COMMONWEALTH OF AUSTRALIA

MINISTRY OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 25

THE GIRALIA AND MARRILLA ANTICLINES NORTH WEST DIVISION WESTERN AUSTRALIA

by

M. A. CONDON, D. JOHNSTONE, C. E. PRICHARD and M. H. JOHNSTONE

Issued under the Authority of Senator the Honourable W. H. Spooner, Minister for National Development

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Commonwealth of Australia

DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: SENATOR THE HON. W. H. SPOONER

Secretary: H. G. RAGGATT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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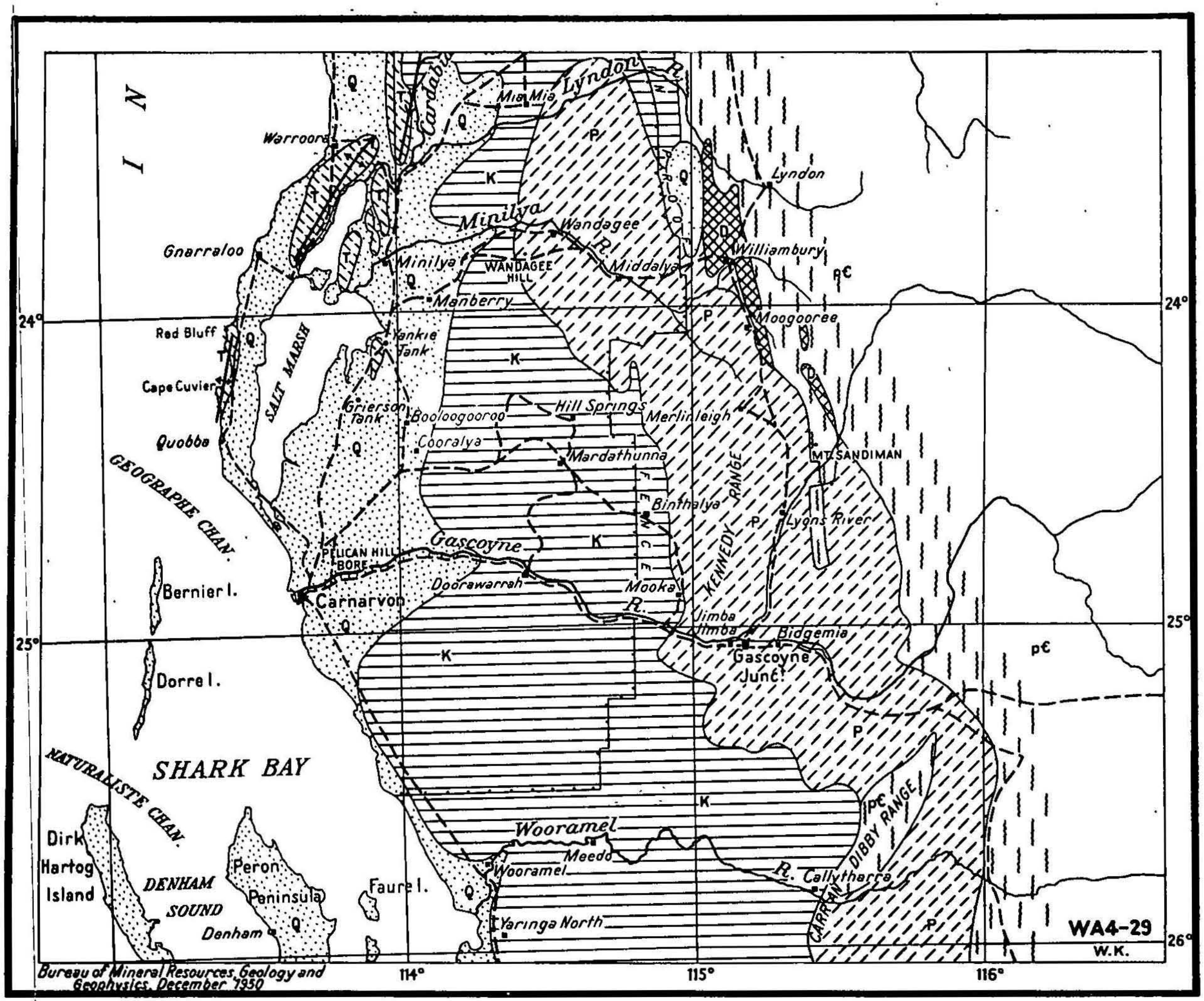
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Grierson Tank
Booloogooroo
Hill Springs
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25°
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Bureau of Mineral Resources, Geology and Geophysics, December 1950

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ABSTRACT

The Giralia and Marrilla Anticlines are in the north-western part of the Carnarvon Basin, North West Division, Western Australia. The Giralia Anticline extends southward for 80 miles from Exmouth Gulf to Salt Lake; the maximum outcrop width across the two anticlines is 18 miles.

The Giralia and Marrilla Anticlines are maturely dissected asymmetrical folds of low relief which consist of sediments deposited in Cretaceous and Tertiary time in a shelf area possibly contiguous with the geosyncline of Timor and East Celebes.

The Giralia Anticline is the second largest of twelve closed anticlines in the post-Palaeozoic sediments of the Carnarvon Basin north of the Gascoyne River. The vertical closure of the Giralia Anticline on the top of the Boongerooda Greensand is 700 feet, and the closed area is 230 square miles.

The anticlines were folded at four different periods, viz. between upper Eocene and lower Miocene, lower Miocene, between lower Miocene and Pleistocene, and Pleistocene or post-Pleistocene.

INTRODUCTION

Local inhabitants refer to the low hills which extend from Exmouth Gulf to the southern boundary of Giralia Station (Plate 2) as the Giralia Range (pronounced ji-ra′-lea); these hills form part of the west flank of the Giralia Anticline. The continuation of the hills on Cardabia Station is called the Cardabia Range (pronounced kar′-da-bi′-a). D. Dale Condit (1935, p.865) defined the "Giralia Range" as "extending southwards from the Gulf for 80 miles to the vicinity of Salt Lake". H. G. Raggatt (1936, p.168) stated that the "Giralia Anticline" extended "from near the mouth of the Lyndon River to the head of Exmouth Gulf", and did not mention the anticline east of the Giralia Anticline.

The authors propose to use "Giralia Range" as defined by Condit, "Giralia Anticline" as defined by Raggatt, and to name the anticline east of the Giralia Anticline the "Marrilla Anticline", as its apical area is in the western part of Marrilla Station.

Location

The Giralia and Marrilla Anticlines are included in the rectangle formed by latitudes 22°25′S and 23°35′S and longitudes 113°55′E and 114°20′E. These co-ordinates are taken from the Military four-mile maps F.50/9 Yanrey and F.50/13 Minilya. The area described in this Bulletin is on the following one-mile map areas, Australian National Grid: Exmouth, Giralia, Whaleback, Marrilla, Cardabia, White Peaks, Warroora, Mia Mia, Farquhar, and Chalubia.

Parts of six pastoral (sheep) holdings—Giralia, Bullara, Cardabia, Warroora, Mia Mia, and Marrilla—are included in the Giralia and Marrilla Anticlines.

Climate, Vegetation, Insects

The annual rainfall of the district averages ten inches. The winter rainfall (May-October) is rather less, and the summer rainfall (November-May) rather more, than five inches. The maximum precipitation is between March and June, and March and June are the two wettest months. The normal mean temperature for July is 60°F.-65°F. January is the hottest month: the temperature in summer frequently exceeds 100°F., and rises on occasions to 110°F.

The Giralia and Marrilla Anticlines are in the *Triodia* steppe of Gardner (1942). The low rainfall and sandy soil control the vegetation. Spinifex (*Triodia*) characterizes the sand dunes and sand-covered areas, which have few trees or shrubs. Stunted trees, shrubs, and patches of spinifex grow on the alluvium and rock outcrops. The larger creeks are prominently marked by Ghost Gums (Eucalypts).

Both the blow-fly (*Lucilia*) and the bush-fly (*Musca*) are common. Sand-flies can be numerous after rain. Mosquitoes (non-malarial type) are not usually troublesome. Many varieties of ants abound.

Accessibility, Communications

The Giralia and Marrilla Anticlines are easily accessible. The most rugged feature is the dissected west limb of the Giralia Anticline, where the steep valley sides and east-facing scarp have a maximum relief of 250 feet.

The northern part of the Giralia Anticline is crossed by a formed earthern road which connects the Giralia and Bullara Homesteads, and continues northward from Bullara Homestead to Learmonth on Exmouth Gulf. At Giralia Homestead the road turns southward to Marrilla Homestead and joins the North West Coast Highway at Winning Pool Post Office. Giralia Homestead is 190 miles from Carnarvon and 155 miles from Onslow via Winning Pool.

An old road which connects Cardabia and Winning Homesteads crosses the Giralia Anticline about six miles south of Remarkable Hill. A branch of this road runs south to Cardabia Pool. From Cardabia Pool one road goes to Winning Homestead; another one continues to Mia Mia Woolshed No. 1 and joins the North West Coast Highway 12 miles west of Mia Mia Homestead. A vehicular track branches to the north from the Cardabia-Winning Road and parallels the escarpment on the west flank of the anticline to a point one mile north of Remarkable Hill. Here the track branches; the east branch connects with the east flank of the Giralia Anticline, and the west branch continues to No. 10 Bore, Cardabia, which is connected to both Cardabia and Bullara Homesteads by road.

Each week stores and mail from Carnarvon are brought to Giralia, Bullara, and Cardabia Homesteads by motor truck.

The closest airfields to the Giralia Range are at Learmonth, and Winning and Cardabia Stations. The bitumen-sealed airfield at Learmonth has two intersecting strips, and is an all-weather airfield. The Winning Station Airfield has two cleared earthen strips at right angles, and is serviceable only in dry weather. Douglas (DC3) aircraft are able to land at both airfields. Aircraft pass through Learmonth weekly on an air route from Perth to Port Hedland, and return the following day. Winning Station is not on a regular air route. Near Cardabia Homestead is an airfield that consists of three intersecting earthen strips; this airfield is suitable only for light aircraft. A cleared earthen strip suitable only for small aircraft is near the Giralia-Bullara Road two miles from Bullara Homestead.

Carnarvon and Onslow are the deep-sea ports now used; both ports are visited weekly by ships of the Western Australia State Shipping Service. Maud, Sandalwood, and Giralia Landings and Learmonth are closer to the Giralia Range. Maud Landing, two and a half miles south-west from

Cardabia Homestead, and Sandalwood and Giralia Landings on the south shore of Exmouth Gulf, were used in the early part of the present century to ship wool in boats with a shallow draft, but are not now in service. During World War II a submarine base was established at Learmonth, and this section of Exmouth Gulf offers the best natural facilities for the establishment of a port for the Cape Range and Giralia Range areas.

Bullara Homestead is in daily contact by radio with the Flying Doctor Service base at Meekatharra. Giralia and Cardabia Homesteads are connected with Carnarvon and Onslow by telephone.

Population, Health

The area is sparsely populated. The few aboriginals in the district live near the homesteads and work on the stations. The inhabitants of the district rely upon the sheep-raising industry and life is centred on the station homesteads.

Although the country is in the tropical zone, the climate is dry and none of the diseases or maladies usually associated with the tropical zone occur. The health of the inhabitants of the district is sound.

Food Supplies

The station homesteads receive their food supplies by road from Carnarvon. Mutton can be bought from the homesteads.

Fish is abundant in Exmouth Gulf. "Plain turkeys" (*Epidotis*), which are protected by law, and kangaroos are the only other game suitable for food.

Water Supply (see Subsurface Geology)

There are no permanent supplies of surface water in the area. After rainfalls of over three inches disconnected water-pools remain in Cardabia Creek and Lyndon River for as long as six months. Cardabia and Korojon Pools are the largest on Cardabia Creek.

Water for domestic and stock purposes is derived mainly from bores and wells. The station homesteads obtain their entire water supply from this source.

The most important sources of water in the Giralia Range areas are: Jubilee, Coast, Centipede, Deep, Salt, and Nabbawarra Bores (Giralia Station), No. 10 and Government or Maud Landing Bores (Cardabia Station), and No. 1 Bore (Warroora Station). All these bores are sub-artesian, except the Maud Landing and Warroora No. 1 Bores, which are artesian.

Centenary Bore (Cardabia Station) was artesian, but it ceased flowing and was abandoned. The top 100 feet of the sub-artesian No. 1 Deep Bore (Cardabia Station) collapsed. The hole was widened and cemented to form a well, but it is not in use.

The water of the Jubilee Bore (said to be 250 feet deep) is potable. The aquifer is in the Jubilee Calcarenite, 180 feet below the bore collar. The bore's capacity is 5,000 to 6,000 gallons daily.

The water from the Coast, Centipede, Deep, and Salt Bores is saline and only suitable for stock. The water from the Nabbawarra Bores is potable.

No. 10 Bore is 300 feet deep and the aquifer, at 190 to 200 feet, is probably the Boongerooda Greensand. The water is potable, but slightly hard.

The Maud Landing Bore is 2359 feet deep. At 55 and 120 feet below the bore collar are small supplies of salt water. The main aquifers are at 2275 feet, which yielded 95,000 gallons, and at 2359 feet, which yielded 559,000 gallons of water daily. The temperature of the water at the collar is about 130°F.

The water-bearing stratum in the Warroora No. 1 Bore is 10 feet of "compressed sand", the top of which is 14 feet from the base of the 1774-foot bore. The daily flow of water is $1\frac{1}{2}$ million gallons.

Subsurface water on the Cardabia Station portion of the Giralia Anticline became such a problem to locate that F. G. Forman inspected the area in 1938. Forman (1939) studied the logs and cores of the shallower bores in this area and recognized three water-bearing horizons in the "*Inoceramus* zone" (Korojon Calcarenite). The water was of "good quality".

An analysis of the logs of the deep bores reveals two important aquifers. The aquifer of the Warroora No. 1 and Maud Landing Bores is a sandstone (probably the Cretaceous Birdrong Formation—refer to p. 78 and Table II) below the blue and black shales of the Winning Group. In the Centenary, No. 1 Deep, and No. 2 Deep Bores, the aquifer is ?Permian sandstone.

As a result of Forman's work and the geological mapping of the present survey, the following seven water-bearing strata were recognized in the sediments of the Giralia and Marrilla Anticlines:

(1) Jubilee Calcarenite, yielding supplies of potable water;

(2) Pirie Calcarenite, yielding limited supplies of salt water;

(3) Boongerooda Greensand, yielding limited supplies of potable water;

(4) Korojon Calcarenite, yielding poor supplies of "good quality" water;

(5) A "sandstone" bed in the Windalia Radiolarite yielding salt water;

(6) Sandstone beneath the Winning Group — an important artesian aquifer capable of producing $1\frac{1}{2}$ million gallons of stock water daily;

(7) Sandstone possibly of Permian age, which is capable of yielding up to $\frac{1}{2}$ million gallons of stock water daily.

