrina d'Orb.	x	—	—	—	—
Dentalina filiformis (d'Orb.)	x	—	—	—	—
Dentalina insecta Schwager	x	—	—	—	—
Dentalina obliqua Linné	x	—	—	—	—
Dentalina cf. *obliqua* Linné	x	—	—	—	—
Dentalina soluta Reuss	x	—	—	—	—
**Discorbis araucana* (d'Orb.)	x	—	—	—	—
Discorbis bertheloti (d'Orb.) *var. papillata* Chapman, Parr & Collins	x	—	—	—	—
Discorbis globularis (d'Orb.)	x	—	—	—	—
Discorbis opercularis (d'Orb.)	x	—	—	—	—
Discorbis cf. *pileolus* (d'Orb.)	x	—	—	—	—
Discorbis patelliformis (d'Orb.)	x	x	—	—	—
Discorbis turbo (d'Orb.)	x	—	—	—	—
Discorbis tuberculata (W. & B.) var. *australiensis* C., P. & C.	x	—	—	—	—
**Discorbis vilardeboana* (d'Orb.)	x	—	—	—	—
Discorbis sp.	—	—	—	—	x
Dorothia parri Cushman	x	x	—	—	—
Dyocibicides biserialis Cushman	x	—	—	—	—
Elphidium adelaidense Howchin & Parr	—	—	x	x	—
Elphidium craticulatum (F. & M.)	x	—	—	x	x
Elphidium crispum (Linné)	—	—	—	—	x
Elphidium hispidulum Cushman	x	x	x	—	—
Elphidium macellum (F. & M.)	—	—	x	—	—
Elphidium pseudonodosum Cushman	—	x	—	—	—
Epistomaria polystomelloides (P. & J.)	—	—	x	—	—
Eponides cf. concentricus (P. & J.)	x	—	—	—	—
Eponides repandus (F. & M.)	x	—	—	—	—
Eponides cf. *praecinctus* (Brady)	x	—	—	—	—
**Flabellina rugosa* (d'Orb.)	x	—	—	—	—
Flosculinella bontangensis (Rutten)	—	x	x	—	—
Flosculinella cucumoides (Chapman)	—	—	x	—	—
**Frondicularia* cf. *decheni* Reuss	x	—	—	—	—
Frondicularia sp. nov.	x	—	—	—	—
Gaudryina rugosa d'Orb.	x	—	—	—	—
Gaudryina sp.	x	—	—	—	—
Gaudryina (Pseudogaudryina) crespinae Cushman	x	x	—	—	—
Glandulina laevigata d'Orb.	x	—	—	—	—
Glandulina sp.	x	—	—	—	—
Globigerina aspera Koch	x	—	—	—	—
Globigerina baroemoenensis Le Roy	x	x	—	—	—
Globigerina bulloides d'Orb.	x	x	—	x	—
Globigerina dubia d'Orb.	x	—	—	—	—
Globigerinoides sacculiferus (Brady)	x	—	—	—	—

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Globigerinoides sacculiferus var. *irregularis* Le Roy	x	—	—	—	—
Globigerinoides trilobus (d'Orb.)	x	—	x	—	x
Globigerinoides trilocularis (d'Orb.)	x	—	—	—	—
Globigerinoides tripartita (Koch)	x	—	—	—	—
Globorotalites sp. nov.	x	x	—	—	—
Globulina gibba (d'Orb.)	x	—	—	—	—
Guttulina austriaca d'Orb.	x	—	—	—	—
Guttulina irregularis d'Orb.	x	—	—	—	—
Guttulina lactea (W. & J.)	x	—	—	—	—
Guttulina problema (d'Orb.)	x	—	—	—	—
Guttulina (Sigmoidina) silvestrii Cushman & Ozawa	x	x	—	—	—
Gypsina globulus Reuss	x	x	x	x	—
Gypsina howchini Chapman	x	x	x	—	—
Gyroidina soldanii (d'Orb.)	x	—	—	—	—
Gyroidina soldanii var. *altiformis* R. E. & K. E. Stewart	x	—	—	—	—
Haplophragmoides sp.	x	—	—	—	—
**Haplophragmium rotulatum* (Brady)	x	—	—	—	—
**Haplophragmium subglobosum* (Sars.)	x	—	—	—	—
Heronallenia sp. nov.	x	—	—	—	—
**Heterostegina depressa* d'Orb.	x	—	—	—	—
Katacycloclypeus annulatus (Martin)	—	x	—	—	—
Lagena acuticosta Reuss	x	—	—	—	—
Lagena apiculata (Reuss)	x	—	—	—	—
Lagena globosa (Montf.)	x	—	—	—	—
**Lagena hispida* Reuss	x	—	—	—	—
Lagena laevis (Montf.)	x	—	—	—	—
Lagena marginata (W. & B.)	x	—	—	—	—
Lagena sulcata (W. & B.)	x	—	—	—	—
Lepidocyclina (Eulepidina) badjirraensis Crespin	x	—	—	—	—
Lepidocyclina (Eulepidina) manduensis Crespin	x	—	—	—	—
Lepidocyclina (Nephrolepidina) acuta Rutten ..	—	x	—	—	—
Lepidocyclina (Nephrolepidina) angulosa Provale	—	x	x	—	—
Lepidocyclina (Nephrolepidina) borneënsis Provale	x	x	—	—	—
Lepidocyclina (Nephrolepidina) ferreroi Provale	—	x	x	—	—
Lepidocyclina (Nephrolepidina) inflata Provale ..	—	x	x	—	—
Lepidocyclina (Nephrolepidina) parva Oppenoorth	x	x	—	—	—
Lepidocyclina (Nephrolepidina) sumatrensis (Brady)	x	x	x	—	—
Lepidocyclina (Nephrolepidina) sumatrensis (Brady) var. *inornata* Rutten	—	x	—	—	—
Lepidocyclina (Nephrolepidina) verbeeki Newton & Holl.	x	—	—	—	—
Lepidocyclina (Nephrolepidina) verrucosa Scheffen	—	x	x	—	—
Lepidocyclina (Trybliolepidina) gippslandica Crespin	x	x	x	—	—
Lepidocyclina (Trybliolepidina) howchini Chapm. & Cresp.	—	x	—	—	—
Lepidocyclina (Trybliolepidina) martini (Schlumberger)	x	x	x	—	—
Lepidocyclina (Trybliolepidina) pilifera Scheffen	x	x	x	—	—
Lepidocyclina (Trybliolepidina) cf. *robusta* Scheffen	—	x	—	—	—
Lepidocyclina (Trybliolepidina) rutteni v. d. Vlerk forma *globosa* Scheffen	—	x	x	—	—
Lepidocyclina (Trybliolepidina) sondaica Yabe & Hanzawa	x	—	—	—	—