Field Methods

The Giralia and Marrilla Anticlines were mapped by geologists of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics. The fieldwork was done from 15 May to 7 July, 1950, by M. A. Condon, Senior Geologist in Charge, D. Johnstone, W. J. Perry, C. E. Prichard, M. H. Johnstone, and J. G. Best. This bulletin was written in the first half of 1953 by D. Johnstone and M. A. Condon. C. E. Prichard and M. H. Johnstone assisted in the compilation of the plates of the bulletin.

Vertical aerial photographs of a scale of about 1:30,000 were used in the field. The points or stations of observation were marked on the photographs. To supply data for a structure contour map of the Giralia and Marrilla Anticlines, barometric elevations were taken on the boundaries of the various formations. A battery of three altimeters was read at the base camp to give the diurnal variations in atmospheric pressure.

Controlled slotted-templet sheets (scale 1:31,000) of the Exmouth, Giralia, and Marrilla one-mile sheets were prepared by the National Mapping Section of the Department of the Interior, and used as a base for the northern part of the map. The Lands and Survey Department of Western Australia compiled the Minilya four-mile sheet, of which the Cardabia, White Peaks, Warroora, Mia Mia, Farquhar, and Chalubia one-mile sheets are part, from a controlled slotted-templet layout of vertical aerial photographs (scale 1:47,500). All these one-mile sheets were reduced photographically to two miles to one inch and compiled to form the map of the area (Plate 3).

Previous Work

Condit and Rudd visited the Giralia Range on behalf of Oil Search Ltd. in 1935 and recognized rocks of Cretaceous and Tertiary ages. Condit (1935) recognized four lithological divisions in the Cretaceous rocks; in descending order they are:

(1) two feet of foraminiferal glauconite sand;

(2) several feet of marly clays abounding in large and small fossils with *Eubaculites* and other cephalopods;

(3) about 75 feet of argillaceous, calcareous shales with *Inoceramus* shells;

(4) gypseous, grey diatomaceous shales.

Condit regarded the friable "chalky limestones with a thickness of a little more than 300 feet" as Tertiary. Specimens from the lowest 100 feet were collected by Condit on the Giralia-Bullara Road, and were referred by Chapman and Crespin (1935) to the middle to upper Eocene — the first marine Eocene rocks discovered in Australia. Younger Tertiary beds with bryozoa and echinoids were thought to be lower Miocene.

Condit, Raggatt, and Rudd (1936) proposed the name "Winning Series" for the radiolarian cherts, white and vari-coloured silts, and glauconitic sands at the base of the Cretaceous System, and "Cardabia Series" for the limestones, chalks, shales, and glauconite sand which outcrop on the Giralia Range.

Forman (1939) investigated the artesian and sub-artesian water possibilities of the Cardabia Station portion of the Giralia Anticline. Forman interpreted bore logs and did not publish any new information on the surface geology of the Giralia Range area.

In 1949, Craig (1950) surveyed the Giralia Anticline from Exmouth Gulf to a point 48 miles south, but did not visit the southern end of the closed anticline.

TOPOGRAPHY

The Giralia Range is a distinct topographical landmark in an otherwise gently undulating terrain of low relief. It consists of a line of hills which extend from the head of Exmouth Gulf to the north end of Salt Lake.

The country adjacent to the Giralia and Marrilla Anticlines is mainly sand and sand dunes. Parallel to the Giralia Anticline and west of Maud Landing and Centenary Bores, the terrain rises, and then gradually slopes seaward before it drops sharply to the Indian Ocean.

Giralia Anticline

The Giralia Anticline is a maturely-dissected fold which is breached along the crest. The undulating western flank has a reduced cuesta-type topography with westward-sloping dip-slopes and steep eastward-facing scarps. On the eastward-facing scarps are Walatharra Hill, Remarkable Hill, and trig point A6, which are respectively 400 feet, 712 feet, and 240 feet above sea level. Of the many consequent streams which drain the western slopes of the anticline, C-Y and Toothawarra Creeks are the only two that are named. The streams disappear in the sand plain to the west of the anticline.

On the east flank of the Giralia Anticline, a narrow low ridge extends for half the length of the structure, and its linear arrangement is only broken by four flexures. From three miles north to 22 miles south of the Giralia-Bullara Road, the ridge rises to about 30 feet above plain level; from there south to Miria Well the ridge is narrow and discontinuous, and ranges in height from 10 to 30 feet above plain level. The east flank has practically no topographical expression south of Miria Well.

The breached apical area of the Giralia Anticline is a topographical depression encircled by escarpments of resistant strata.

Marrilla Anticline

The Marrilla Anticline is a replica of the Giralia Anticline in form and development, but is only a third of its size. The height of the eastward-facing scarp of the western slope of the Marrilla Anticline ranges from 260 feet above sea level at the north end to 410 feet west of the apical area and 526 feet at the south end.

On the east flank of the Marrilla Anticline, a narrow, linear, discontinuous ridge from five to fifteen feet above plain level extends for the entire length of the structure. South of the apex are two prominent curves in the ridge. The breached apical area is a shallow flat-bottomed topographical basin drained by east-flowing creeks.

STRATIGRAPHY

Lithological Nomenclature

The lithological terms calcarenite, calcilutite, caliche, claystone, coquinite, coquinoid, lutite, radiolarite, and travertine are used as defined in Condon (1955).

Stratigraphical Summary

The formations exposed on the Giralia and Marrilla Anticlines are listed in Table I.

The main lithological units are the Cretaceous Winning Group, the Cretaceous to Cretaceous-Tertiary Cardabia Group, the Eocene Giralia Calcarenite, and the Miocene Trealla Limestone. Minor formations are the Miocene Lamont Sandstone and the ?Pleistocene Walatharra Formation.

There is a disconformity between the Winning Group and the Cardabia Group, two disconformities within the Cardabia Group, an erosional disconformity between the Cardabia Group and the Giralia Calcarenite, an agular and erosional unconformity between the Giralia Calcarenite and the Lamont Sandstone or the Trealla Limestone, and an angular and erosional unconformity between the Trealla Limestone and the Walatharra Formation.

Winning and Cardabia Groups

Raggatt (1936, pp.155-162) divided the Cretaceous strata of the Giralia Anticline and Winning Station into two lithological units which he named "Winning Series" and "Cardabia Series". As these units as described are lithological, the term "series" is not valid, and as each contains several formations it is proposed to re-name the units WINNING GROUP and CARDABIA GROUP.

The Cretaceous sediments of the Giralia and Marrilla Anticlines and on Winning and Middalya Stations indicate two different environments of deposition.

(a) A moderately deep marine environment with quite a considerable supply of terrigenous, and possibly volcanic, sediments. Fine-grained rocks (shale, siltstone, radiolarite, chert, bentonitic siltstone) with pelagic fossils were deposited in this environment. The

TABLE I.

STRATIGRAPHY OF THE GIRALIA AND MARRILLA ANTICLINES.

Proposed Name	Derivation of Name	Type Locality of Formation	Lat. and Long. of Type Section	Thickness in feet of type section	Lithology	Percent Calcarenite, Limestone, etc.	Common Fossils	Age
Walatharra Formation	Walatharra Paddock, Giralia Station	3¼ miles west-south-west of Deep Bore, Giralia Station	22° 42′ S. 114° 15′ E.	91	Soft brown calcarenite with limestone pebbles and hard brown limestone pebble conglomerate.	43% calcarenite 35% no outcrop 22% conglomerate		?Pleistocene
EROSIONAL AND ANGULAR UNCONFORMITY								
Trealla Limestone	Original name of Mt. Lefroy, Cape Range, North-West Cape Peninsula	Mt. Lefroy		179 69 (Giralia Anticline)	White to cream fossiliferous limestone	100% limestone	Foraminifera (*Austrotrillina, Flosculinella, Marginopora*), mollusca.	lower Miocene (stage ?f2)

Muderong Shale, Windalia Radiolarite, and Gearle Siltstone are the formations included in this lithological unit.

(b) A shallow marine (neritic) environment with a small supply of terrigenous sediment. Clastic limestone with benthonic and abundant pelagic fossils was the main rock type deposited. The Korojon Calcarenite, Miria Marl, Boongerooda Greensand, Wadera Calcarenite, Pirie Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite are the formations included in this lithological unit.

Raggatt (1936) stated that the "Winning Series" was 1100 feet, and the "Cardabia Series" 1070 feet, thick. Both thicknesses were compiled from outcrops and bore logs. An examination of Raggatt's table (p.156) suggests that the stated thickness of the "Cardabia Series" is too great. Raggatt included in the "Cardabia Series" 835 feet of "chalk, chalky clays and calcereous claystones" (680 feet of which is Gearle Siltstone—see p. 78) from Maud Landing Bore. In the Giralia and Marrilla Anticlines, the total thickness of the type sections of the formations within the Cardabia Group is only 376 feet.

Although Raggatt's thickness of the "Winning Series" agrees with the thickness (estimated from bore logs) of the Winning Group, his section of the "Series" (p.156) contains a duplication of the Windalia Radiolarite and includes the Muderong Shale and only 315 feet of Gearle Siltstone. In Winning No. 1 Bore (see p. 80 of this report), the Winning Group is more than 1040 feet thick. The Winning Group in Winning No. 2 Bore is 1015 feet thick (from 30 to 1045 feet depth in the bore).

Although Raggatt's definition is somewhat confused by the incorrect correlation of surface and bore-log information (p.156) his intention is reasonably definite: "The upper limit of the Winning Series is readily recognised in well logs by the change from foraminiferal chalks (Cardabia series) to dark shaly beds with nodules of pyrites passing downwards into radiolarian mudstones, silts and cherts" (p.158).

In terms of the formations named in this report, the WINNING GROUP comprises the Muderong Shale, Windalia Radiolarite and Gearle Siltstone, and the CARDABIA GROUP comprises the Korojon Calcarenite, Miria Marl, Boongerooda Greensand, Wadera Calcarenite, Pirie Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite.

Cretaceous System

Upper Cretaceous Formations

WINNING GROUP

The Winning Group consists of fine-grained sediments and comprises the Muderong Shale, Windalia Radiolarite, and Gearle Siltstone.

The name Winning is taken from Winning Station. Raggatt's type locality of the "Winning Series" is near Winning Pool Post Office, which is half a mile west of Winning Homestead. However, no single section includes the entire group in outcrop.

Muderong Shale

The Muderong Shale, the oldest formation in the Winning Group, is formally defined by Condon (1954). It is not exposed on the Giralia and Marrilla Anticlines.

Windalia Radiolarite

The Windalia Radiolarite includes the chert, chalky silts, sandy siltstones, shaly rock, and yellow sand, measured by Raggatt (1936, p.156) at Windalia Hill. The Radiolarite is the oldest formation exposed on the Giralia Anticline.

The name Windalia (pronounced win-da'-le-a) is derived from Windalia Hill (trig. point A.46, lat. 23°16'S., long. 114°48'E.), Winning Station.

The type section at Windalia Hill consists of 100 feet of vari-coloured permeable micaceous radiolarite and sandy radiolarite and chert, with foraminifera, pelecypods, belemnites, and ammonites. The base of the Windalia Radiolarite is not exposed on the Giralia and Marrilla anticlines, but the formation conformably overlies the Muderong Shale on Winning and Middalya Stations. The only contact between the Windalia Radiolarite and the Gearle Siltstone known to crop out in the Carnarvon Basin is on the Giralia Anticline; it is poorly exposed and no evidence of a disconformity has been found. The maximum thickness of the Windalia Radiolarite exposed on the Giralia Anticline is 50 feet, in a section three and three-quarter miles north-east from No. 2 Deep Bore, Cardabia. The lithology, in descending order, is

	Gearle Siltstone;
15 feet	Radiolarite (consisting of radiolaria, diatoms, few foraminifera, few ammonites, and few belemnites, in a very fine-grained ground mass of fragments of radiolaria and a little quartz silt), white, blue, pink, buff, green, in beds which range from three inches to one foot thick; interbedded are several three-inch hard brown crystalline limestone beds, and several three-inch ferruginous greensand bands with pelecypods and belemnites.
35 feet	Radiolarite (same as above) with no limestone or greensand bands interbedded, jointed; secondary gypsum formed on bedding and joint planes. Base not exposed.
50 feet	

Whitehouse (Raggatt, 1936, p.157) suggested that the Windalia Radiolarite is equivalent to the Tambo Series (Albian) of Queensland.

Chapman (Raggatt, 1936, and Crespin, 1946) considered the radiolarian rocks to be similar to those of Fanny Bay (Darwin, Northern Territory) and placed them in the Upper Albian.

From rock samples collected during this survey, H. S. Edgell (1952) identified the following foraminifera and radiolaria from the Windalia Radiolarite and attributed an upper Albian to Cenomanian age to the formation:

Foraminifera

Ammobaculites cf. *fisheri* Crespin	(c)*
Ammomarginulina cf. *cragini* Loeblich and Tappan	(r)
Haplophragmoides eggeri Cushman	(f)
Haplophragmoides excavata Cushman	(c)
Pelosina lagenoides Crespin	(r)

Radiolaria

Cenosphaera sp. 1	(a)
Cenosphaera sp. 2	(f)
Dictyomitra australis Hinde	(c)
Dictyomitra multicostata Zittel	(f)
Lithocampe fusiformis Hinde	(f)
Lithocyclia exilis Hinde	(c)
Porodiscus sp.	(f)
Rhopalodictya sp.	(f)
Spongodiscus cf. *expansus* Hinde	(f)
Spongasteriscus sp.	(r)

At various levels in the type section at Windalia Hill large discoidal *Acanthoceratidae*, probably of late Cenomanian age, are fairly common. The *Acanthoceratidae* are associated with several new small species of the *Aconeceratidae*—a family previously believed to be restricted to sequences of Aptian and Albian age (R. O. Brunnschweiler, personal communication, 1953).

The Windalia Radiolarite crops out only in the apical area of the Giralia Anticline, and is not exposed on the Marrilla Anticline.

The Windalia Radiolarite extends in outcrop about 300 miles from Minderoo Station, on the Ashburton River, to the Wooramel River, and up to 90 miles eastward of the coast line.

Craig (1950, p.212) referred to the Windalia Radiolarite as an argillaceous rhyolitic tuff. Petrological examination of radiolarite from the Giralia

*The frequency of the microfossils in this report is shown by: a= abundant, c = common, f = few, r = rare.

Anticline and Winning Station did not show any glass fragments, primary quartz, plagioclase, biotite, hornblende, augite, zircon, etc. In general, the radiolarite is laminated (laminae 0.2mm) and the composition of the samples examined is:

whole radiolarian test (0.1mm) — about 2-5 percent,
quartz (0.05-0.005mm) — about 2 percent,
? diatoms,
? chalcedony (a faintly anisotropic material),
a very fine-grained (less than 0.002mm) ground-mass of rods, rings, and stars of ?opal. Probably the rods, etc., of ?opal are fragments of radiolaria as they have the same colour and refractive index as the material of the radiolarian tests.

Fig. 1.—River cliff in west branch of Cardabia Creek, 7½ miles north of Cardabia Pool. Looking east, at a thin-bedded white Windalia Radiolarite.

Gearle Siltstone

The gypseous clay shales and chalk with barytic concretions found by Raggatt (1936, p.156) at Remarkable Hill and placed in this "Cardabia Series" corresponds to the top of the Gearle Siltstone.

The name Gearle (pronounced gee′-ah-luh, hard g) is taken from Gearle Paddock on Cardabia Station. In this paddock the siltstone is well exposed in Cardabia Creek.

The Gearle Siltstone consists of soft dark grey, brownish, and greyish-green bentonitic siltstone and claystone with secondary gypsum and, in the upper third of the section, barytes nodules up to nine inches in diameter. Fossils include foraminifera, radiolaria, and belemnites.

The formation comfortably overlies the Windalia Radiolarite and is disconformably overlain by the Korojon Calcarenite. The disconformity is discussed on p. 21.

The type section is at lat. 22°54′S., long. 114°09′E. in C-Y Creek, where the contact between the Gearle Siltstone and Korojon Calcarenite is exposed. As C-Y is on the northern plunge of the anticline where dips and strikes are not uniform, the thickness of the Gearle Siltstone was not calculated there.

Fig. 2.—Same locality. Detail of bedding and jointing in Windalia Radiolarite.

The section east of Remarkable Hill is calculated to be 535 feet thick, and consists, in descending order, of:

	Korojon Calcarenite;
160 feet	Siltstone and claystone, bentonitic, dark brown to pale greyish green; soft, tough (when moist), friable (when dry), with many bartyes concretions, up to 9 inches in diameter, derived from thin beds of primary barytes; much secondary gypsum; foraminifera, radiolaria, ostracods
375 feet	Siltstone and claystone (as above) with a few barytes concretions; foraminifera, radiolaria, ostracods, belemnites.
	Windalia Radiolarite.
535 feet	

Fig. 3.—East branch, Cardabia Creek, 3½ miles north-east of Cardabia Pool. Looking south at outcrop of Gearle Siltstone showing typical white gypsite soil over dark grey bentonitic siltstone.

Chapman and Crespin (Raggatt, 1936, pp. 160-1) attributed a Turonian age to the foraminifera of the "marls and chalks" of the "Cardabia Series", that is Gearle Siltstone and Korojon Calcarenite.

Crespin (1938a) suggested a Turonian age for the "chalks" and the possibility that strata of Cenomanian to Campanian age may be in the area.

Edgell (1952) determined the following foraminifera from the Gearle Siltstone:

Foraminifera

Ammobaculites cf. *fisheri* Crespin	(c)
Ammodiscus cretaceus (Reuss)	(f)
Ammomarginulina cragini Loeblich & Tappan	(r)
Anomalina rubiginosa Cushman	
Frondicularia sp.	(r)
Gaudryinella irregularis (Tappan)	(f)
Globigerina cretacea d'Orb.	(f)
Globigerinella aspera (Ehren.)	(r)
Globotruncana cf. *arca* (Cushman)	(r)
Globorotalites micheliniana (d'Orb.)	
Haplophragmoides sp.	(f)
Lagena sulcata (W. and J.)	(r)
Marssonella oxycona (Reuss)	
Pelosina sp.	
Planularia cf. *liebusi* Brotzen	
Planulina taylorensis (Carsey)	(r)
Saracenaria triangularis (d'Orb.)	
Spiroplectammina grzybowskii Frizzell	(a)
Textularia cf. *washitensis* Carsey	
Trochamminoides cf. coronus (Loeblich & Tappan)	(r)
Vaginulina cf. *recta* Reuss	(r)

The only mega-fossils identified from the Gearle Siltstone were:

Pecten sp.
Dimitobelus sp. nov. (Brunnschweiler, 1952).

The fauna examined are insufficient to determine the age of the Gearle Siltstone exactly. The age of the Gearle Siltstone is discussed with the age of the Korojon Calcarenite (p. 24).

The Gearle Siltstone crops out in the apical areas of the Giralia and Marrilla Anticlines, in a small dome three miles south-west of Korojon Pool, and as three small inliers on the northern plunge of the Giralia Anticline. The Gearle Siltstone is the oldest formation exposed on the Marrilla Anticline. Topographically the outcrop of the Gearle Siltstone forms low flat areas — a basin in the apical area of the Marrilla Anticline, an annular plain and several small basins in the Giralia Anticline. Large shrinkage cracks are a feature of these small flat areas.

The Gearle Siltstone was calculated to be 400 feet thick six and a quarter miles east-south-east from No. 10 Bore and 565 feet thick six miles north-west from No. 1 Deep Bore.

Outside the Giralia and Marrilla Anticlines, the Gearle Siltstone crops out north of Chinkia Creek on Mia Mia Station, near Wandagee Station Woolshed, and on Hill Springs, Mardathunna, and Doorawarrah Stations. A black shale, probably the equivalent of the Gearle Siltstone, was encountered in the Neemarabadoo Bore, Minilya Station, in the Yankie Tank Anticline.

A feature of the Gearle Siltstone is its bentonite content. Bentonite is commonly supposed to have a volcanic origin. The residue obtained on washing out the clay from samples of Gearle Siltstone contains limonite-stained clay, quartz, calcite, and gypsum, but no fragments of volcanic glass, plagioclase, pyroxenes, or other minerals typical of volcanic origin. The precise mineralogical composition of the bentonitic siltstone is not completely known, but it is thought that the montmorillonite and beidellite may have been derived from mature soils on a source area of low relief. These clay minerals are not known from marine sediments but are common in mature soils.

CARDABIA GROUP

The Cardabia Group consists of the Korojon Calcarenite, Miria Marl, Boongerooda Greensand, Wadera Calcarenite, Pirie Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite. The Group corresponds to the "*Inoceramus* marls", "glauconite sand to sandstone," and "sandy polyzoal limestone" of the "Cardabia Series" (Raggatt, 1936).

The name (pronounced kar-da-bi'-a) was taken by K. Washington Gray and Raggatt (Raggatt, 1936, p.158) from Cardabia Station, where the Group is well exposed.

Korojon Calcarenite

The name Korojon (pronounced kor'-o-jon) is derived from Korojon Pool, on Cardabia Creek where it cuts through the steeply dipping strata of the south nose of the Giralia Anticline.

The Korojon Calcarenite consists of friable white and cream calcarenite and hard cream coquinoid calcarenite with abundant shells and fragments of *Inoceramus*.

The Korojon Calcarenite is the oldest formation of the Cardabia Group and is disconformable with the Gearle Siltstone below and the Miria Marl above. The contact between Gearle Siltstone and Korojon Calcarenite is marked by a two-inch conglomerate which is seen *in situ*, and which is probably a minor basal transgression of the Korojon Calcarenite. Components of the conglomerate litter the surface east of the contact between the Gearle

Siltstone and the Korojon Calcarenite on the west flank, and show on the aerial photographs as dark brown to black, irregularly shaped, thickly matted patches. The pebbles of the conglomerate range in size from half an inch to four inches, with an average of about three quarters of an inch. The conglomerate is composed of rounded and platy ironstone nodules (limonite,

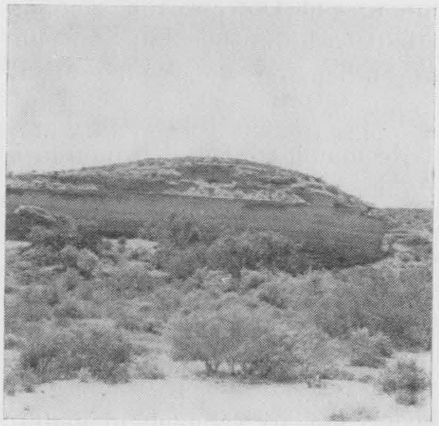

Fig. 4.—Same locality, showing thin-bedded cream Korojon Calcarenite.

Fig. 5.—Same locality showing details of Inoceramus coquinoid calcarenite. a-a: valve of Inoceramus about 36 ins. long.

Fig. 6.—C-Y Creek, 6 miles east-north-east of No. 10 bore, Cardabia Station. Looking north-west. Uppermost beds of Korojon Calcarenite.

limonite after hematite, crystalline hematite), and angular and rounded granules and pebbles of banded chert, quartzite, and white quartz. The contact between the Korojon Calcarenite and the Miria Marl is sharp and irregular, and in places there is a bed of calcareous nodules (one inch in diameter) at the contact.

The type section is at lat. 22°53′S., long. 114°07′E. in C-Y Creek. Sections of the supper two-thirds of the formation crop out at many places, but only the type section exposes the lower part of the Korojon Calcarenite and its contact with the Gearle Siltstone. The type section of the Korojon Calcarenite consists, in descending order, of:

Miria Marl;

1 inch Nodule bed, calcareous nodules grown on *Inoceramus* plates.

5 feet Marl, friable to loose, light brown, with *Inoceramus* (Specimen R3997)*;

12 feet Calcarenite, *Inoceramus* coquinoid, friable, light grey, with small fossils (R3998);

5 feet Calcarenite, friable, light grey, with *Inoceramus* and six-inch beds of *Inoceramus* coquinoid calcarenite;

2 inch Nodule bed, two inch diameter calcareous nodules grown on *Inoceramus* plates;

5 feet NO OUTCROP;

5 feet Calcarenite, friable, cream, with *Inoceramus* (R3999);

3 feet Coquinite, *Inoceramus*, medium hard, white;

8 feet Calcarenite, *Inoceramus* coquinoid, firm to medium hard, light grey;

9 feet Calcarenite, marly, friable, light grey, with *Inoceramus* and foraminifera (R4000);

½ foot Calcarenite, fine-grained, medium hard, with *Inoceramus*;

6½ feet NO OUTCROP;

1 foot Calcarenite, medium hard, white, with *Inoceramus;*

19 feet Calcarenite, *Inoceramus* coquinoid, friable and medium hard, white;

1 foot Calcarenite, hard, white, with *Inoceramus* (R4001);

5 feet Calcarenite, *Inoceramus* coquinoid, friable, cream;

1 foot Coquinite, *Inoceramus,* medium hard, white;

3 feet Calcarenite, *Inoceramus* coquinoid, friable, light grey;

6 feet Calcarenite, friable, light grey, with *Inoceramus* fragments;

1 inch Nodule bed, one inch diameter nodules of calcite on *Inoceramus* fragments;

1 foot Calcarenite, marly, friable, light grey, with small pelecypods and *Inoceramus* fragments (R4002);

1 inch Nodule bed;

5 feet Calcarenite, marly, friable, light grey, with calcareous nodules and *Inoceramus* prisms;

1 inch Nodule bed;

8 feet Calcarenite, marly, friable, light grey, with large *Inoceramus;*

---

* Numbers refer to specimens in the Bureau's collection.

17 feet Alternating calcarenite and marl. Calcarenite, friable, light grey (weathers white), with *Inoceramus*; marl, friable, grey, with *Inoceramus* prisms (R4003);

1 inch Nodule bed, three-quarter of an inch diameter brown calcareous nodules;

2 inches Conglomerate of brown calcareous and hematite nodules up to 1½ inches in diameter;
Gearle Siltstone.

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126 feet

On foraminiferal evidence Chapman and Crespin (Raggatt, 1936, p.161) referred the "*Inoceramus* marls" (Korojon Calcarenite) to the Turonian Stage of the Upper Cretaceous.

Edgell (1952) examined foraminifera from the Korojon Calcarenite and divided the formation into a lower and an upper part. The following foraminifera were identified:

Upper Part (Top 20 to 25 feet of the Korojon Calcarenite):

Bolivinoides draco draco (Marsson)	(a)
Globotruncana cf. *arca* (Cushman)	(f)
Neoflabellina reticulata (Reuss)	(f)
Pseudotextularia varians Rzehak	(f)

Lower Part (Bottom 100 to 105 feet of the Korojon Calcarenite):

Cibicides ribbingae Brotzen	(c)
Frondicularia biformis Marsson	(f)
Globotruncana lapparenti var. Brotzen	(r)
Planulina taylorensis (Carsey)	(a)

Brunnschweiler (pers. com., 1953) identified the following mega-fossils:

Cephalopoda

Baculites sp.
Bostrychoceras indicum (Stol.)
Desmoceras (*Latidorsella*?) sp.
Hauericeras sp. (*H. pseudogardeni* (Schluter)?)
Puzosia sp. indet.

Brunnschweiler states that *Bostrychoceras indicum* (Stol.) is at present the only fossil that is of some value for an age determination. It allows an approximate correlation with the Pondicherry Beds of Southern India, which are regarded as Santonian by most authors. As with the Gearle Siltstone, the total time interval for the formation of the Korojon Calcarenite is unknown. It can be placed between probable Turonian (upper part of the Gearle Siltstone) and certain late Campanian (basal part of the Miria Marl), but the formation seems to represent only a comparatively short interval of the later Senonian. The Korojon Calcarenite includes certainly Santonian, but perhaps also early Campanian.

The Korojon Calcarenite is well exposed on the north, north-east, south, and west flanks of the Giralia Anticline; on the south-east flank the exposures are poor.

The hard beds in the upper half of the Korojon Calcarenite form the innermost and most prominent scarp on the Giralia Anticline.

Outcrops of the Korojon Calcarenite are poor on the north, east, and south flanks of the Marrilla Anticline; the best exposure is on the west flank where the hard beds of the upper half of the Korojon Calcarenite form a prominent scarp.

The Korojon Calcarenite at Remarkable Hill is 130 feet thick. The bottom 50 feet is poorly exposed and the thickness was calculated. The top 80 feet, in descending order, consists of:

	Miria Marl;
13 feet	Calcarenite, slightly glauconitic, friable, soft, brownish-white, with foraminifera, small mollusca, few *Inoceramus* fragments (R3904);
31 feet	Calcarenite, friable, soft, white, with *Inoceramus* plates;
4 feet	Calcilutite, partly crystalline, hard, white, with *Inoceramus* (R3903);
24 feet	Calcarenite, slightly glauconitic, friable, soft, with *Inoceramus*;
2 feet	Calcarenite, *Inoceramus* coquinoid, hard, yellowish white;
1 foot	Calcarenite, *Inoceramus* coquinoid (R3902);
5 feet	Calcarenite, friable, soft, buff, with *Inoceramus* plates;
	50 feet of Korojon Calcarenite.
80 feet	

The thickness of the Korojon Calcarenite was calculated to be: 185 feet, three and a half miles west-south-west of Lamont Well; 200 feet, seven miles south of Lamont Well; 175 feet, one mile west of Korojon Pool; and 75 feet, four miles south-west of Korojon Pool, where the lower Miocene Trealla Limestone unconformably overlaps the Korojon Calcarenite.

In the Giralia and Marrilla Anticlines the Korojon Calcarenite has a depositional convergence to the north-north-west of 10 feet per mile.