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Lepidocyclina (Trybliolepidina) transiens Umbgrove	—	x	—	—	—
Listerella victoriensis Cushman	x	—	—	—	—
Loxostomum hentyanum (Chapman)	x	—	—	—	—
Marginopora sp.	—	—	—	—	x
Marginopora vertebralis Quoy & Gaimard	—	—	x	x	x
**Marginulina bullata* (Reuss)	x	—	—	—	—
**Marginulina costata* (Batsch)	x	—	—	—	—
**Marginulina glabra* d'Orb.	x	—	—	—	—
Massilina lapidigera (Parr)	—	—	x	—	—
Miliolinella oblonge (Montagu)	x	—	—	—	—
Miogypsina excentrica Tan	—	x	—	—	—
**Miogypsina cf. irregularis* (Michelotti)	x	—	—	—	—
Miogypsina kotoi Hanzawa	—	x	—	—	—
Miogypsina kotoi var. *digitata* Tan	—	x	—	—	—
Miogypsina musperi Tan	—	x	—	—	—
Miogypsina polymorpha Rutten	—	x	—	—	—
Miogypsina thecidaeformis Rutten	x	x	x	—	—
Miogypsina sp.	—	x	—	—	—
Nodosaria cf. *deceptoria* Schwager	x	—	—	—	—
Nodosaria exilis Schwager	x	—	—	—	—
**Nodosaria longiscata* d'Orb.	x	—	—	—	—
Nodosaria radicula (Linné)	—	—	x	—	—
**Nodosaria subtertenuata* Schwager	x	—	—	—	—
Nodosaria vertebralis (Batsch)	x	—	—	—	—
Nodosaria tubulata Koch	x	—	—	—	—
Nonion depressulum (W. & J.)	x	—	—	—	—
Nonion cf. *elongatum* d'Orb.	x	—	—	—	—
Nonion cf. grateloupii (d'Orb.)	x	—	—	—	—
Nonionella sp. nov.	x	—	—	—	—
Operculina victoriensis Chapman & Parr (form B)	x	x	—	—	—
Operculina victoriensis Chapman & Parr (form A)	x	x	x	—	—
Operculina sp.	—	—	—	x	—
Operculinella venosa (F. & M.)	—	—	x	—	—
Orbulina universa d'Orb.	—	—	—	x	—
Osangularia bengalensis (Schwager)	x	—	—	—	—
Osangularia cf. *bengalensis* (Schwager)	x	—	—	—	—
Osangularia sp. nov.	x	—	—	—	—
Palmula sp. nov.	x	—	—	—	—
Patellina corrugata Williamson	x	—	—	—	—
Patellina sp. nov.	x	—	—	—	—
Peneroplis planatus (F. & M.)	—	—	—	x	x
Planorbulina mediterranensis d'Orb.	—	x	—	x	—
Planorbulinella inaequilateralis (Heron-Allen & Earland)	x	x	—	—	—
Planulina wuellerstorfi (Schwager)	x	—	—	—	—
Pleurostomella alternans Schwager	x	—	—	—	—
Polystomellina miocenica Cushman	—	x	x	—	—
Pseudoparrella sp.	—	x	—	—	—
Pullenia quinqueloba (Reuss)	x	—	—	—	—
Pyrgo anomala (Schwager)	—	x	—	—	—
Pyrgo bulloides (d'Orb.)	x	x	—	—	—
Quinqueloculina pygmaea Reuss	x	—	—	—	—
Quinqueloculina seminulum d'Orb.	x	—	—	—	—
Quinqueloculina vulgaris d'Orb.	x	—	—	—	—
Quinqueloculina sp.	—	x	x	x	—
**Rectobolivina bifrons* (Brady)	x	—	—	—	—
**Rectobolivina columellaris* (Brady)	x	—	—	—	—
**Reophax scorpiurus* Montf.	x	—	—	—	—
Reussella decorata (Heron-Allen & Earland)	x	—	—	—	—

Foraminifera	Tmm	Tmk	Tmt	Ty	Qpe
Reussella ensiformis (Chapman)	x	—	—	—	—
Reussella spinulosa (Reuss)	x	x	—	—	—
Reussella cf. *spinulosa* (Reuss)	x	—	—	—	—
**Robulus aculeatus* (d'Orb.)	x	—	—	—	—
**Robulus bronni* (Roemer)	x	—	—	—	—
Robulus cultratus (Montf.)	x	—	—	—	—
Robulus gibbus (d'Orb.)	x	—	—	—	—
Robulus cf. *inornatus* (d'Orb.)	x	—	—	—	—
Robulus nigriseptus (Koch)	x	—	—	—	—
Robulus nikobarensis (Schwager)	x	—	—	—	—
Robulus orbicularis (d'Orb.)	x	—	—	—	—
**Robulus ovalis* (Reuss)	x	—	—	—	—
Robulus cf. *politus* (Schwager)	x	—	—	—	—
Robulus rotulatus (Lam.)	x	—	—	—	—
Robulus submammilligerus (Cushman)	x	—	—	—	—
Robulus cf. tangens Le Roy	x	—	—	—	—
Robulus sp.	x	—	—	—	—
Rotalia beccarii d'Orb.	—	—	—	x	x
Rotalia calcar d'Orb.	—	—	x	x	—
Rotalia cf. *schroeteriana* P. & J.	—	x	—	—	—
Rotorbinella balcombensis (Chapman, Parr & Collins)	—	x	—	—	—
Rotorbinella cycloclypeus (Howchin & Parr)	—	x	x	—	—
Sigmoidella elegantissima (d'Orb.)	x	—	—	—	—
**Siphonina reticulata* (Cz.)	x	—	—	—	—
Siphonina sp. nov.	x	—	—	—	—
Sorites aff. martini Verbeek	—	—	x	x	—
Sphaeroidina bulloides d'Orb.	x	—	—	—	—
Sphaeroidina multiloba Le Roy	x	—	—	—	—
Spiroloculina canaliculata d'Orb.	—	—	x	—	—
Spiroloculina excavata d'Orb.	—	x	x	—	—
Spiroloculina sp.	—	—	x	x	—
Spiroplectammina arenacea Le Roy	x	—	—	—	—
**Spiroplectammina nussdorfensis* (d'Orb.)	x	—	—	—	—
Spiroplectammina sp.	x	—	—	—	—
**Textularia gramen* d'Orb.	x	—	—	—	—
Textularia sagittula Defr.	—	x	—	—	—
Textularia cf. *semialata* Cushman	x	—	—	—	—
Textularia sp.	—	x	—	x	—
Trifarina bradyi Cushman	x	—	—	—	—
Triloculina tricarinata d'Orb.	—	x	x	x	—
Triloculina trigonula (Lam.)	x	—	—	—	—
Tubulogenerina mooraboolensis Cushman	x	—	—	—	—
Uvigerina nomalandi Le Roy	x	—	—	—	—
Uvigerina cf. *peregrina* Cushman	x	—	—	—	—
Uvigerina cf. schwageri Brady	x	—	—	—	—
Uvigerina cf. soendaensis Le Roy	x	—	—	—	—
Uvigerina sparsicostata Le Roy	x	—	—	—	—
**Vaginulina legumen* (Linné)	x	—	—	—	—
Vaginulinopsis gemmata (Brady)	x	—	—	—	—
Vaginulinopsis gradata Thalmann	x	—	—	—	—
Vaginulinopsis infrapapillata (Stache)	x	—	—	—	—
Vaginulinopsis sumatrica Le Roy	x	—	—	—	—
Valvulina chapmani Cushman	—	x	—	—	—
Valvulina davidiana Chapman	—	x	x	—	—
Valvulina fusca (Williamson)	—	—	x	—	—
Valvulina sp.	—	—	x	—	—
Verneuilina triquetra (Münster)	x	x	—	—	—
Verneuilina sp.	x	—	—	—	—
Virgulina schreibersiana Cz.	x	—	—	—	—

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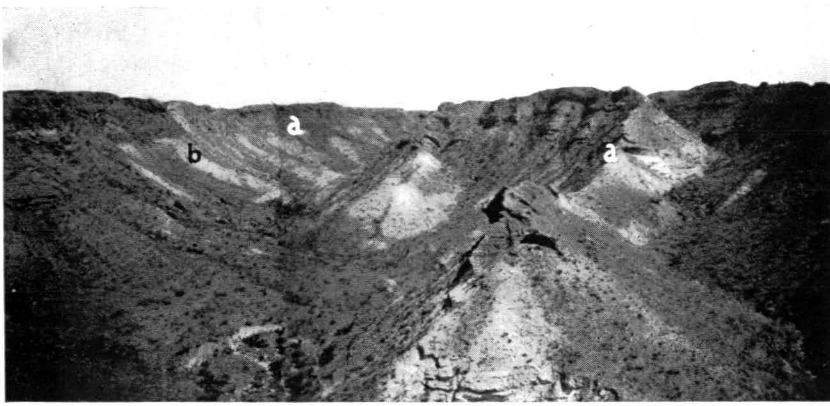


FIG. 1

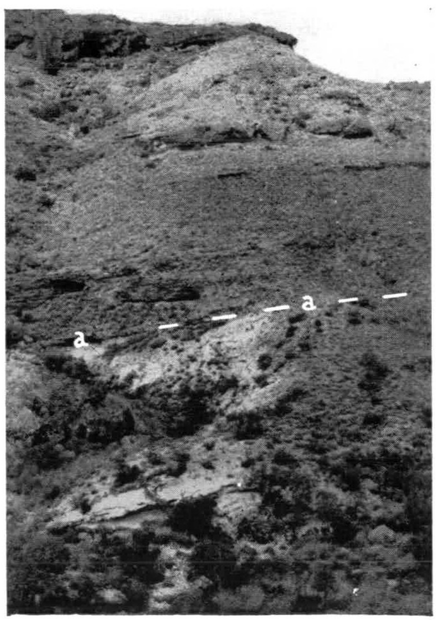


FIG. 2

Fig. 1.—Panorama of Badjirrajirra Creek valley. View west from type section of Tulki Limestone showing (*a*) contact between Mandu Calcarenite and Tulki Limestone and (*b*) Mandu Calcarenite type section.

Fig. 2.—Tulki Limestone type section, Badjirrajirra Creek. (*a*) Contact between Mandu Calcarenite and Tulki Limestone.

PLATE 3

Fig. 1.—Mandu Calcarenite type section, Badjirrajirra Creek, showing (*a*) contact between Mandu Calcarenite and Tulki Limestone, and (*b*) bed of foraminiferal limestone.

Fig. 2.—Mount Lefroy, view from 1½ miles east of trig. point, showing (*a*) contact between Tulki Limestone and Trealla Limestone.

Fig. 3.—Trealla Limestone type section, Mt. Lefroy. View south-west across canyon eroded in Tulki Limestone. (*a*) Contact between Tulki Limestone and Trealla Limestone, (*b*) Trig. Point 705.

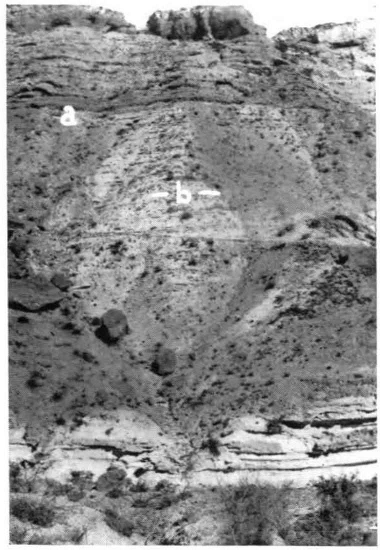


FIG. 1

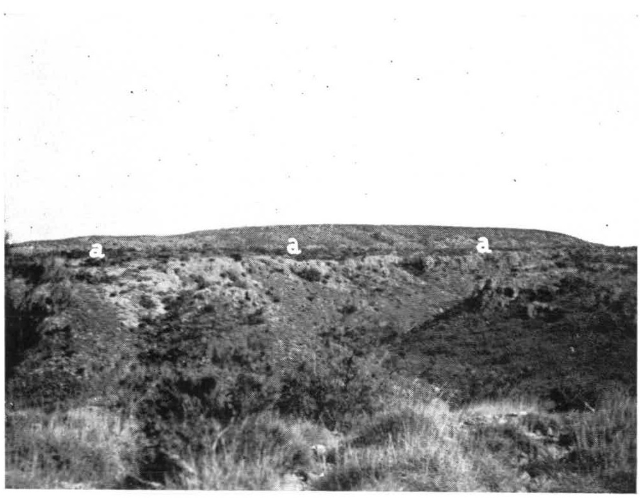


FIG. 2

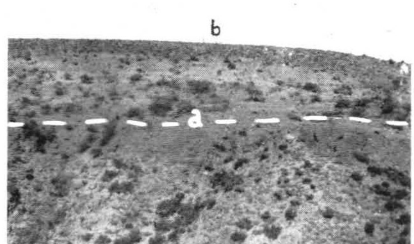


FIG. 3

PLATE 4

Fig. 1.—Red-brown ferruginous sandy limestone, Mt. Lefroy. (*a*) Tulki Limestone, (b) Trealla Limestone.

Fig. 2.—Yardie Creek. View west from knoll 1½ miles from mouth.

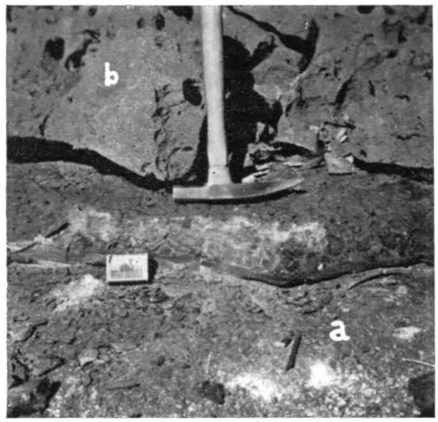


FIG. 1

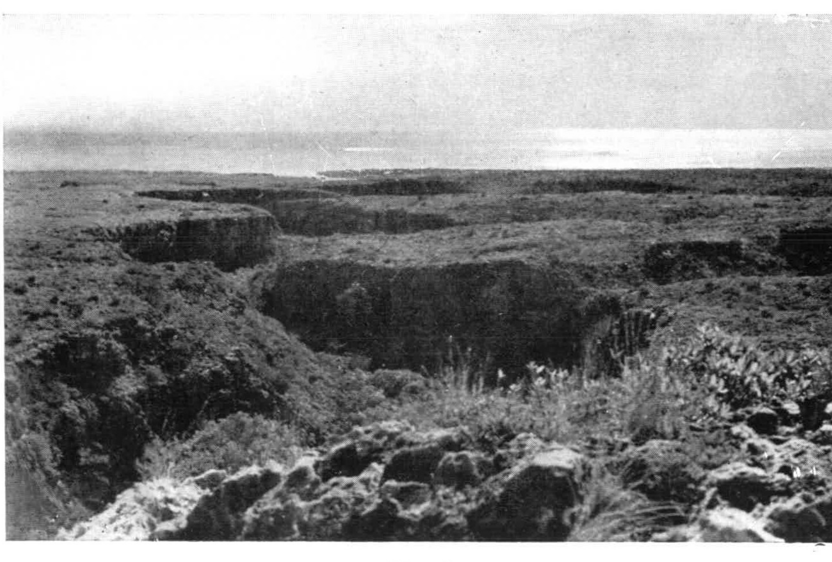


FIG. 2

PLATE 5

Fig. 1.—Pilgramunna Formation type section, Yardie Creek. View from right bank looking south. (*a*) Tulki Limestone, (*b*) Pilgramunna Formation.

Fig. 2.—Trig. Point 400, two miles south-east of Tantabiddy Well, Yardie Creek Station. Characteristic outcrop of the Yardie Group bordering the coastal plain. (*a*) Contact between Tulki Limestone and Pilgramunna Formation, (*b*) Trealla Limestone interbedded in the Pilgramunna Formation, (*c*) Trig. Point 400.

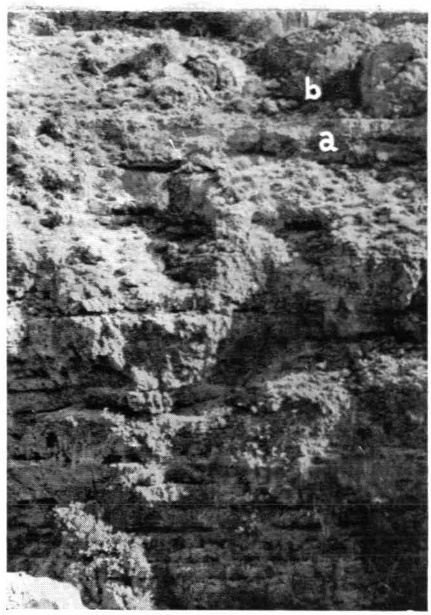


FIG. 1

FIG. 2

PLATE 6

Fig. 1.—Bundera Calcarenite type section. (*a*) Cross-bedded white calcarenite, (*b*) cream shelly limestone, (*c*) red-brown sand.

Fig. 2.—Mowbowra Conglomerate type section. (*a*) Friable red-brown calcarenite, (*b*) bedded limestone conglomerate.

Fig. 3.—Close view of Mowbowra Conglomerate. Note well-rounded pebbles of Tertiary limestone.