Except for the Gearle Siltstone, the Korojon Calcarenite has the largest area of outcrop of the formations in the Giralia and Marrilla Anticlines. It is the oldest formation exposed on the Warroora and Chargoo Anticlines

(Plate 1), and also crops out on Yankie Tank Anticline. Poor exposures of the Korojon Calcarenite occur north of Chinkia Creek, two miles east of Mia Mia No. 4 Bore (Plate 3), and on Hill Springs, Mardathunna, and Doorawarrah Stations.

"Chalks" crop out in the Murchison River area, and at Dandarragan and Gingin. The "chalk" is 35-120 feet thick at Murchison River, 20-40 feet at Dandarragan, and 70 feet at Gingin. Teichert (1946) states that the "chalk" at Gingin contains crinoids (including *Marsupites*, *Uintacrinus*), small brachiopods, pelecypods (including *Inoceramus* almost 20 inches long), and ammonites. The Toolonga Chalk of the Murchison River and the "chalk" at Dandarragan contain fossils identical with those of the "chalk" of Gingin, which is Santonian in age (Teichert, 1946).

A feature of the Korojon Calcarenite is the abundance and size of *Inoceramus*. *Inoceramus* shells 36 inches long and 0.8 inch thick occur. A complete *Inoceramus* shell is rare. Individual pieces of the shell are not parallel to the bedding-plane, and, although the fragments are distributed throughout the entire formation, they are more abundant in some parts of the sequence, both laterally and vertically, than others. Before stratification, the *Inoceramus* shells were reworked and broken. Many shells which escaped destruction from being reworked were crushed and broken by the weight of the overlying sediments during compaction and consolidation.

Miria Marl

Condit (1935) recognized several feet of marly clays with small and large fossils (*Eubaculites* and other cephalopods). For this formation the name "Miria Marl" is proposed.

Raggatt (1936) erroneously referred to the lithological unit which overlies the Korojon Calcarenite ("*Inoceramus* marls" of Raggatt) as "glauconite sand to sandstone with ammonites and coprolite" and "ammonite greensand". This error is also found in publications by Spath (1940) and Teichert (1946). The authors of this report found that it is not the conspicuous greensand (Boongerooda Greensand, p. 29) which contains the ammonites, but a thin marl formation (the Miria Marl) between the Korojon Calcarenite and the Boongerooda Greensand.

Miria (pronounced mir'-ia) is the name of a paddock on Cardabia Station 20 miles south-south-east of the type section.

The Miria Marl consists of marl and calcarenite, with foraminifera, corals, many brachiopods, pelecypods, gastropods, and abundant ammonites and nautiloids. The Miria Marl is disconformable with the Korojon Calcarenite below and the Boongerooda Greensand above. The contact between the Korojon Calcarenite and the Miria Marl was discussed on p. 22 The contact between the Miria Marl and the Boongerooda Greensand is sharp and in places is marked by a one-inch band of coarse-grained quartz sand (see section p. 23); the top of the Miria Marl is white and leached.

The type section is at lat. 22°50′S., long. 114°08½′E. in Toothawarra Creek. It consists, in descending order, of:

Boongerooda Greensand;

1 foot	Marl, loose, light greenish-grey, with foraminifera, corals, many brachiopods, pelecypods, and gastropods, abundant ammonites and nautiloids, a few shark teeth (R.3927).
3 feet	Calcarenite, friable, light brown, with brachiopods and pelecypods. 1 inch nodule bed at the top of the Korojon Calcarenite.
4 feet	

Previous workers who examined ammonites from the marl assigned them to the following ages:

Lower Campanian by Whitehouse (Condit, 1935);
Lower Maestrichtian and possibly late Campanian by Spath (1940);
Maestrichtian by Teichert (Craig, 1950).

Edgell (1952) determined the following foraminifera from the Miria Marl and attributed a Maestrichtian age to the formation:

Bolivinoides draco draco Marsson	(a)
Globotruncana arca (Cushman)	(c)
Globotruncana spp.	(f)
Lituola taylorensis Cushman	(c)
Pseudotextularia acervulinoides (Egger)	(f)
Pseudotextularia varians Rzehak	(c)

Brunnschweiler (1952) studied the ammonite fauna systematically and recognised two successive, though partly overlapping, assemblages; one is upper Campanian, the other lower Maestrichtian in age.

Some of the ammonites identified are:

Upper Part

Diplomoceras cylindraceum (Defrance)
Eubaculites vagina (Forbes)
Pachydiscus cf. *P. egertoni* (Forbes)
Pachydiscus cf. *P. fresvillensis* Seunes
Pseudophyllites indra (Forbes)

Lower Part

Desmophyllites cf. *D. larteti* (Seunes)
Eubaculites vagina (Forbes)
Gandryceras varagurense Kossmat

Glyptoxoceras indicum (Forbes)
Kossmaticeras (Gunnarites) sp.
Pachydiscus cf. *P. ootacodensis* (Stol.)
Paraphylloceras surya (Forbes)
Tetragonites cf. *T. cala* (Forbes).

The Miria Marl normally crops out as a thin bed at the base of a five-to-ten-foot scarp capped by the hard basal beds of the Wadera Calcarenite. A subsequent stream in the soft beds at the top of the Korojon Calcarenite parallels the scarp.

The Miria Marl is exposed on all flanks of the Giralia and Marrilla Anticlines except the south-east flank of the Giralia Anticline and the north-east flank of the Marrilla Anticline.

The Miria Marl ranges in thickness from two to seven feet.

On the west flank of the Giralia Anticline five miles west of Lamont Well, the Baria Marl consists of:

	Boongerooda Greensand;
5 feet	Marl, friable, dark greenish grey, with foraminifera, corals, many small brachiopods, pelecypods, and gastropods, abundant ammonites and nautiliods;
	Korojon Calcarenite.
5 feet	

Three-quarters of a mile south-south-east from Remarkable Hill, the Miria Marl consists of:

	Boongerooda Greensand;
1 foot	Calcarenite, fine-grained, loose, light brown, with foraminifera, many small brachiopods, pelecypods, and gastropods, abundant ammonites and nautiliods;
6 feet	Calcarenite, fine-grained, loose, light brown;
1 inch	Nodule bed at the top of the Korojon Calcarenite.
7 feet	

The Miria Marl crops out on the Warroora and Chargoo Anticlines. No formation comparable with it is exposed in the Upper Cretaceous strata at Murchison River, Dandarragan, or Gingin.

The Miria Marl is a well-defined marker bed which is characterized by an abundance of many different types of megafossils. Although it is not always exposed, the approximate position of the marl is indicated by the numerous pelecypods, ammonites, and nautiloids which litter the ground.

Cretaceous-Tertiary Formations

CARDABIA GROUP

The micro-fossils of the Boongerooda Greensand, Wadera Calcarenite, Pirie Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite suggest a Palaeocene age (Edgell, 1952), whereas the mega-fossils of these formations have Danian affinities (Brunnschweiler, 1952). Because of the world-wide dispute as to whether the Danian shall be included in the Tertiary or not, and until more conclusive evidence is produced from the Giralia and Marrilla Anticlines, this apparent inconsistency will be overcome in this report by referring to the ages of the Boongerooda Greensand, Wadera Calcarenite, Pirie Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite as CRETACEOUS-TERTIARY FORMATIONS (meaning Cretaceous-to-Tertiary).

Boongerooda Greensand

The name Boongerooda (pronounced as spelt, with G hard) is taken from Boongerooda Clay Hole on C-Y Creek. The location of Boongerooda C.H. is shown on the W.A. Lands and Survey Department's Sheet 13 (Onslow) of the 10-mile Topographical Series.

Fig. 7.—Remarkable Hill from the north.
a.—Cashin Calcarenite
b.—Pirie Calcarenite
c.—Wadera Calcarenite.
d.—Boongerooda Greensand and Miria Marl
e.—Korojon Calcarenite.

The Boongerooda Greensand is a thin formation composed of green glauconite sand, and is disconformable with the Miria Marl below and conformable with the Wadera Calcarenite above.

The type section, at lat. 22°50′S., long. 114°08½′E. in Toothawarra Creek, is as follows:

	Wadera Calcarenite;
10 feet	Sand, glauconite, loose, dark green, with foraminifera and many brachiopods (R3926);
	Miria Marl.
10 feet	

Condit (1935) placed the "two feet of foraminiferal glauconite sand" at the top of the Cretaceous. Crespin (1938a) gave the age of foraminifera from the "glauconite sands" as Santonian. Miss Crespin states that the material examined consisted of unconsolidated glauconite sand, which, it is now known, was not collected *in situ* (pers. com., 1952).

Edgell (1952) identified the following foraminifera from the Boongerooda Greensand:

Anomalinoides danica Brotzen	(c)
Bulimina aspero-aculeata Brotzen	(c).
Bulimina midwayensis (Cushman and Parker)	(r)
Citharina plummoides (Plummer)	(r)
Clavulinoides aspera (Cushman)	
Gavelinella lellingensis (Brotzen)	(c)
Globigerina mexicana (Cushman)	(a)
Globigerina pseudobulloides Plummer	(f)
Globigerina triloculinoides Plummer	(f)
Globorotalia cocoaensis Cushman	
Globorotalia membranacea (Ehrenberg)	(f)
Globorotalia spinulosa Cushman	(c)
Globorotalia wilcoxensis Cushman and Pouton	
Guttulina hantkeni Cushman and Ozawa	(f)
Nodosaria vertebralis (Batsch)	
Osangularia velascoensis (Cushman)	(c)
Siphonodosaria plummerae Cushman	(c)
Vaginulina legumen Linne	

Brunnschweiler (pers. comm., 1953) determined the following megafossils from the Greensand:

Corala

Asterosmilia spp.
Caryophyllia spp.

Brachiopoda

Cyclothyris spp. nov.
Liothyrina sp. nov.
Magas spp.
Terebratulina sp. cf. *T. dutempleans* d'Orb.

Pelecypoda

Gryphaeostrea vomer (Morton)
Lima spp.
Ostrea (*Pycnodonta*) *vesicularis* Lam.
Trigonia sp. indet.

Annelida

Tubulostium sp. cf. T. *besairiei* Collignon.

The Boongerooda Greensand is regarded as Palaeocene (basal Tertiary) in age by Edgell and Danian (uppermost Cretaceous) by Brunnschweiler. In this paper the Greensand will be referred to as Cretaceous-Tertiary in age.

The Boongerooda Greensand crops out as a thin bed and has the same distribution and outcrop pattern as the Miria Marl, but its exposures are better.

Three and one-quarter miles east-south-east from No. 10 Bore, Cardabia, the section of the Boongerooda Greensand is:

	Wadera Calcarenite;
5 feet	Sand, glauconite, greenish-grey, with small brachiopods;
1 inch	Sand, quartz, coarse-grained, with well-rounded glauconite (GC41); Miria Marl.
5 feet 1 inch	

The thickness of the Boongerooda Greensand ranges from two to eight feet and averages three feet. Apart from the Giralia and Marrilla Anticlines the only known outcrops of Boongerooda Greensand in the Carnarvon Basin are on the Waroora and Chargoo Anticlines.

Although the Cretaceous formations contain small amounts of glauconite it is most abundant in the Boongerooda Greensand. Further information on the glauconite is given in the section on non-metallic minerals (p. 84).

Wadera Calcarenite

In a section "near Remarkable Hill", Raggatt (1936, p.156) measured 85 feet of "sandy, white or yellow polyzoal limestone with hard yellowish-green bands up to 10 feet thick". The bottom 40 to 47 feet of the section is referred to in this report as the Wadera Calcarenite.

Wadera (pronounced wod-ee'-ruh) is the name of a paddock on Cardabia Station 13 miles south-west from the type section.

The Wadera Calcarenite consists of friable greenish-grey glauconitic calcarenite with a few beds of brown glauconitic crystalline limestone, with foraminifera, corals, echinoids, bryozoa and brachiopods. The Wadera Calcarenite is conformable with the Pirie Calcarenite above and the Boongerooda Greensand below.

The type section is at lat. 22°49$\frac{3}{4}$'S., long. 114°08$\frac{1}{2}$'E., in Toothawarra Creek. The section, in descending order, consists of:

	Pirie Calcarenite;
2 feet	Calcarenite, glauconitic, greenish brown, hard;
3 feet	Coquinite, bryozoan, friable;
1$\frac{1}{2}$ feet	Calcarenite, glauconitic, greenish-brown, hard, with well-developed joints;

2 feet	NO OUTCROP;
4½ feet	Calcarenite, glauconitic, friable and hard, yellowish-brown, with brachiopods (R3922);
4 feet	Calcarenite, glauconitic, friable and hard, yellowish-green (R3923);
16 feet	NO OUTCROP. Possibly friable calcarenite;
3 feet	Calcarenite, friable, greenish-grey, with foraminifera, many echinoids, bryozoa and brachiopods (R3924);
19 feet	NO OUTCROP; possibly friable calcarenite; faulting;
2 feet	Limestone, crystalline, fine-grained, light brown, hard;
6 feet	Calcarenite, friable, light greenish-grey;
1 foot	Limestone, crystalline, fine-grained, light brown, hard;
10 feet	Calcarenite, loose to friable, light greenish-grey, with brachiopods and bryozoa (R3925);
1 foot	Limestone, crystalline, glauconitic, fine-grained, light brown, hard: Boongerooda Greensand.
75 feet	

Edgell (1952) recognized the following foraminifera from the Wadera Calcarenite.

Alabamina obtusa (W. & B.) var. *westraliensis* Parr	(r)
Anomalinoides danica Brotzen	(f)
Anomalina perthensis Parr	(f)
Bulimina aspero-aculeata Brotzen	(f)
Citharina plummoides (Plummer)	(r)
Coleites reticulosus Plummer	(r)
Globigerina mexicana Cushman	(a)
Globigerina triloculinoides Plummer	(a)
Globorotalia spinulosa Cushman	(c)
Globorotalia membranacea (Ehrenberg)	(c)
Gyroidina soldanii (d'Orb.) var. *subangulata* Plummer	(r)
Karreria cubensis (Cushman and Bermudez)	(r)
Palmula sp. I	(f)
Osangularia velascoensis (Cushman)	(f)
Siphonodosaria plummerae Cushman	(r)
Vaginulinopsis longiformis (Plummer)	(a)

The following fossils were identified from the Wadera Calcarenite by Brunnschweiler (pers. com., 1953):

Echinoidea

Cardiaster spp.
Centrechinoides spp.
Echinocorys sulcatus Goldf. (only in the one to two foot thick hard limestone bed at the base of the formation).

Brachiopoda

Liothyrina carnea Sow.
Liothyrina sp. nov. aff. *L. carnea* Sow.
Terebratulina sp. aff. T. *dutempleana* d'Orb.

The age of the Wadera Calcarenite is Cretaceous-Tertiary.