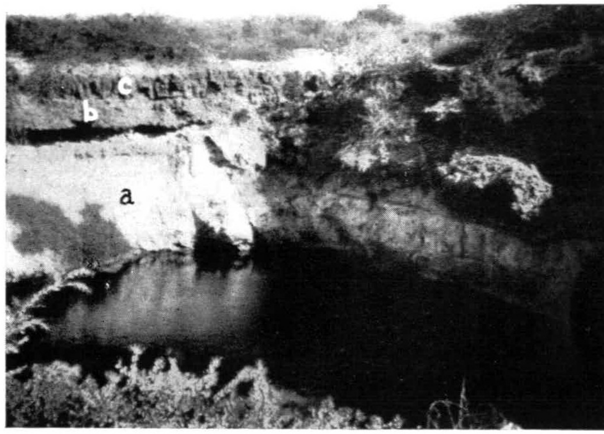


FIG. 1

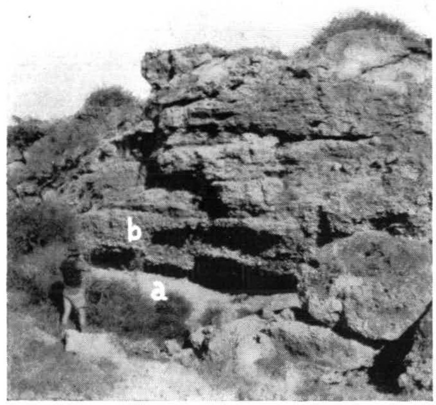


FIG. 2

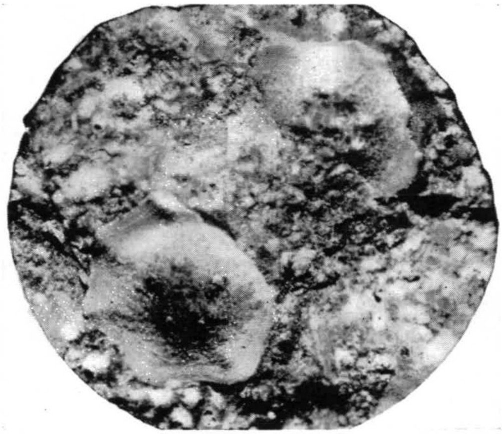
FIG. 3

Plate 7

Fig. 1.—*Lepidocyclina* (*Trybliolepidina*) *verrucosa* Scheffen. 3¾ miles N. 88° W. of Mowbowra Well, Yardie Creek Station. Tulki Limestone. ×5.

Fig. 2.—*Lepidocyclina* (*Eulepidina*) *badjirraensis* Crespin. Megalospheric form. Badjirrajirra Creek, 4 miles upstream from mouth. Mandu Calcarenite. Nat. size.

Fig. 3.—*Lepidocyclina* (*Eulepidina*) *badjirraensis* Crespin. Megalospheric and microspheric forms. Locality as Fig. 2. Mandu Calcarenite. 2-3 nat. size.



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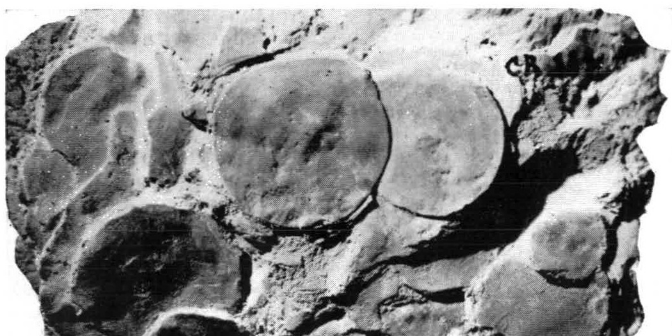

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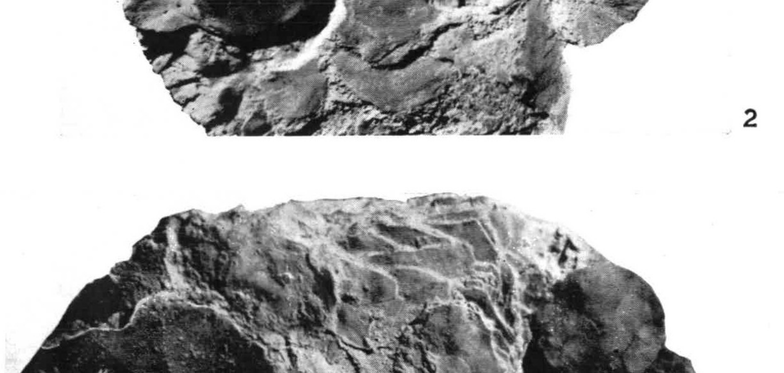

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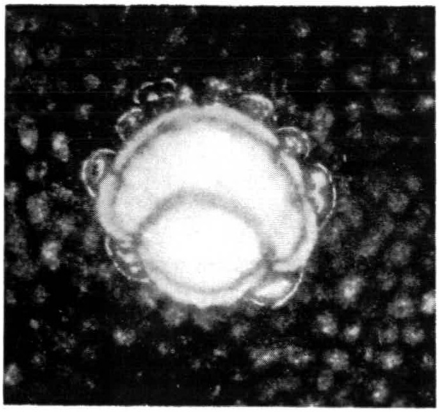
PLATE 8

Fig. 1.—*Lepidocyclina (Trybliolepidina) sondoica* Yabe and Hanzawa. Median section of megalospheric specimen showing trybliolepidine type of embryonic apparatus with 2 primary auxiliary chambers and 7 auxiliary chambers on outer wall. Badjirrajirra Creek. Mandu Calcarenite. ×100.

Fig. 2—*Lepidocyclina (Eulepidina) manduensis* Crespin. Median section of megalospheric specimen, showing typical eulepidine embryonic apparatus. Badjirrajirra Creek. Mandu Calcarenite. ×31.

Fig. 3.—*Lepidocyclina (Eulepidina) manduensis* Crespin. Vertical section of megalospheric specimen. Badjirrajirra Creek. Mandu Calcarenite. ×60.

Fig. 4.—*Lepidocyclina (Eulepidina) badjirraensis* Crespin. Median section of megalospheric specimen showing typical eulepidine embryonic apparatus surrounded by broadly rectangular-shaped chambers. Badjirrajirra Creek. Mandu Calcarenite. ×22.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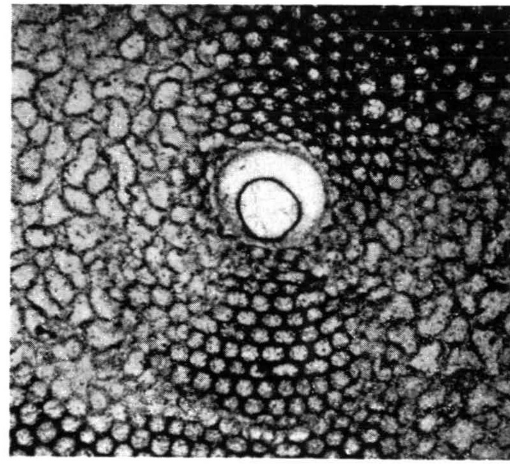
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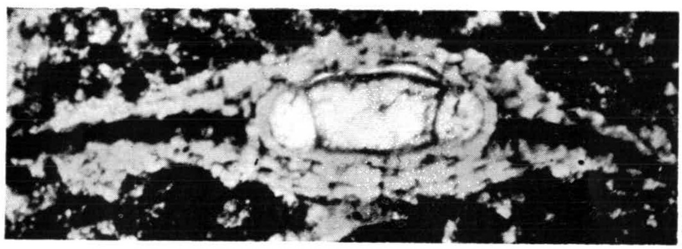
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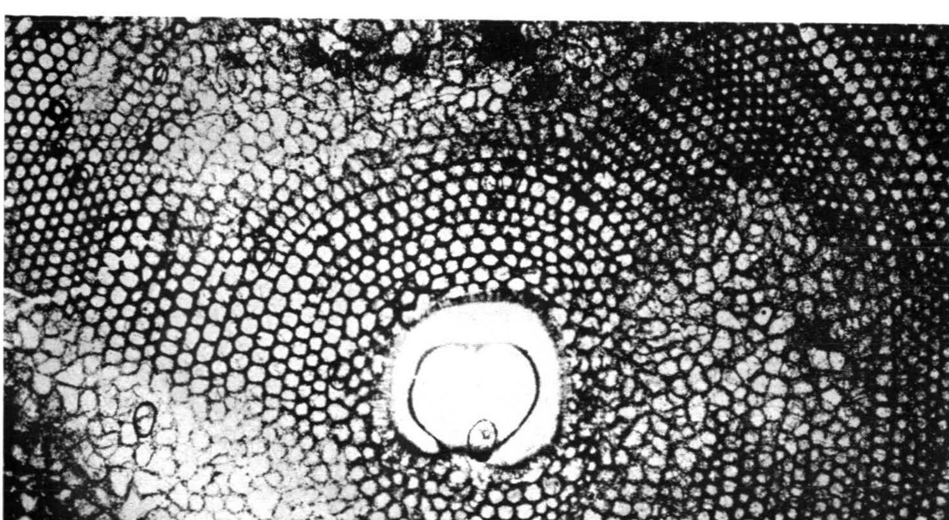
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Plate 9

Fig. 1.—*Cycloclypeus eidae* Tan. Horizontal section of megalospheric specimen, showing 16 nepionic chambers. Badjirrajirra Creek. Mandu Calcarenite. ×22.

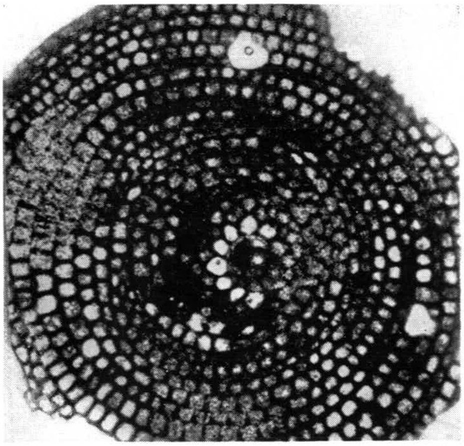
Fig. 2.—*Cycloclypeus indopacificus* Tan. Median section of megalospheric form showing 7 nepionic chambers. Badjirrajirra Creek. Tulki Limestone. ×19.

Fig. 3.—*Cycloclypeus indopacificus* Tan. Median section of microspheric specimen. Badjirrajirra Creek. Tulki Limestone. ×50.

Fig. 4.—*Austrotrillina howchini* (Schlumberger). Tranverse section. $3\frac{1}{2}$ miles E. of Mulyering Well, Yardie Creek Station. Trealla Limestone. ×15.

Fig. 5.—*Flosculinella bontangensis* (Rutten). Tangential section. $2\frac{3}{4}$ miles N. 49° W. of No. 1 Well, Exmouth Gulf Station. Trealla Limestone. ×18.

Fig. 6.—*Miogypsina excentrica* Tan. Tranverse section. $3\frac{1}{4}$ miles S. 19° E. from Yardie Creek Homestead. Tulki Limestone. ×23.



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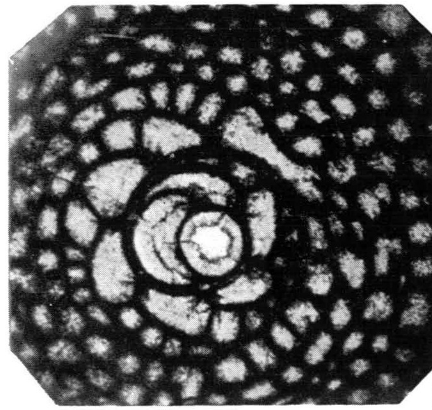

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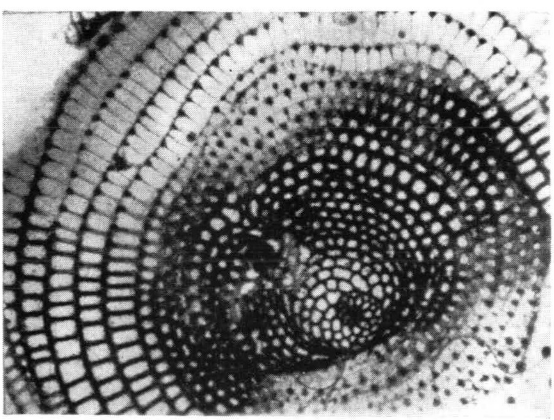

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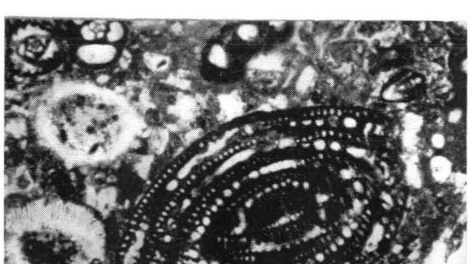


5

6

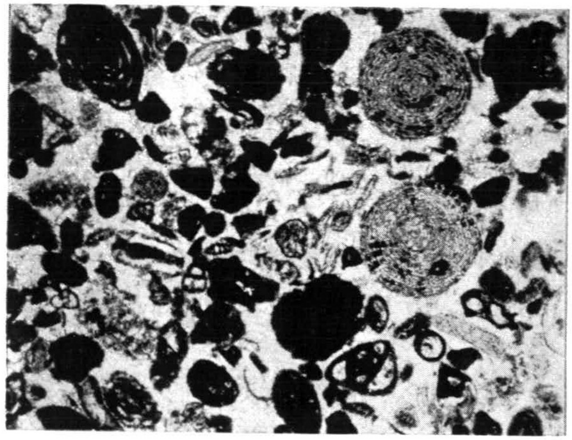
PLATE 10

Fig. 1.—Thin section of Trealla Limestone showing *Gypsina globulus* and numerous miloilidae. 3¼ miles N. 35° W. from Central Hill. × 15.

Fig. 2.—Thin section of ferruginous sandy limestone with fragment of Tulki Limestone containing *Lepidocyclina (Nephrolepidina) angulosa* (Provale) and *Gypsina howchini* Chapman. 150 feet below top of ridge at Mt. Lefroy. Top of Tulki Limestone. × circ. 13.

Fig. 3.—Thin section of Mandu Calcarenite showing vertical sections of *Lepidocyclina (Eulepidina) badjirraensis* Crespin, *Cycloclypeus eidae* Tan, and *Operculina victoriensis* Chapman and Parr. × 7.5.

All photographs in Plates 7 to 10 inclusive were prepared by H. S. Edgell, formerly of Bureau of Mineral Resources, Geology and Geophysics, Canberra.



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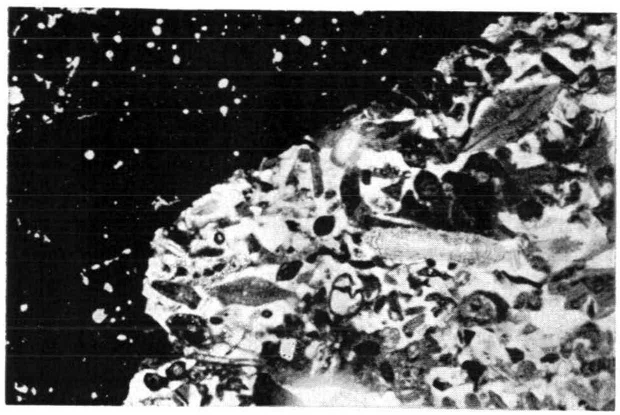