The Wadera Calcarenite crops out on the north nose, north-east flank, south nose and west flank of the Giralia Anticline and the north nose and south-west flank of the Marrilla Anticline, as a gentle slope with a five-to-ten-foot scarp formed by hard beds at the base of the formation. Steep scarps expose the formation on the south nose and north-west flank of the Marrilla Anticline. The Wadera Calcarenite is poorly exposed on the south-east flank of the Giralia Anticline and the east flank of the Marrilla Anticline. Outliers of the Calcarenite occur near Remarkable Hill, C-Y Creek, north of Toothawarra Creek, and on the south-west flank of Marrilla Anticline.

A section of the Wadera Calcarenite on the east flank of the Giralia Anticline, four miles north-north-west of Deep Bore, consists, in descending order, of:

	Pirie Calcarenite;
13½ feet	Alternating calcarenite, glauconitic, recrystallized, hard, greenish-yellow, and calcarenite, glauconitic, soft;
5½ feet	Calcarenite, glauconitic, soft, with foraminifera, many bryozoa, and terebratulids, worm casts;
5 feet	Alternating limestone, glauconitic, hard, and calcarenite, glauconitic, soft; beds average 2 feet thick;
6 feet	Calcarenite, glauconitic, slightly friable, soft, greenish-yellow with foraminifera, echinoids, bryozoa, terebratulids (GC217);
5 feet	Limestone, glauconitic, medium hard; beds average 6 inches thick;
5 feet	Limestone, sandy, glauconitic, medium hard, greyish-white; slightly silty;
10 feet	Limestone, sandy, glauconitic, dense, hard, greenish-yellow with foraminifera, many bryozoa, and silicified brachiopods (GC216);
13 feet	Alternating calcilutite, hard, and calcarenite, soft; beds average 6 inches thick;
1 foot	Calcilutite, few glauconite grains, grey, with corals, foraminifera, and bryozoa (GC215);
8½ feet	NO OUTCROP;
5 feet	Calcarenite, glauconitic, slightly friable, soft, greyish-white, with foraminifera and many bryozoa (GC214);
2½ feet	Calcarenite, glauconitic, medium hard, grey;
5 feet	NO OUTCROP;
1 foot	Calcarenite, glauconitic, recrystallized, greyish-brown, dense, hard;
	Boongerooda Greensand.
86 feet	

The thickness of the Wadera Calcarenite is: 30 feet, eight and a half miles south of Lamont Hill; 40 feet, two and a half miles north of Remarkable Hill; 47 feet, Remarkable Hill.

With the information available, an isopach map showing the variations in thickness of the original deposition of the Wadera Calcarenite was drawn. No thicknesses of the Formation are known on the south-east and south-west flanks of the Giralia and Marrilla Anticlines. The isopach map (Plate 7) may be considered in two sections:

(a) north of Toothawarra Creek;

(b) south of Toothawarra Creek.

(a) The type section of the Wadera Calcarenite is on the southern termination of a broad valley (Plate 7) trending north-north-west, the eastern slope of which runs to the north-east. The rate of divergence increases from 8 feet per mile north-west near the type section to 22 feet per mile west-north-west one and a half miles north of the Giralia-Bullara Road. South of the road the divergence is six feet per mile north-westward on the east flank of the Giralia Anticline and on the Nabbawarra Syncline.

(b) The minimum thickness of the formation is on the south nose of the Marrilla Anticline and immediately to the south, where a broad "terrace", fairly uniform in thickness, gently slopes to the north-east, south-west, and west.

The "terrace" extends to Remarkable Hill and Centenary Bore. The divergence to the south-west is one and a half, to the west two, feet per mile. Similar thicknesses to those south of the Marrilla Anticline are suggested for the south-west flank of the Giralia Anticline. A "ridge" parallel to the trend of the outcrop occupies the western half of the south-west flank. To the east of this "ridge" the divergence is four feet per mile eastward. The Remarkable Hill area is in a "valley" between the "ridge" and "terrace" mentioned above, and to the north of a "?ridge" which extends to the south-south-east.

Apart from the Giralia and Marrilla Anticlines, the Wadera Calcarenite is only exposed on the Warroora and Chargoo Anticlines.

The upper half of the Wadera Calcarenite contains hard beds of recrystallised calcarenite, and one or two hard limestone beds which form the top of the formation. North of the Cardabia-Winning Road the formation is characterised by hard beds which increase in number towards the north. North of C-Y Creek the top two or three hard beds have a well-developed joint system. A petrographical examination of Sample R3909 from Remarkable Hill showed:

85 percent calcite (grains 0.1 to 0.2 mm. diameter)
10 percent glauconite (to 0.1 mm.)
5 percent quartz (grains to 0.1 mm., angular to subangular).

Pirie Calcarenite

The Pirie Calcarenite comprises the top 38 to 45 feet of the 85 feet of "sandy, white to yellow polyzoal limestone" of Raggatt's section "near Remarkable Hill" (Raggatt, 1936, p.156).

Fig. 8.—Hill 2½ miles north of Remarkable Hill, from the north.
a.—Cashin Calcarenite b.—Pirie Calcarenite c.—Wadera Calcarenite d.—Korojon Calcarenite.

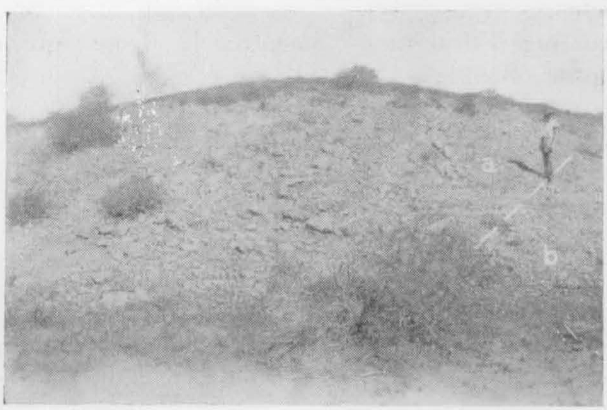

Fig. 9.—Zone of steep dips, East Flank, 12 miles south-west of Giralia Homestead.
a.—Pirie Calcarenite b.—Wadera Calcarenite.

Pirie (pronounced pi'-ri) is the name of a paddock on Cardabia Station, eight miles south-south-west from the type section.

The Pirie Calcarenite is composed of friable greenish-white calcarenite with abundant bryozoa and many echinoids, and, in places, beds of grey cherty calcilutite. The Pirie Calcarenite is conformable with the Wadera Calcarenite below and the Cashin Calcarenite above.

The type section is at lat. 22°49½'S., long. 114°08'E. in Toothawarra Creek. The section is 97 feet thick, and in descending order consists of:

		Cashin Calcarenite;
11	feet	Calcarenite, friable greenish-white with two one-foot beds of medium hard calcarenite;
1	foot	Calcarenite, medium hard, with many "worm burrows";
10½	feet	Calcarenite, friable, greenish-white, with foraminifera (R3918);
1	foot	Calcarenite, medium hard, with "worm burrows";
10	feet	Calcarenite, friable, greenish-white, with nodules of recrystallized medium-hard calcarenite with few bryozoa;
1	foot	Calcarenite, medium-hard, with "worm burrows";
6	feet	Calcarenite, friable, greenish-white, with bryozoa;
1	foot	Calcarenite, medium-hard;
6	feet	Calcarenite, friable, greenish-white, with echinoids, abundant bryozoa (R3919);
1	foot	Calcarenite, medium-hard, with hard nodules of recrystallized light brown calcarenite;
3	feet	Calcarenite, friable, greenish-white;
½	foot	Calcilutite, cherty, light grey, hard, with foraminifera (R3920);
15	feet	Calcarenite, friable, light grey, with chert nodules to five inches diameter;
8	feet	Alternating calcarenite, fine-grained, loose, greenish-grey, and calcilutite (R3921);
2	feet	NO OUTCROP;
3	feet	Calcarenite, friable to medium hard, greenish-grey;
17	feet	NO OUTCROP;
		Wadera Calcarenite.
97	feet	

The type section is thicker than Raggatt's section "near Remarkable Hill" because the Pirie Calcarenite thickens north of the Remarkable Hill area.

The following assemblage of foraminifera and radiolaria from the Pirie Calcarenite was determined by Edgell (1952):

Foraminifera

Alabamina obtusa (W. & B.) var. *westraliensis* Parr	(r)
Angulogerina subangularis Parr	(f)
Anomalina perthensis Parr	(c)
Anomalinoides danica Brotzen	(f)
Bolivinoides cf. *velascoensis* (Cushman)	(r)
Cibicides ekblomi Brotzen	(f)
Cibicides umbonifer Parr	(a)
Discorbis midwayensis (Plummer)	(a)

Globigerina mexicana Cushman	(a)
Globigerina triloculinoides Plummer	(a)
Globorotalia spinulosa Cushman	(a)
Gumbelina venezuelana Nuttall var. *rugosa* Parr	(f)
Karreria cubensis (Cushman and Bermudez)	(r)
Osangularia velascoensis (Cushman)	(a)
Stomatorbina torrei (Cushman and Bermudez)	(f)
Vaginulinopsis longiformis (Plummer)	(f)

Radiolaria

Cenosphaera sp.	(c)
Podocyrtis sp.	(f)
Spongasteriscus sp. aff. *cruciferus* Clark & Campbell	(r)
Stylosphaera sp.	(r)
Stylotrochus sp. aff. *festivus* Clark & Campbell	(f)

Brunnschweiler (pers. com., 1953) identified the following fossils from the Pirie Calcarenite:

Echinoidea

Cardiaster spp.
Centrechinoides spp.
Cidaris spp.
Hemiaster spp.
Holaster spp.
Gen. nov. aff. *Hemipatagus*.
Gen. nov. aff. *Schizaster*.
Phymosoma spp.
Salenia spp.

Brachiopoda

Liothyrina sp. cf. *L. carnea* Sow.
Terebratulina spp.

Pelecypoda

Diploschiza sp. cf. *D. chavani* Collignon
Gryphaea sp. cf. *G. newberryi* Stanton
Lima sp. indet.

Gastropoda

Procerithium sp. cf. *P. morgani* Douville
Tympanotonus sp.

Cephalopoda

Deltoidonautilus sp. indet.

The age of the Pirie Calcarenite is Cretaceous-Tertiary.

The Pirie Calcarenite crops out on the north nose, north-east flank, south nose, and west flank of the Giralia Anticline. Poor exposures of Pirie or Cashin Calcarenite, or both, extend from two miles north to five miles south of trig. point A6.

The Pirie Calcarenite is soft and contains a few hard beds at about the middle of the formation; these hard beds in places form a small ridge. In the Remarkable Hill area the Calcarenite crops out in valley walls and on top of ridges, and three miles south-east of Jubilee Bore it outcrops on a scarp capped by Jubilee Calcarenite. The Pirie Calcarenite occurs in outliers near C-Y Creek and Remarkable Hill, and as an inlier four and a half miles north of the Giralia-Bullara Road.

A section two and a half miles north of Remarkable Hill consists of, in descending order:

	Cashin Calcarenite;
10 feet	Calcarenite, bryozoal, medium hard, with echinoids, brachiopods, pelecypods (*Ostrea*) (R3966);
10 feet	Coquinite, bryozoal, calcarenaceous, friable to medium hard, cream, white (weathered) (R3965);
6 feet	Calcarenite, bryozoal, medium hard to friable, light yellowish-brown, white (weathered);
1 foot	Limestone, crystalline, hard, light brown;
3 feet	Calcarenite, bryozoal coquinoid, friable, light brown (when fresh), white (weathered);
	Wadera Calcarenite.
30 feet	

The thickness of the Pirie Calcarenite is: 82 feet, three and a quarter miles west-south-west of Deep Bore; 45 feet, at trig. point A8; 66 feet, five miles south of Jubilee Bore.

The variations in thickness of this formation are depositional and not due to erosion.

Sections of the Pirie Calcarenite on the west and east flanks show that the percentage of lutite increases towards the north from nothing three miles north of Remarkable Hill, until near the Giralia-Bullara Road the lower half of the section consists mainly of calcilutite and marl. Bryozoa are abundant in the Remarkable Hill area and to the south, but towards the north they are less characteristic of the formation.

On the Marrilla Anticline the Pirie and Cashin Calcarenites were mapped as one unit (Pirie - Cashin Calcarenite). The unit crops out on the north nose, south-east and west flanks. Exposures on the south-west flank are poor. Outliers of the Pirie - Cashin Calcarenite occur on the north nose and south-west flank of the Anticline. On the west flank the Pirie - Cashin Calcarenite is 40 feet thick.

A formation equivalent to the Pirie - Cashin Calcarenite crops out on the Warroora and Chargoo Anticlines.

In the description of the Cashin Calcarenite reference is made to the convergence of the Pirie-Cashin Calcarenite.

Cashin Calcarenite

Cashin (pronounced as spelt) is the name of a paddock on Cardabia Station, 22 miles south-south-west from the type section.

The Cashin Calcarenite is composed of alternating friable white calcarenite and grey crystalline limestone with foraminifera, many echinoids and bryozoa, small brachiopods. The Cashin Calcarenite conformably overlies the Pirie Calcarenite, and is itself overlain, possibly disconformably, by the Jubilee Calcarenite.

The type section of the Cashin Calcarenite is at lat. 22°49½'S., long. 114°07½'E., in Toothawarra Creek. The sequence, in descending order, is:

	Jubilee Calcarenite;
7 feet	Calcarenite, friable, light grey;
1 foot	Limestone, crystalline, hard, light grey (R3917);
1 foot	Calcarenite, friable;
½ foot	Limestone, crystalline, hard;
1½ feet	Calcarenite, friable, white;
1 foot	Limestone, crystalline, hard, light grey, with small brachiopods;
5 feet	Calcarenite, friable, white, with thin lenses of limestone, crystalline;
1 foot	Limestone, crystalline, hard, light grey;
2 feet	Calcarenite, friable, white;
2 feet	Limestone, crystalline, hard, light grey;
1 foot	Calcarenite, friable, white;
1 foot	Limestone, crystalline, hard, light grey;
4 feet	Calcarenite, friable, white, with two 6 inch beds of hard, light grey crystalline limestone;
	Pirie Calcarenite.
28 feet	

Edgell (1952) identified the following foraminifera from the Cashin Calcarenite:

Anomalina perthensis Parr	(c)
Cibicides pseudoconvexus Parr	(r)
Cibicides umbonifer Parr	(a)
Globigerina triloculinoides Plummer	(c)

Only a small number of species could be determined owing to the hard rocks collected and the difficulty of determining the smaller foraminifera in thin section.

Brunnschweiler identified the following mega-fossils:

Echinoidea

Cardiaster spp.
Cidaris spp.
gen. indet. aff. *Schizaster.*
Hemiaster spp.
Holaster spp.
Salenia spp.

Brachiopoda

Liothyrina sp. nov. aff. *L. carnea* Sow.
Terebratulina sp. nov. aff. *T. dutempleana* d'Orb.
Zeilleria spp.

Pelecypoda

Gryphaea sp. cf. *G. wratheri* Stephenson.

Gastropoda

Tympanotonus sp.

Cephalopoda

Deltoidonautilus sp. indet.

The age of the Cashin Calcarenite is Cretaceous-Tertiary. The area of outcrop of the Cashin Calcarenite is the same as that of the Pirie Calcarenite, with the following differences:

(1) The Cashin Calcarenite is missing from the north-west flank of the Giralia Anticline north of a point three miles south-east of Jubilee Bore;

(2) On the east flank of the Giralia Anticline near C-Y Creek, the Cashin Calcarenite was probably not deposited.

Unlike the Pirie Calcarenite, the Cashin Calcarenite contains many hard beds. These hard beds form a prominent scarp on the south-west flank of the Giralia Anticline. Elsewhere the formation is not a distinct topographical feature, but crops out on a scarp capped by the hard basal beds of the Jubilee Calcarenite. The Cashin Calcarenite occurs as outliers south-west of Korojon Pool, two miles south-west of trig. point A8, and at A8, and as an inlier near A8.

Two and a half miles north of Remarkable Hill, the Cashin Calcarenite consists in descending order of:

Jubilee Calcarenite;

15 feet Alternating calcarenite, fine-grained, hard, buff, in beds three to four feet thick, and calcarenite, friable, in beds 6 inches to one foot thick, with silicified bryozoa (R3967);

20 feet	Alternating calcarenite, friable, light greenish-grey, and calcarenite, hard, light greenish grey, with bryozoa;
3 feet	Calcarenite, medium hard, light greenish-grey;
1 foot	Calcarenite, loose, light greenish-grey;
7 feet	Calcarenite, hard, white, with a bed one foot thick of friable white calcarenite;
	Pirie Calcarenite.
46 feet	

The thickness of the Cashin Calcarenite is:

23 feet, four miles north-north-west of Deep Bore;
14 feet, three and a quarter miles west-south-west of Deep Bore;
29 feet, four and a half miles south-south-west of Jubilee Bore.

The variations in thickness of the Cashin Calcarenite are mainly depositional but may have been affected slightly by erosion.

An isopach map (Plate 7) of the Pirie-Cashin Calcarenite was drawn. The map is incomplete as no formation thicknesses are obtainable from the east flank and south nose of the Nabbawarra Syncline, and the south-east flank of the Giralia Anticline.

The isopach map may be considered in two sections:

(a) North-westward of a line which runs at 40° through a point four miles west of Remarkable Hill, the Pirie-Cashin Calcarenite diverges gradually;

(b) To the south-eastward of this line the formation thickness is variable.

(a) North-west of Remarkable Hill the Pirie-Cashin Calcarenite diverges at 10 feet per mile to the north-west. Near Toothawarra Creek and to the south-east, the divergence is 20 feet per mile north-west. To the north, the rate of divergence decreases until it is only five feet per mile where the Giralia-Bullara Road crosses the east flank. On the east flank, one and a half miles north of the road is the eastern "nose" of a narrow, east-west trending "valley".

(b) The minimum thicknesses of the Pirie-Cashin Calcarenite on the Giralia and Marrilla Anticlines are on the west flank of the Marrilla Anticline and near Korojon Pool. Five miles south of Nabbawarra Bore is a narrow "ridge," trending east-west, which slopes gently to the north and south and steeply to the west (Plate 7). To the south of this "ridge" and to the east of Remarkable Hill is a broad "terrace" or "shelf" which probably rises gently to the south-south-west to form a "ridge" extending from Remarkable Hill to Cardabia Pool. One and a quarter miles east of trig. point A8 the western slope of this "ridge" suddenly steepens to indicate that the westward divergence of the formation has increased from 11 to 46 feet per mile. A8 is on the steep western slope of a broad "valley", the northern slopes of which gradually rise towards Remarkable Hill. The thickest sequence of the Pirie-Cashin Calcarenite was deposited in this "valley".

Jubilee Calcarenite

The Jubilee Calcarenite is the youngest formation of the Cardabia Group. Jubilee is the name of a bore on Giralia Station.

The Jubilee Calcarenite consists of friable white glauconitic calcarenite and hard yellowish-brown glauconitic limestone, with foraminifera, corals, echinoids, bryozoa, and brachiopods. The Jubilee Calcarenite is possibly disconformable with the Cashin Calcarenite below and it is disconformable with the Giralia Calcarenite above. The disconformity between the Jubilee and Giralia Calcarenites is marked by:

(1) A one-foot bed of friable, slightly calcareous, very coarse-grained quartz sandstone to fine quartz conglomerate — two miles west-north-west of Remarkable Hill;

(2) A thin ferruginous zone in places;

(3) Absence, probably by erosion, of the Jubilee Calcarenite in some places.

Brunnschweiler (pers. com.) has found reworked and damaged mega-fossils characteristic of the Cashin Calcarenite in the base of the Jubilee Calcarenite. This occurrence suggests that the contact between the Jubilee and Cashin Calcarenites may be disconformable.

The type section is at lat. 22°40½'S., long. 114°11½'E., four and a half miles south of Jubilee Bore. The section is 35 feet thick and, in descending order, consists of:

Giralia Calcarenite;

2½ feet Calcarenite, glauconitic, soft, white, with pebble-sized nodules of hard yellowish-brown glauconitic limestone; beds average 1 foot (R3941);

2½ feet Limestone, crystalline, glauconitic, yellowish-brown;

1½ feet Calcarenite, soft, white, with pebbles of recrystallized calcarenite;

5½ feet Alternating calcarenite, glauconitic, soft, white, and glauconitic hard yellowish-brown limestone; beds average 1 foot;

4½ feet Limestone, glauconitic, yellowish-brown and grey, foraminifera, echinoids, bryozoa, brachiopods (calcified and silicified), nautiloids (*Aturoidea*) (R3940);

6½ feet Alternating calcarenite, glauconitic, soft, white, with pebble-sized nodules of yellowish-brown limestone, and glauconitic, hard, yellowish-brown limestone, beds average 6 inches;

3 feet NO OUTCROP;

5 feet Alternating calcarenite, glauconitic, white, with pebble-sized nodules of recrystallized calcarenite and yellowish-brown glauconitic limestone; beds average 6 inches; foraminifera, echinoids, bryozoa (R3939);

4 feet Alternating calcarenite, partly recrystallized, glauconitic, hard, yellowish-brown, and glauconitic soft white calcarenite, with pebble-sized nodules of recrystallized calcarenite;
Cashin Calcarenite.

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35 feet

Edgell (1952) identified the following foraminifera from the Jubilee Carcarenite:

Angulogerina subangularis Parr	(c)
Angulogerina wilcoxensis (Cushman & Ponton)	(f)
Anomalina perthensis Parr	(c)
Bolivinoides velascoensis (Cushman)	(f)
Cibicides umbonifer Parr	(a)
Cibicides ekblomi Brotzen	(f)
Globigerina mexicana Cushman	(c)
Globigerina triloculinoides Plummer	(c)
Globorotalia spinulosa Cushman	(f)
Gyroidina soldanii (d'Orb.) var. *subangulata* Plummer	(c)
Siphogenerina cf. *eleganta* Plummer	(f)

Brunnschweiler (pers. comm., 1953) determined the following fossils from the Jubilee Calcarenite:

Pelecypoda

Ostrea cf. *O. sellaeformis* Conrad
Ostrea spp.

Gastropoda

Gisortia spp.

Cephalopoda

Aturoidea sp.

During field mapping the Jubilee Calcarenite was regarded as being related more to the Cashin Calcarenite than to the Giralia Calcarenite and so is shown on plates 3, 4, and 6 to be Cretaceous-Tertiary in age. However recent palaeontological work has indicated that the Jubilee Calcarenite may be Eocene in age.

The Jubilee Calcarenite crops out on the north nose and north-east and north-west flanks of the Giralia Anticline, and on the north nose and south-east and west flanks of the Marrilla Anticline.

Two miles south-west of No. 10 Bore, the Jubilee Calcarenite consists, in descending order, of:

	Giralia Calcarenite;
6 feet	Calcarenite, friable to medium hard, with thin beds of crystalline hard light-brown limestone;
1 foot	Limestone, crystalline, fine-grained, hard, light brown;
3 feet	Limestone, crystalline, fine-grained, medium hard, light brown, with thin beds of friable cream calcarenite;
10 feet	Alternating calcarenite, friable, white, and limestone, crystalline, hard, light brown, with echinoids, bryozoa, brachiopods (R3969); Cashin Calcarenite.
23 feet	

The variations in thickness of the Jubilee Calcarenite are mainly due to deposition but are also controlled by erosion previous to the deposition of the Giralia Calcarenite.

The Jubilee Calcarenite has many limestone beds which contain silicified fossils and small "blebs" of silica. These hard limestone beds cap cuestas on the west flanks of the Giralia and Marrilla Anticlines.

Tertiary System

EOCENE FORMATIONS

Giralia Calcarenite

"Giralia Limestone" was proposed by Singleton (1941, p.36) "for the *Discocyclina* limestones . . . resting with a disconformity upon the Cardabia Series . . . of the Upper Cretaceous . . ." Singleton designated the *Discocyclina* limestones as a type Eocene Stage for the standard time-rock classification of Australia. The thickness was stated to be 10-30 (?) feet, but as the lithological sequence was not discussed the upper and lower limits of the formation were not defined. Field mapping in 1950 showed:

(a) that the "Cardabia Series" of Raggatt (1936, p.161) includes Cretaceous-Tertiary as well as Upper Cretaceous sediments;

(b) that the *Discocyclina* limestones have a thickness of 200 feet;

(c) that rather more than half of the sediments of the "Giralia Limestone" is calcarenite.

Hence it is proposed to name the formation which contains the *Discocyclina* limestones of Singleton the GIRALIA CALCARENITE.

In many places, including the type locality, the Giralia Calcarenite consists of two lithological units:

(a) the upper part—brown crystalline limestone with calcite veins and yellowish-brown calcarenite, with foraminifera, bryozoa, and mollusca;

(b) the lower part—cream calcarenite and crystalline limestone with limonite "ooides" and foraminifera, echinoids, bryozoa, brachiopods, pelecypods (*Ostrea*), nautiloids (*Hercoglossa*), and fish teeth.

As the two lithological types are interbedded in places they have not been given separate formation names.

The Giralia Calcarenite is disconformable with the Jubilee Calcarenite below and is separated by an erosional and angular unconformity from the Lamont Sandstone or Trealla Limestone above.

The erosional and angular unconformity below the Lamont Sandstone is one of the most important features of the geology of the Giralia and Marrilla Anticlines. The angle of unconformity is less than three degrees. The evidence for the unconformity is:

(a) the overlap of the Lamont Sandstone and Trealla Limestone upon formations older than the Giralia Calcarenite;

(b) the strongly ferruginized (lateritized) uneven surface of the Giralia Calcarenite;

(c) the presence on the surface of the Giralia Calcarenite of a six-inch bed of black ferruginized calcareous fine quartz conglomerate;

(d) the lenticularity of the Lamont Sandstone.

(a) One to two miles west of Korojon Pool, the Lamont Sandstone and Trealla Limestone overlap the Boongerooda Greensand and the Pirie Calcarenite. On the west and east flanks of the Giralia Anticline the Trealla Limestone overlaps the lower and upper Giralia Calcarenite. On the Marrilla Anticline the Lamont Sandstone overlaps the Wadera, Pirie-Cashin, and Jubilee Calcarenites.

(b) West of Remarkable Hill, pebbles and cobbles of black ferruginized sandy limestone are embedded in the buff hard sandy limestone of the upper part of the Giralia Calcarenite. Above the ferruginized zone is the Trealla Limestone. On the east flank of the Giralia Anticline, two miles south from Centipede Bore, a seven foot thickness of the Lamont Sandstone is separated from 24 feet of the upper part of the Giralia Calcarenite by a black, strongly ferruginized surface.

(c) West of Remarkable Hill, at the top of the upper part of the Giralia Calcarenite, is a six-inch bed of black ferruginized calcareous fine quartz conglomerate. The quartz, white in colour, is sub-rounded and rounded. Five miles south-south-west from trig. point A8 is a 10-foot-high hillock of the upper Giralia Calcarenite. A bed with ironstone gravel and some quartz pebbles is thickest at the base of the hillock and lenses out below the top. The ironstone gravel is overlain by hard white quartz sandstone which also lenses out. The Trealla Limestone progressively overlaps the upper Giralia Calcarenite, the ironstone gravel and the sandstone. Two miles north-east of Lamont Well, the Lamont Sandstone is separated from the lower Giralia Calcarenite by a sub-horizontal surface which consists of an old soil (possibly lateritized) with fragments of quartz, quartzite, and limonite.

The name, pronounced ji-ra'-lia rhyming with Australia, is taken from Giralia Station.

The type section, at lat. 22°55½'S., long. 114°02½'E., near No. 10 Bore, Cardabia, consists, in descending order, of:

		Trealla Limestone;
30	feet	Poor outcrop. Calcarenite, with beds of limestone, crystalline, hard, brown, with calcite veins and a few quartz grains (maximum diameter 2 mm.);
3	feet	Limestone, crystalline, hard, brown, with quartz grains, very coarse. well rounded (R3988);
4	feet	Limestone, hard, cream, with polished limonite grains, bryozoa (R3987);
20	feet	Poor outcrop; scattered fragments of limestone, crystalline, hard;
1	foot	Limestone, crystalline, hard, brown, with calcite veins and limonite grains; bryozoa (R3986);
		Break in Section — a thickness not greater than 20 feet not mapped because of poor outcrop;
17	feet	Alternating calcarenite, friable, and limestone, crystalline, hard, yellowish-brown, with silicified bryozoa;
2	feet	Limestone, crystalline, hard, yellowish-brown (R3985);
14	feet	Calcarenite, friable, yellowish-brown, with one-foot-thick beds of crystalline hard yellowish-brown limestone, with bryozoa;
10	feet	Alternating calcarenite, friable, cream, and crystalline, hard, yellowish-brown limestone (R3984);
10	feet	Calcarenite, friable, light grey, with foraminifera, bryozoa and thin beds of crystalline hard light-brown limestone (R3983);
10	feet	Limestone, crystalline, glauconitic, hard, light brown, with 6-inch beds of friable calcarenite with bryozoa;
1	foot	Limestone, crystalline, fine-grained, glauconitic, hard, light molluscs;
6½	feet	Calcarenite, medium hard, white;
2	feet	Limestone, crystalline, fine-grained, hard, light brown, with pelecypods (*Chlamys*), gastropods;
2	feet	Chert, hard, light grey (R3982);
1	foot	Limestone, crystalline, fine-grained, glauconitic, hard, light yellowish-brown (R3981);
15	feet	Calcarenite, glauconitic, friable to medium hard, cream, with many foraminifera and echinoids, bryozoa, molluscs (R3978);
10	feet	Limestone, crystalline, hard, cream and speckled green and brown, with polished limonite grains (?ooides) and with "pebbles", consisting of polished limonite and quartz grains, in an iron oxide matrix, near the base (R3976);

½ foot	Bed of limonite grains in limonite matrix;
5 feet	Calcarenite, friable to medium hard, cream, with limonite-coated "pebbles" of limonite grains and limonite matrix (R3975);
5 feet	Limestone, crystalline, hard, green, with limonite grains, and chalcedonic silica in lenses (6 inches by 1 inch) at base (R3973);
7 feet	Calcarenite, glauconitic, friable, green (R3974);
3 feet	Limestone, crystalline, fine-grained, hard, light brown, with some glauconite (R3972);
9 feet	Calcarenite, friable, light brown;
2 feet	Limestone, crystalline, fine-grained, hard, light greenish-brown, with glauconite, brachiopods, and silicified bryozoa (R3970);
7 feet	Poor outcrop; calcarenite, friable;
3 feet	Limestone, crystalline, fine-grained, hard, light brown, with polished limonite grains and some glauconite (R3971);
	Jubilee Calcarenite.
200 feet	

Condit (1935) collected two samples of the Giralia Calcarenite where the Giralia-Bullara Road crosses the east and west flanks of the Giralia Anticline; Chapman and Crespin (1935) determined the samples as "b"-stage (East Indes letter classification), that is middle to upper Eocene in age.