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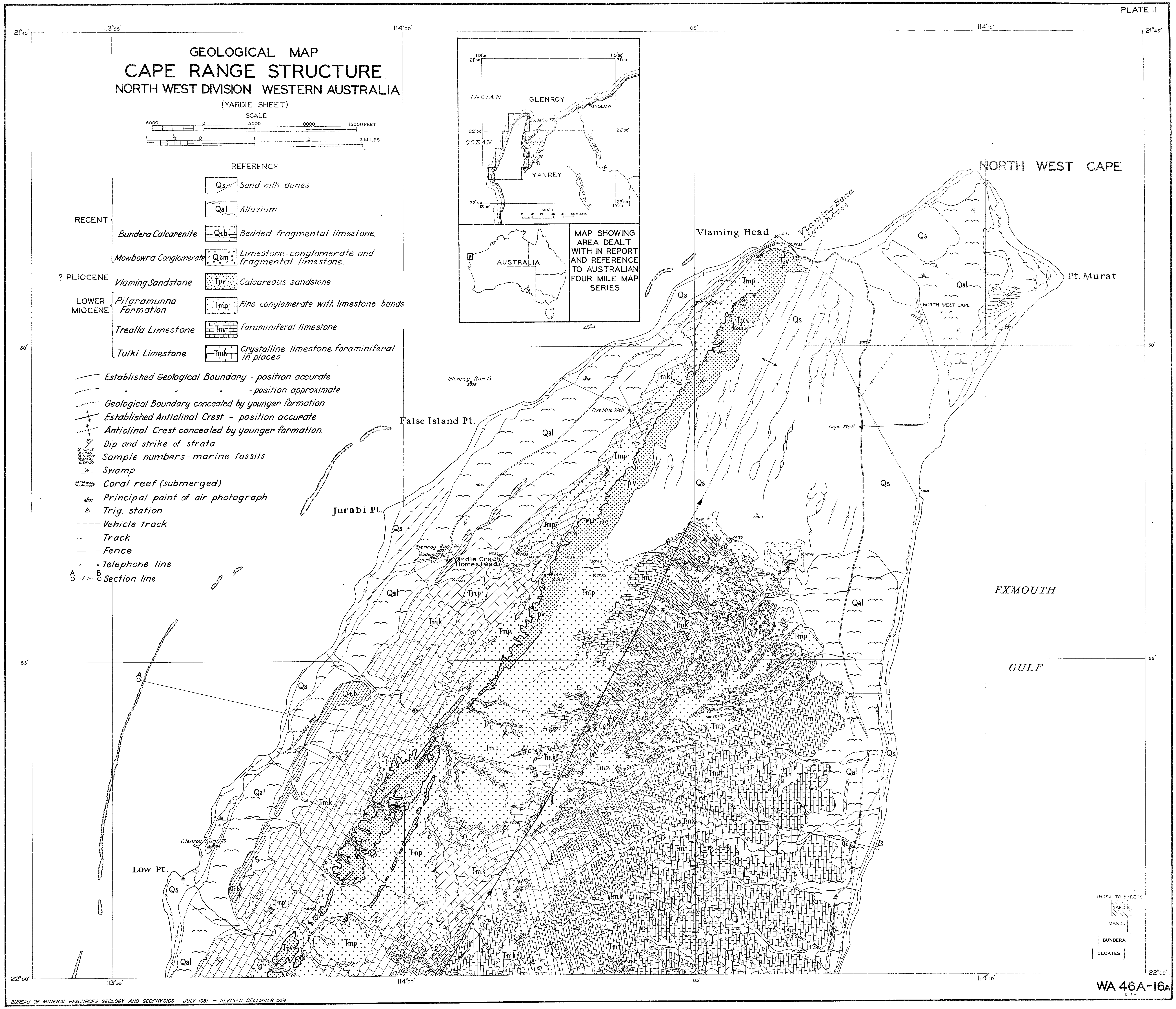
PLATE II
GEOLOGICAL MAP
CAPE RANGE STRUCTURE
NORTH WEST DIVISION WESTERN AUSTRALIA
(YARDIE SHEET)
SCALE
5000 0 5000 10000 15000 FEET
1 ½ 0 1 2 3 MILES
REFERENCE
RECENT
Qs Sand with dunes
Qal Alluvium.
Bundera Calcarenite Qcb Bedded fragmental limestone.
Mowbowra Conglomerate Qcm Limestone-conglomerate and fragmental limestone.
? PLIOCENE Vlaming Sandstone Tpv Calcareous sandstone
LOWER MIOCENE
Pilgramunna Formation Tmp Fine conglomerate with limestone bands
Trealla Limestone Tmt Foraminiferal limestone
Tulki Limestone Tmk Crystalline limestone foraminiferal in places.
Established Geological Boundary - position accurate
-position approximate
Geological Boundary concealed by younger formation
Established Anticlinal Crest - position accurate
Anticlinal Crest concealed by younger formation.
Dip and strike of strata
Sample numbers - marine fossils
Swamp
Coral reef (submerged)
Principal point of air photograph
Trig. station
Vehicle track
Track
Fence
Telephone line
Section line
INDIAN
OCEAN
GLENROY
ONSLOW
EXMOUTH GULF
YANREY
AUSTRALIA
MAP SHOWING AREA DEALT WITH IN REPORT AND REFERENCE TO AUSTRALIAN FOUR MILE MAP SERIES
NORTH WEST CAPE
Vlaming Head
Vlaming Head Lighthouse
Pt. Murat
False Island Pt.
Jurabi Pt.
Low Pt.
Yardie Creek Homestead
Five Mile Well
Cape Well
Kuburu Well
Glenroy Run 13
Glenroy Run 14
Glenroy Run 15
EXMOUTH
GULF
113°55′
114°00′
05′
114°10′
21°45′
50′
55′
22°00′
INDEX TO SHEETS
YARDIE
MANDU
BUNDERA
CLOATES
WA 46A-16A
BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS JULY 1951 - REVISED DECEMBER 1954

PLATE 13


GEOLOGICAL MAP
CAPE RANGE STRUCTURE
NORTH WEST DIVISION WESTERN AUSTRALIA
(BUNDERA SHEET)
SCALE
5,000 0 5,000 10,000 15,000 FEET
1 ½ 0 1 2 3 MILES
RECENT
Qs Sand with dunes
Qal Alluvium.
Bundera Calcarenite
Qrb Bedded fragmental limestone.
PLEISTOCENE
Exmouth Sandstone
Qpe Calcareous sandstone.
? PLIOCENE
Vlaming Sandstone
Tpv Calcareous sandstone
LOWER MIOCENE
Pilgramunna Formation
Tmp Sandy limestone and fine conglomerate with limestone bands
Trealla Limestone
Tmt Foraminiferal limestone
Tulki Limestone
Tmk Crystalline limestone foraminiferal in places
Established Geological Boundary - position accurate
" " " -position approximate
Strike and dip of strata
Prevailing dip
Established anticlinal crest -position accurate
Established synclinal trough -concealed by younger formation
CR78 RC58 NWC51 HGR161 MX34 ER89 Sample numbers - marine fossils
Type section
Coral reef (submerged)
Principal point of air photograph
Trig. station
Vehicle track
Track
Fence
Telephone line
Mangroves
E F Section line
Rough Range 1 Oil bore - productive
" " 2 " " - dry
" " - gas
" " - drilling
Water bore or well
22°15'
113°45'
50'
55'
114°00'
05'
10'
20'
25'
22°30'
Sandy Pt.
Bundera Run 2
Bundera Run 3
Bundera Run 4
Bundera Run 5
Bundera Run 6
Bundera Well
North Yardie Well
BAY OF REST
SYNCLINE
ANTICLINE
DINGO
ROUGH RANGE
Exmouth Gulf Homestead
West Well
Nobilgee Well
Patersons Bore
Dingo Well
Four Corners Bore
South Bore
Bunbury Bore
Exmouth Run 3
Exmouth Run 4
Exmouth Run 5
R.R.2
R.R.3
R.R.4
R.R.5
ROUGH RANGE 1
INDEX TO SHEETS
YARDIE
MANDU
BUNDERA
CLOATES
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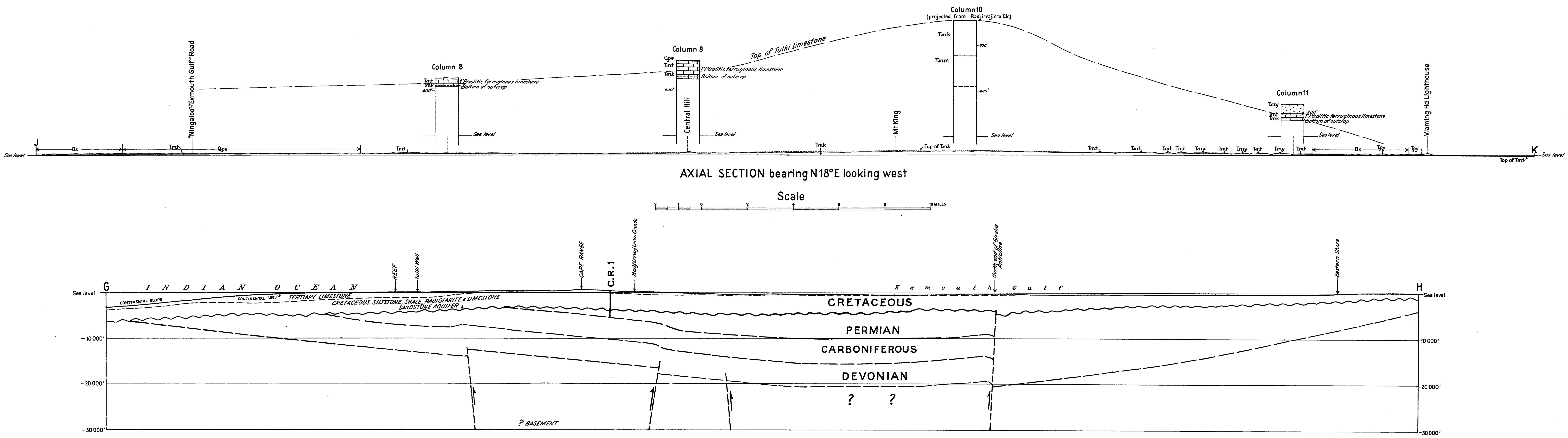
WA 46A-18A

CAPE RANGE STRUCTURE

NORTH WEST DIVISION WESTERN AUSTRALIA



AXIAL SECTION bearing N18°E looking west

Scale

DIAGRAMMATIC
REGIONAL CROSS-SECTION
Bearing 90°
Latitude 22°05'30"