Edgell (1952) identified the following foraminifera from the Giralia Calcarenite:

"Larger" Foraminifera

Alveolina cf. *timorense* Verbeek	(f)
Asterocyclina stellaris (Brunner)	(c)
Asterocyclina stella Gumbel	(a)
Assilina orientalis (Douville)	(r)
Discocyclina cf. *chudeaui* (Schlumberger)	(f)
Discocyclina discus (Rutimeyer) Kaufmann	(a)
Discocyclina fritschi (Douville)	(f)
Discocyclina cf. *turnerensis* Vaughan	(a)
Nummulites aff. *irregularis* Deshayes	(f)
Nummulites cf. *kemmerlingi* Caudri	(r)
Operculina cf. *vaughani* (Cushman)	(c)

"Smaller" Foraminifera.

Angulogerina sp. II	(f)
Anomalina cf. *perthensis* Parr	(f)
Cibicides umbonifer Parr	(a)
Crespinella sp. I	(f)
Gaudryina (*Siphogaudryina*) cf. *victoriana* Cushman	(r)
Glabratella sp. I	(r)
Globigerina eocenica Terquem	(f)
Globigerina mexicana Cushman	(c)

Globigerina triloculinoides Plummer .... (a)
Globorotalia spinulosa Cushman .... (a)
Linderina brugesi Schlumberger .... (r)
Notorotalia sp. aff. *clathrata* Brady .... (f)
Osangularia mexicana (Cole) .... (f)
Stomatorbina torrei (Cushman and Bermudez) .... (r)
Victoriella plecte (Chapman) .... (f)

Brunnschweiler (pers. comm., 1953) identified the following fossils:

Gastropoda

Gisortia (*Vicetia*) *depressa* (Sow.)

Cephalopoda

Hercoglossa sp. nov.

On the Giralia and Marrilla Anticlines the "larger" foraminifera first appear in the Giralia Calcarenite. The "larger" foraminifera in the Giralia Calcarenite are important index fossils and their presence indicates conditions of deposition which did not prevail during the formation of the Jubilee and Cashin Calcarenites.

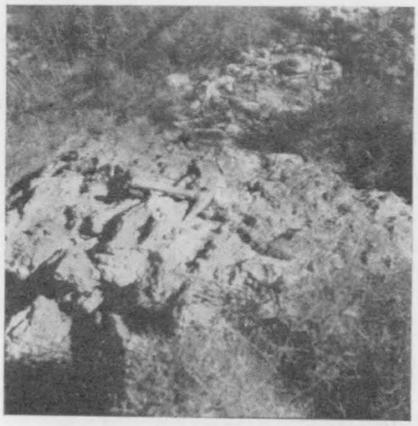

Fig. 10.—One mile east of No. 10 bore, Cardabia Station. Looking south-east at roughly bedded Giralia Calcarenite.

Fig. 11.—Same locality. Limonite pebbles in Giralia Calcarenite.

Assilina, *Asterocyclina* and *Discocyclina* range from "a" to "b" stage in the East Indes (van der Vlerk, 1948). *Nummulites* ranges from "a" to "d" stage. Brunnschweiler (pers. comm., 1953) states that *Gisortia* (*Vicetia*) *depressa* (Sow.) is characteristic of the late middle Eocene.

Fossils regarded as being restricted to either "a" or "b" stages were not reported and the age of the Giralia Calcarenite is regarded as "a" to "b" stage (East Indes), i.e. middle to upper Eocene (van Bemmelen, 1949).

The lower part of the Giralia Calcarenite crops out on the north nose and north-east and west flanks of the Giralia Anticline. It is also exposed on a scarp from two and a half miles north to five miles south of trig. point A6. Outliers of the lower part of the Giralia Calcarenite occur near Remarkable Hill and trig. point A8, and inliers outcrop two miles north of Nipper Well, Giralia Station.

The upper part of the Giralia Calcarenite is exposed on the north-east and north-west flanks of the Giralia Anticline. Outliers occur four miles west-south-west from Remarkable Hill.

The following section of the Giralia Calcarenite was measured four and a half miles south-south-west of Jubilee Bore, and in descending order consists of:

	Trealla Limestone
	Ferruginized surface;
6 feet	Limestone, crystalline, coarse-grained, hard, yellowish-brown, with "milky" calcite crystals (R3957);
½ foot	Limestone, hard, dark brown, with numerous medium to coarse polished limonite grains (R3956);
11½ feet	Poor outcrop; calcarenite, soft with two 6-inch beds of hard brown limestone with coarse-grained limonite grains; foraminifera, mollusca, bryozoa;
41 feet	Poor outcrop. Calcarenite, soft, with four 6-inch beds of crystalline medium to coarse hard greyish-brown limestone with calcite and silica veins, foraminifera, bryozoa;
10½ feet	Limestone, crystalline, medium to coarse greyish-brown, thin-bedded, with medium-grained limonite (R3954);
1 foot	Limestone, crystalline, medium-grained, hard, yellowish-brown, with chalcedonic vugs, foraminifera, bryozoa (R3953);
5 feet	Alternating limestone, crystalline, medium to coarse, glauconitic, hard, brown, "milky" calcite crystals, with foraminifera and bryozoa, and soft glauconitic calcarenite;
18 feet	Alternating limestone, crystalline, medium-grained, glauconitic, hard, yellowish-brown, and glauconitic calcarenite; foraminifera, bryozoa (R3952);
3 feet	Calcarenite, glauconitic, slightly friable, greenish-grey, with pelecypods;
3½ feet	Alternating limestone and calcarenite, foraminifera, silicified bryozoa (R3951);
11 feet	Poor outcrop; probably calcarenite, with three one-foot beds of limestone, crystalline, fine-grained to medium-grained, hard, brown, with limonite grains, discoidal foraminifera (up to 1½ inches in diameter), bryozoa, mollusca;
5 feet	Alternating limestone, crystalline, fine-grained to medium-grained, hard, light brown, with limonite grains, and soft calcarenite; discoidal foraminifera, bryozoa, mollusca;

1 foot	Limestone, crystalline, medium-grained, foraminiferal coquinoid, hard, cream; discoidal foraminifera (up to 1¼ inches in diameter), mollusca (R3950); ...
1½ feet	Calcarenite, foraminiferal coquinoid, glauconitic, soft, greyish-white; shells;
2 feet	Alternating limestone and calcarenite;
11 feet	Limestone, crystalline, medium-grained to coarse-grained, sandy, hard, light brown, with coarse-grained limonite; foraminifera, echinoids, mollusca, with a one-foot bed of limestone, crystalline, medium-grained, sandy foraminiferal coquinoid, medium-hard, brown with limonite and glauconite grains;
1 foot	Limestone, foraminiferal coquoinoid, crystalline, coarse-grained, sandy; medium-hard (R3949);
4 feet	Alternating limestone and calcarenite;
2 feet	Limestone, crystalline, medium-grained to coarse-grained, hard, cream, with limonite grains, and quartz (coarse-grained), foraminifera, bryozoa (R3948);
10½ feet	Alternating limestone, glauconitic (medium-grained), hard, light brown, with limonite, medium-grained and very-coarse-grained, and calcarenite, beds average 6 inches; foraminifera, bryozoa, mollusca;
1½ feet	Limonite, fine conglomerate size, brown, with limonite nodules (up to 2 inches in diameter), few coarse quartz grains;
5½ feet	Alternating calcarenite, friable, in 1½-foot beds, and hard limestone with limonite grains, in 6-inch beds;
1 foot	Limestone, crystalline, hard, yellow, abundant rounded, elliptical, medium-sized, polished limonite grains, foraminifera, numerous mega-fossils (R3947);
2 feet	Limestone, crystalline, fine-grained, yellowish-brown, foraminifera, bryozoa, mollusca (R3946);
12½ feet	Alternating calcarenite and limestone, beds average 6-inches thick;
½ foot	Calcarenite, brachiopod coquinoid (R3945);
7 feet	Limestone, crystalline, fine-grained, glauconitic, hard, greenish-yellow, fine to medium-grained, limonite, limonitized foraminifera, brachiopods (R3944);
9 feet	Alternating calcarenite, glauconitic, friable, buff, with glauconitic limestone, glauconite medium-grained and abundant brachiopods;
2 feet	Limestone, crystalline, glauconitic, hard, brown, with limonite grains and occasional medium-sized quartz grains;
7 feet	Calcarenite, glauconitic, friable, buff, with pebble-sized nodules of recrystallized calcarenite, with coarse quartz grains (R3943);

20 feet	Poor outcrop. Only occasional beds of limestone, brown, with limonite and glauconite grains, and quartz, coarse-grained, sub-rounded (R3942); Jubilee Calcarenite.
225 feet	

The thickness of the Giralia Calcarenite is:

61 feet, two miles south of Centipede Bore;
20 feet, nine and a half miles south-south-west of Lamont Well.

The variation in thickness of the Giralia Calcarenite is large and it is mainly controlled by deposition. However erosion is a factor which contributed more to the variation in thickness of the Giralia Calcarenite than to that of any older formation outcropping on the Giralia and Marrilla Anticlines.

Sediments of similar age to the Giralia Calcarenite outcrop on the sea-cliffs at Red Bluff and Cape Cuvier, 60 and 50 miles respectively north-north-west of Carnarvon.

The Giralia Calcarenite possesses two features each of which is characteristic of a part of the formation. The abundance of polished limonite grains, which range in size from 0.12 to 6 mm., foraminifera with a thin veneer of dark brown and brownish-black limonite, glauconite, and fine-grained clastic angular quartz, in the calcarenite typify the lower part of the Giralia Calcarenite. The limestone of the upper part of the formation is more coarsely crystalline than that of the lower part, and it contains calcite veins and voids and may be dolomitic.

Sections of the foraminiferal limestone of the lower part of the Giralia Calcarenite show:

(1) many discoidal foraminifera with a sub-rounded opaque limonite grain within the test;

(2) three or four limonite grains within a calcite void the outline of which is irregular and crosses whorls, septa, and chambers of a test of a nummulite.

Insufficient petrological and chemical analyses were made to determine precisely the composition of the limonite grains. A preliminary examination, however, suggests that the grains are ooides which consist of limonite, hematite, siderite, and possibly other minerals. The ooides were formed before or during the deposition of the sediments which contain them, and are not secondary. Ooides are found inside some foraminifera and it appears that the iron, and probably some ooides, were derived from an old lateritized land surface upon which the Giralia Calcarenite transgressed.

Lamont Sandstone

Craig (1950) referred to the "linear arrangement of discontinuous, massive, quartzite outcrops, close to and east of the steep dips". He regarded the quartzite as a derivative of solutions which ascended along a fault, but this survey has shown that it is a stratigraphical unit deposited by marine sedimentation.

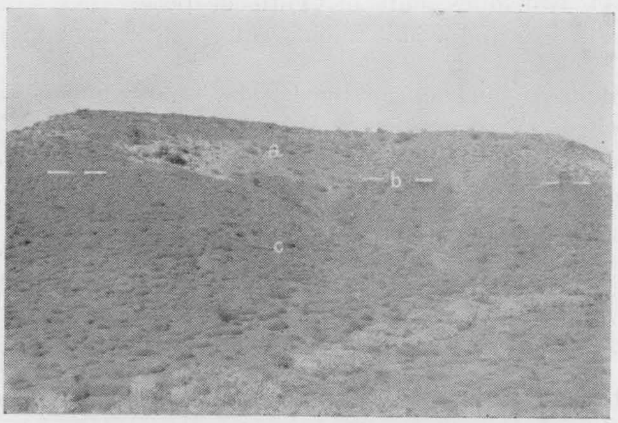

Fig. 12.—Walatharra Hill, 9½ miles north-west of Giralia Homestead. a.—Trealla Limestone b.—Laterite c.—Giralia Calcarenite.

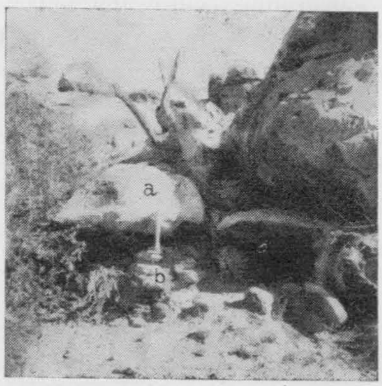

Fig. 13.—Six miles south-west of Giralia Homestead. Looking west. a.—Lamont Sandstone b.—Giralia Calcarenite.

Lamont (pronounced la-mont') is derived from Lamont Well, Giralia Station.

The Lamont Sandstone is a quartz sandstone with few foraminifera. The formation rests upon the Giralia Calcarenite with an erosional and angular unconformity, and is separated from the overlying Trealla Limestone by an erosional and angular unconformity.

The angle of unconformity between the Trealla Limestone and the Lamont Sandstone is less than two degrees. In places the surface of the sandstone is silicified and ferruginized, and half a mile west of Korojon Pool conglomerate separates the two formations. The conglomerate consists of rounded fragments of *Inoceramus* shells, quartz and quartzite of fine conglomerate size, dark limestone fragments, and chalcedony pebbles (up to two inches in diameter).

The type section is 11 feet thick, and, in descending order, consists of:

	Top of outcrop;
10 feet	Quartz sandstone, hard, white, grades laterally and vertically into quartz sandstone with a calcareous cement, strongly jointed;
1 foot	Quartz sandstone, very-coarse-grained, hard, white, with calcareous cement.
	Lateritized soil with fragments of quartz, quartzite, limonite grains.
	Giralia Calcarenite.
11 feet	

Edgell (1952) identified the following foraminifera from the poorly fossiliferous Lamont Sandstone:

Discorbis sp.
Triloculina cf. *tricarinata* d'Orb.

From its stratigraphical position and the above mentioned foraminifera, the Lamont Sandstone is assigned to the lower Miocene.