Scale

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WA 46A-14A

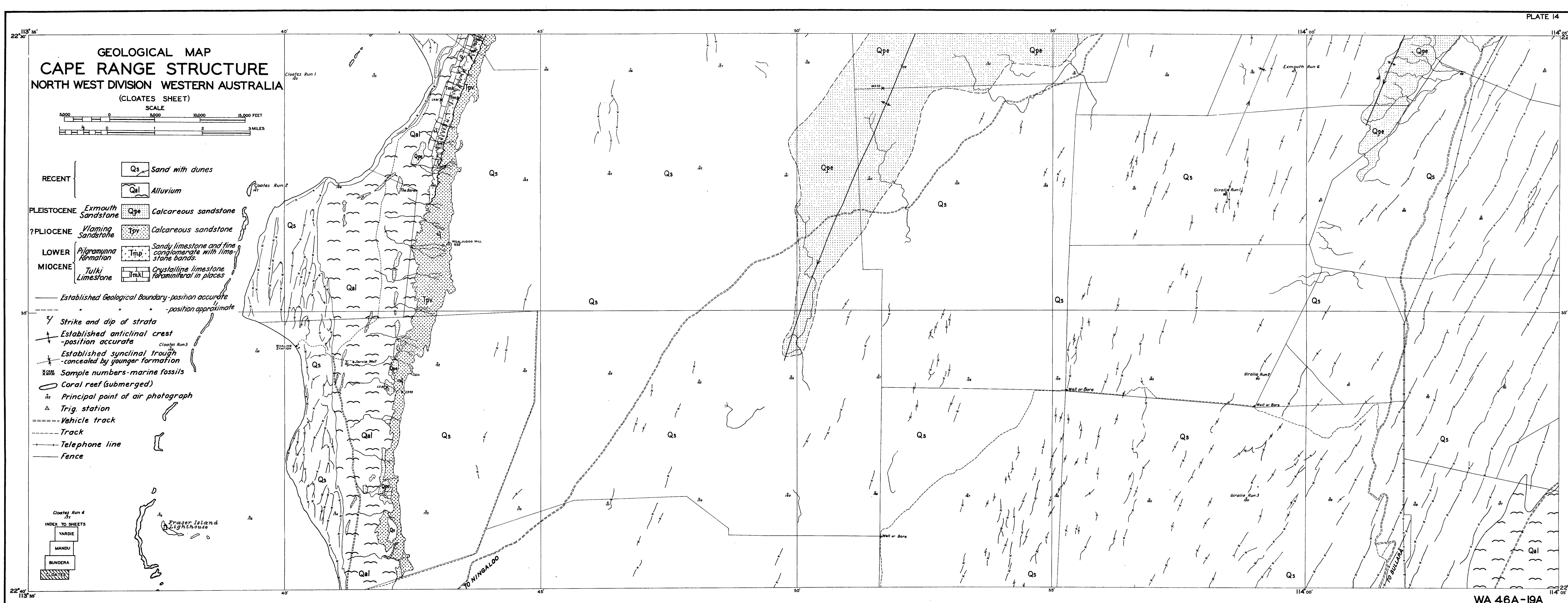

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PLATE 17
CAPE RANGE ANTICLINE
STRUCTURAL CONTOUR MAP
CONTOURS REFER TO THE TOP OF THE TULKI LIMESTONE
CONTOUR INTERVAL 100 FT.
SCALE
FEET 10000 0 10000 20000 30000 FEET
MILES 2 1 ½ 0 1 2 3 4 5 6 MILES
DIP SCALE
MILES
0 2 4 6 8
DEGREES
VLAMING HEAD LIGHTHOUSE
LEARMONTH AIRFIELD
CAPE RANGE ANTICLINE
DINGO SYNCLINE
ROUGH RANGE ANTICLINE
C.R.1
R.R.1
R.R.2
R.R.3
R.R.4
R.R.5
100
200
300
400
500
600
700
800
900
1000
FRASER I. LIGHTHOUSE
NINGALOO WOOLSHED
113°40'
113°45'
113°50'
113°55'
114°00'
114°05'
114°10'
21°50'
21°55'
22°00'
22°05'
22°10'
22°15'
22°20'
22°25'
22°30'
22°35'
22°40'
Bureau of Mineral Resources,
Geology & Geophysics. February, 1951. - Revised December 1954
WA 46A-10A
A.J.S.

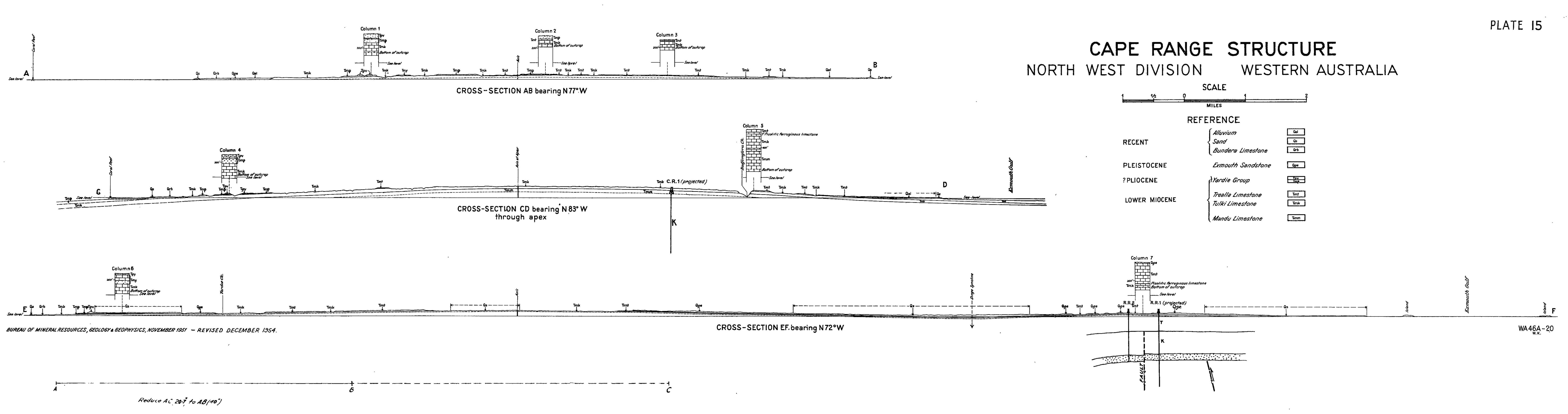
PLATE 15
CAPE RANGE STRUCTURE
NORTH WEST DIVISION WESTERN AUSTRALIA
SCALE
MILES
REFERENCE
RECENT
Alluvium
Sand
Bundera Limestone
PLEISTOCENE
Exmouth Sandstone
? PLIOCENE
Vardie Group
LOWER MIOCENE
Trealla Limestone
Tulki Limestone
Mandu Limestone
CROSS-SECTION AB bearing N71°W
CROSS-SECTION CD bearing N83°W through apex
CROSS-SECTION EF bearing N72°W
BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS, NOVEMBER 1951 — REVISED DECEMBER 1954.
WA 46A-20

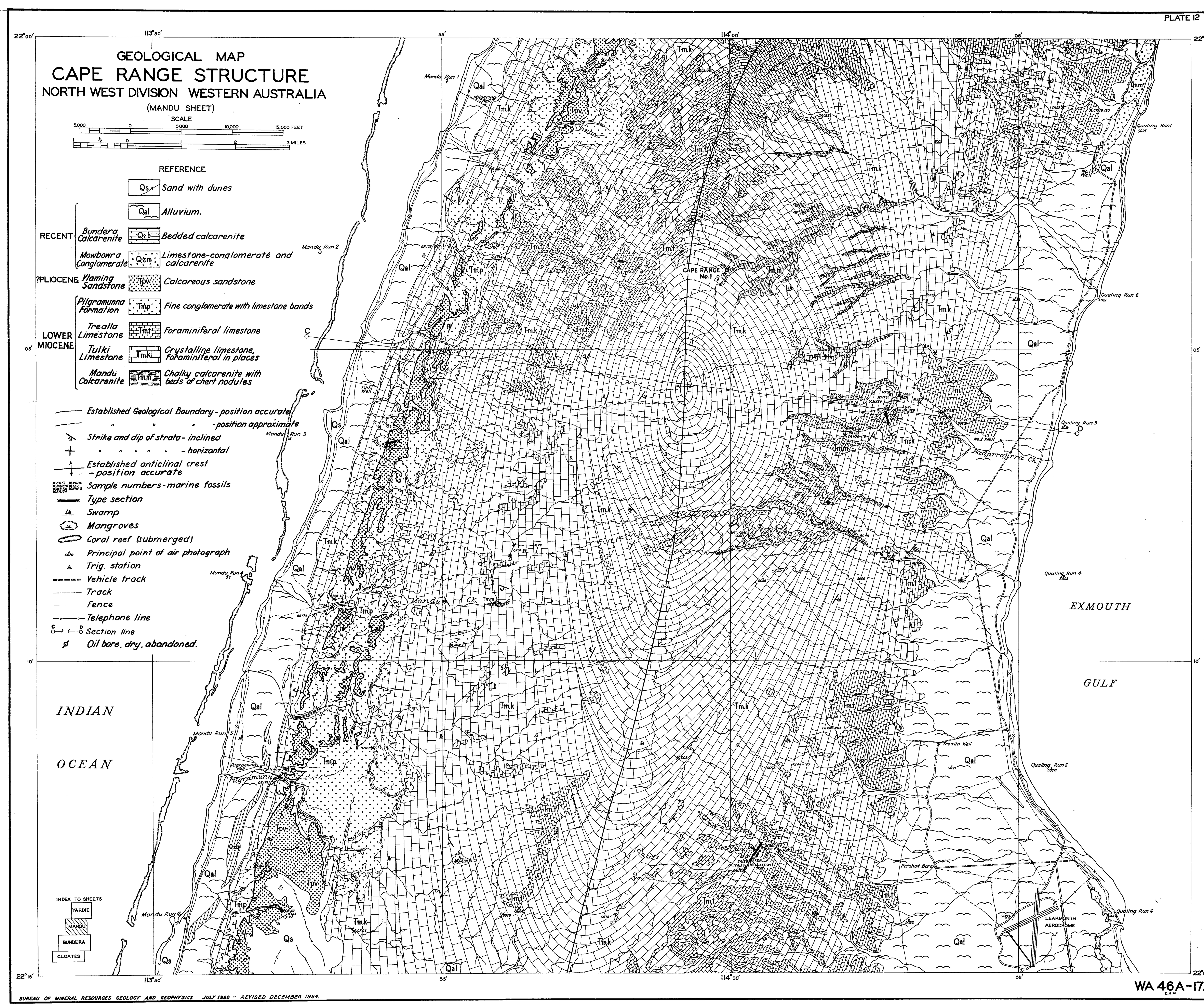
PLATE 12
GEOLOGICAL MAP
CAPE RANGE STRUCTURE
NORTH WEST DIVISION WESTERN AUSTRALIA
(MANDU SHEET)
SCALE
5,000 0 5,000 10,000 15,000 FEET
3 MILES
REFERENCE
Qs Sand with dunes
Qal Alluvium.
RECENT
Bundera Calcarenite Qcb Bedded calcarenite
Mowbowra Conglomerate Qcm Limestone-conglomerate and calcarenite
?PLIOCENE Vlaming Sandstone Tpv Calcareous sandstone
LOWER MIOCENE
Pilgramunna Formation Tmp Fine conglomerate with limestone bands
Trealla Limestone Tmt Foraminiferal limestone
Tulki Limestone Tmk Crystalline limestone, foraminiferal in places
Mandu Calcarenite Tmm Chalky calcarenite with beds of chert nodules
Established Geological Boundary - position accurate
- position approximate
Strike and dip of strata - inclined
- horizontal
Established anticlinal crest - position accurate
Sample numbers - marine fossils
Type section
Swamp
Mangroves
Coral reef (submerged)
Principal point of air photograph
Trig. station
Vehicle track
Track
Fence
Telephone line
Section line
Oil bore, dry, abandoned.
INDIAN
OCEAN
EXMOUTH
GULF
CAPE RANGE No.1
LEARMONTH AERODROME
INDEX TO SHEETS
YARDIE
MANDU
BUNDERA
CLOATES
22°00'
22°15'
113°50'
114°00'
BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS JULY 1950 — REVISED DECEMBER 1954.
WA 46A-17A

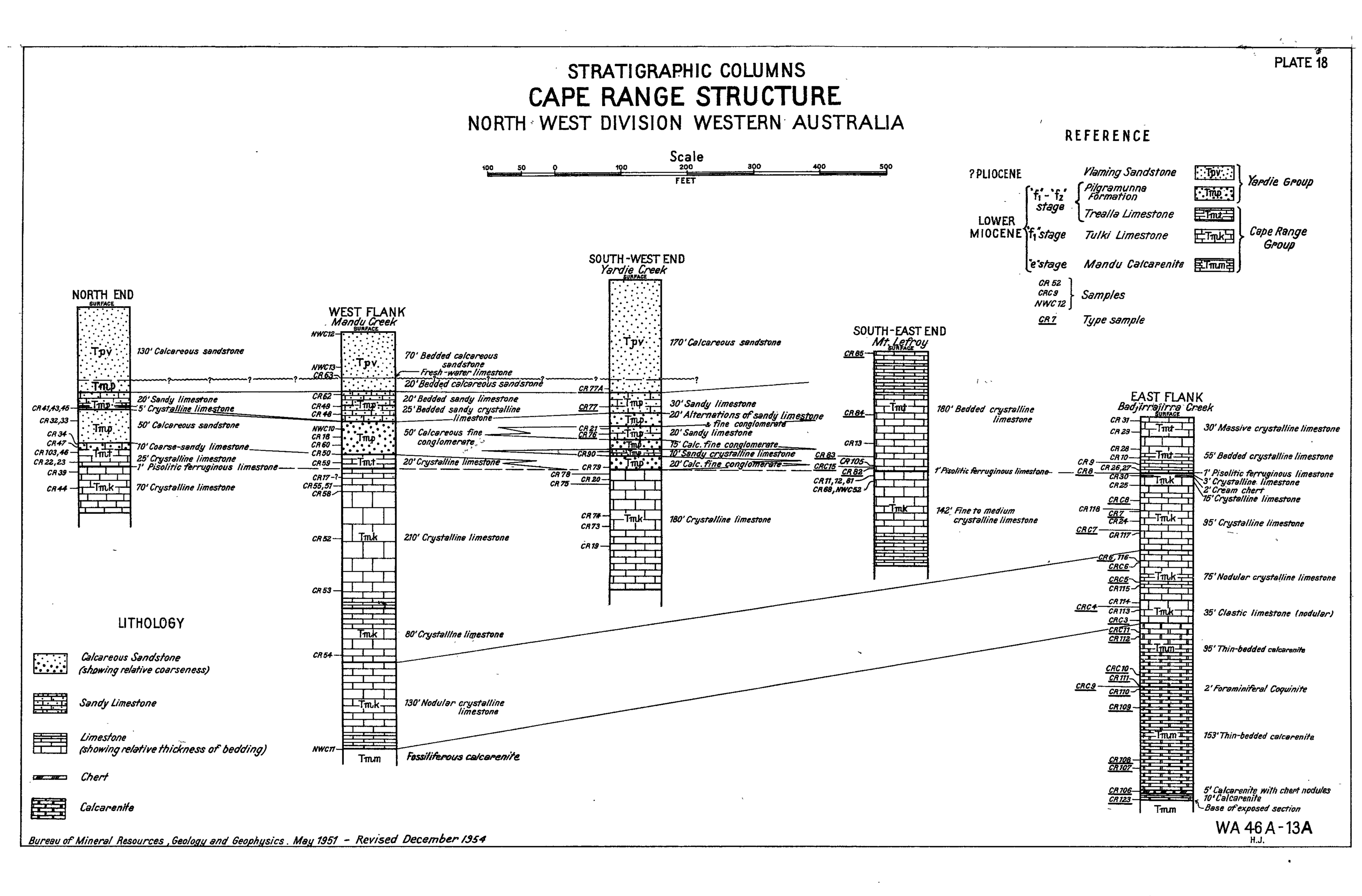
PLATE 18
STRATIGRAPHIC COLUMNS
CAPE RANGE STRUCTURE
NORTH WEST DIVISION WESTERN AUSTRALIA
Scale
FEET
REFERENCE
? PLIOCENE
Vlaming Sandstone
Yardie Group
LOWER MIOCENE
Pilgramunna Formation
Trealla Limestone
Tulki Limestone
Mandu Calcarenite
Cape Range Group
Samples
Type sample
NORTH END
WEST FLANK Mandu Creek
SOUTH-WEST END Yardie Creek
SOUTH-EAST END
EAST FLANK
LITHOLOGY
Calcareous Sandstone (showing relative coarseness)
Sandy limestone
Limestone (showing relative thickness of bedding)
Chert
Calcarenite
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