The Lamont Sandstone occurs as isolated lens-like outcrops. The formation crops out near Korojon Pool, five miles south-south-west from A8, and three miles south-west from A8. Half-a-dozen discontinuous outcrops of the sandstone occur on the north-east flank of the Giralia Anticline. On the west flank of the Giralia Anticline the lenses cannot be traced laterally for greater distances than 50 yards, and the thickness ranges from one to three feet. The lens-like outcrops on the east flank range from two to six feet thick, and have a greater lateral extent than on the west flank.

The maximum development of the Lamont Sandstone is on the north nose and north-east and west flanks of the Marrilla Anticline. The outcrops of the Lamont Sandstone on the Marrilla Anticline are massive and continuous. The maximum thickness is 30 feet, seven miles south-south-west of Lamont Well, and the formation is from 10 to 15 feet thick on the north nose.

Two miles south of Centipede Bore, the sequence in descending order is:

	Trealla Limestone;
3 feet	Quartz sandstone, coarse-grained to fine-grained, hard, with a calcareous cement;

4 feet Quartz sandstone, coarse-grained to fine-grained, friable, sugary texture, white, with a few very coarse quartz grains (R3992);
Ferruginized surface;
Giralia Calcarenite.

7 feet

The only known outcrop of Lamont Sandstone outside the Giralia and Marrilla Anticlines is on the Chargoo Anticline.

The Lamont Sandstone is distinguishable from other formations on the Giralia and Marrilla Anticlines by its lithology and type of outcrop. The lenticularity of the formation is particularly apparent. The Lamont Standstone consists mainly of quartz of uneven grain-size and it ranges from a friable sugary-textured fine-grained to coarse-grained quartz sandstone to a hard fine-grained to very-coarse-grained quartz sandstone with calcareous cement. A petrographical examination of a hard quartz sandstone showed the following:

quartz (0.05 to 0.2 mm.), sub-angular to sub-rounded—about 95 percent;
calcite (the cement)—less than 5 percent;
tourmaline, ? sphene, rutile—less than 2 percent.

CAPE RANGE GROUP

Trealla Limestone

The Cape Range Group and the Trealla Limestone were defined by Condon, Johnstone and Perry (1953). The name (pronounced tre-al'-la) is taken from the original name of Mount Lefroy (lat. 22°13'S., long. 114°00'E.), five miles west of Learmonth airfield. The 179-foot type section of the Trealla Limestone is on the north flank of Mount Lefroy.

The Trealla Limestone as exposed on the Giralia Anticline consists of hard white, cream, and yellowish-brown crystalline limestone, interbedded with sandy crystalline limestone and chalky limestone, with foraminifera and mollusca. The Trealla Limestone overlies the Lamont Sandstone unconformably, and is overlain either by the Walatharra Formation or by travertine with an erosional and angular unconformity.

The maximum thickness of the Trealla Limestone in the Giralia and Marrilla Anticlines is at lat. 22°56'S., long. 114°01'E., one and a half miles south-west of No. 10 Bore. The section consists, in descending order, of:

Travertine.
20 feet Limestone, crystalline, fine-grained, hard, white, with foraminifera, mollusca;
13 feet Alternating limestone, crystalline, fine-grained, hard, white, and limestone, chalky, soft, white; foraminifera, mollusca;
8 feet Limestone, crystalline, fine-grained, hard yellowish-brown, with large nodules (12 x 1 x 1 inches) of acicular aragonite; foraminifera;

3 feet	Limestone, crystalline, fine-grained, hard, white, with foraminifera;
25 feet	Limestone, crystalline, medium-grained, hard, yellowish-brown, with foraminifera;
	Giralia Calcarenite.
69 feet	

Crespin, in Condon, Crespin, Johnstone and Perry (1953), places the Trealla Limestone in the "f1-?f2" stage of the East Indes classification, that is the lower Miocene. The following foraminiferal assemblage characterizes the Trealla Limestone on the Giralia and Marrilla Anticlines.

Austrotrillina howchini (Schlumberger)
Flosculinella bontangensis (Rutten)
Marginopora vertebralis Quoy and Gaimard
Lepidocyclina (*Nephrolepidina*) *borneensis* (Provale)
Lepidocyclina (*Trybliolepidina*) *martini* (Schlumberger)
Lepidocyclina (*Trybliolepidina*) *verrucosa* (Scheffen)
Valvulina cf. *davidiana* Chapman

The hard Trealla Limestone outcrops as cuestas on the north and south noses and the west flank of the Giralia Anticline. The most continuous outcrops of the limestone are on the north nose of the Giralia Anticline and the ridge which extends from south-west of Korojon Pool to the Lyndon River. The cuestas of Trealla Limestone on the west flank of the Giralia Anticline are discontinuous and occur on the western edges of the divides of the consequent streams. Hogbacks of the limestone occur on the east flank to four miles south of the Giralia-Bullara Road, and outliers of the formation are on the south-west flank of the Nabbawarra Syncline and two miles south-south-east of Deep Bore. The Trealla Limestone does not outcrop elsewhere on the Marrilla Anticline. The outcrops on the west flank of the Giralia Anticline are separated from those on the Cape Range only by sand cover, and continuity of deposition has been proved by shallow water bores.

Two miles south from Centipede Bore is the following section of the Trealla Limestone:

	Top of outcrop;
3 feet	Limestone, crystalline, sandy, hard, grey, with foraminifera, mollusca;
3 inches	Limestone, sandy (very coarse-grained), molluscan coquinoid foraminifera;
3 feet	Limestone, crystalline, fine-grained, sandy, hard, grey and cream, quartz grains, sub-angular to sub-rounded, medium-grained to very coarse-grained; foraminifera, mollusca;
	Lamont Sandstone.
6 feet 3 inches	

The thicknesses of outcrop of the Trealla Limestone are:

(1) on the west flank of the Giralia Anticline—
20 feet, near trig. point A6,
30 feet, west of Korojon Pool,
25 feet, near Jubilee Bore.

(2) on the east flank—
4 feet, two miles north of the Giralia-Bullara Road,
20 feet, nine and a half miles south-south-west from Lamont Well.

The Trealla Limestone crops out on the Cape Range, Rough Range, Warroora Anticline, Chargoo Anticline, Gerardi, Chirrida, and Yankie Tank Anticlines on Minilya Station and at Cape Cuvier and Red Bluff.

The type section of the Trealla Limestone at Mount Lefroy consists entirely of limestone, although on the north end of the Cape Range Anticline the limestone contains some rounded quartz grains. On the Giralia Anticline the formation contains many sub-angular to rounded quartz grains which range in size from medium to coarse. Also, the basal limestone is more coarsely crystalline and contains more iron than the type section and in many places the limestone in the bottom half of the formation is chalky and contains large nodules (12 x 1 x 1 inches) of aragonite crystals. The lower part of the Trealla Limestone is in places covered by a white chalky soil.

Quaternary System

Apart from the Walatharra Formation, the sediments of the Quaternary System were not mapped in detail, and geographical names were not assigned to them. Differences in the Quaternary sediments were noted, however, and the following tentative divisions were made:

Marine muds and shelly sands;
Marine muds and sands;
Lacustrine deposits;
Travertine;
Residual soil;
Wash (thin sheet-flow deposits);
Sand (including dunes);
Alluvium (stream deposited).

PLEISTOCENE FORMATIONS

Walatharra Formation

Walatharra (pronounced wol'-a-tha'-ra) is the name of a paddock on Giralia Station, seven miles west of Giralia Homestead.

The Walatharra Formation is composed of unfossiliferous soft brown calcarenite with limestone pebbles, and hard brown limestone pebble conglomerate. The formation overlies the Trealla Limestone with an erosional and angular unconformity of 16°, and is overlain by recent gravels with an erosional and angular unconformity of 25°.

Fig. 14.—Seven miles west of Giralia Homestead, looking south.
a.—Recent alluvium b.—Walatharra formation, dipping east.

The type section is in a creek at lat. 22°42′S., long. 114°15′E., three and a quarter miles west-south-west of Deep Bore, Giralia Station. Although no current-bedding was observed in the type section, it is possible that the large thickness measured is due to this factor. The type section consists, in descending order, of:

	Gravel of Recent Age;
8 feet	Conglomerate, limestone pebble, hard, with matrix of calcarenite, partly recrystallized, ferruginized;
14 feet	NO OUTCROP. Soft material removed and replaced by pebble conglomerate of later age (Recent);
3 feet	Conglomerate, pebble, hard, with matrix of partly recrystallized. ferruginized calcarenite;
11 feet	NO OUTCROP; probably calcarenite;
4 feet	Conglomerate, limestone pebble, hard, brown-red, with ferruginized calcarenite matrix with many coarse limonite grains;
	Angular and erosional unconformity;
	Trealla Limestone.
91 feet	

No fossils were found in the Walatharra Formation, and whether the sediments are marine or fluviatile is not known. Above the Walatharra Formation are 17 feet of Recent pebbly gravel and sandy loam with fine-grained gravel lenses. The gravel formation is horizontal and is possibly the equivalent of the marine ?Recent Mowbowra Conglomerate (see Table

II) in the Cape Range area (Condon et al., 1953). It is therefore thought that the Walatharra may possibly be Pleistocene in age.

The type section of the Walatharra Formation is the only known outcrop.

Marine muds and sands

Marine muds and sands consist of calcarenite, calcareous clay, and limestone fine conglomerate, with gypsum and shelly fossils. The best exposures are in the banks of the tributaries of the Lyndon River near the north end of the Chargoo Anticline; the strata are practically horizontal (probably a slightly northerly dip). A section consists, in descending order, of:

	Top of outcrop;
4 feet	Conglomerate, fine, limestone, with calcarenite matrix, pelecypods (including *Ostrea*), gastropods;
1 foot	Calcarenite, friable, white;
5 feet	Clay, calcareous friable, reddish-brown, with gypsum;
12 feet	Calcarenite, friable, yellowish-brown;
	Base of outcrop.
22 feet	

These beds weather to form a soft puffy very fine soil flecked with numerous crystals of gypsum and salt. In some areas pelecypods (*Arca, Ostrea*) gastropods, and echinoids are scattered on the soil surface.

These beds are marine and probably Pleistocene in age because of their elevation—15 to 30 feet above sea level.

The marine muds and sands are bounded on the west by sand and on the east by the Giralia Anticline. They also outcrop between the Lyndon River and the south end of the Giralia Anticline, and between the Lyndon River and the north end of the Chargoo Anticline (Plate 3).

RECENT FORMATIONS

Marine muds and sands

Muds and sands with gypsum and salt were deposited by recent small incursions of the sea. No section of the sediments was measured.

The outcrop is usually low-lying and flat and the surface moist. "Salt marshes" are formed on the Recent marine muds and sands south of Giralia Bay, west of Coast Tank, near the Bullara Homestead turn-off on the Cardabia-Ningaloo Road and south of Cardabia Homestead.

Lacustrine deposits

Gypsiferous calcareous clay of the lacustrine deposits is well exposed on the banks of the Lyndon River near the north-west flank of the Chargoo

Anticline. The strata are horizontal. A section consisted in descending order of:

	Top of outcrop;
5 feet	Clay, calcareous, gypsiferous, friable, grey; nodules of gypsum and one to two inch beds of gypsum;
7 feet	Clay, calcareous, gypsiferous, friable, grey, nodules (up to two inches diameter) of gypsum; no bedding;
	Marine muds and sands.
12 feet	

The weathered material is a soft, puffy and very fine soil with numerous gypsum and salt crystals.

No fossils were noticed, and the deposits are tentatively regarded as lacustrine and Recent in age.

This gypsiferous clay crops out south of the ?Pleistocene marine muds and sands and is confined on the west by alluvium adjacent to the Warroora Anticline, on the east by the western edge of the ?Pleistocene marine muds and sands, and on the south by the Salt Lake, the floor of which consists of a similar deposit.

Travertine

Although some concretionary or pisolitic kunkar occurs in the area mapped, travertine predominates. The maximum thickness is five feet.

Travertine caps the Trealla Limestone on the east and west flanks of the Giralia Anticline, the Wadera Calcarenite on the south nose of the Nabbawarra Syncline, and the Lamont Sandstone on the north nose and east flank of the Marrilla Anticline.

The distribution of travertine is shown on Plate 3.

Residual soil

Residual soil is formed from the breaking down of the parent rock *in situ* and has not been transported by any agency.

The distribution of the residual soil is shown on Plate 3.

Wash

The wash is a sheet-flow deposit of unconsolidated sediments usually only one to two feet thick.

The only area of wash on the map (Plate 3) is one to three miles west of Cardabia Pool.

Sand

The areas of sand consist of reddish and white quartz sand and sand dunes. The sand dunes are of two types:

(a) red or inland sand dunes,

(b) white or coastal sand dunes.

(a) The red sand dunes consist of semi-consolidated or loose reddish fine-grained to very coarse-grained sub-rounded quartz sand grains with iron oxide staining, with a hard band of travertine near the water table.

(b) The white sand dunes are composed of carbonate and quartz sand which contains medium-grained to fine conglomerate sized, angular to sub-rounded fragments of foraminiferal tests and molluscan shells. The sand dunes are semi-consolidated and loose.

Alluvium

Alluvium is the soil and fine-grained to coarse-grained sediments deposited by stream action.

For the distribution of the alluvium refer to Plate 3.

STRUCTURE

GENERAL FEATURES

The sediments of the Giralia Range area are folded into two closed asymmetrical anticlines and three asymmetrical synclines (Plate 7). The narrow, elongated Giralia Anticline extends from Exmouth Gulf to the Salt Lake, and the Marrilla Anticline from two miles south of Deep Bore, Giralia Station, to a point bearing 80° from Remarkable Hill. The axial trend of the Giralia Anticline is 15° and that of the Marrilla Anticline 25°.

The synclines are named the Bullara, Nabbawarra, and White Peaks Synclines. The Bullara Syncline is a broad, slightly asymmetrical structure bounded on the west by the Cape Range Structure and the Warroora Anticline, and on the east by the Giralia Anticline. The Nabbawarra Syncline is narrower and more asymmetrical than the Bullara Syncline, and is between the Giralia and Marrilla Anticlines. The White Peaks Syncline is bounded on the west by the Marrilla Anticline and the south-east flank of the Giralia Anticline. The eastern flank of this syncline is the regional westward dip of the Cretaceous sediments.

Transverse and longitudinal faults cut the anticlines, but sand and alluvium cover any faults that may be within the synclines. The throws of most of the faults on the Giralia and Marrilla Anticlines are less than 30 feet, although the throw of some faults is about 100 feet, as, for instance, where the Giralia-Bullara Road crosses the crest of the Giralia Anticline.

The closure of the Giralia and Marrilla Anticlines on the top of the Boongerooda Greensand is 800 feet. The closure is limited by the high point of the White Peaks Syncline about three miles south-south-east of Miria Well. The total area of closure of both anticlines on the top of the Boongerooda Greensand is 300 square miles. East of the axis of the Giralia Anticline, the area of drainage of the Giralia and Marrilla Anticlines is 750 square miles, and the drainage area west of the axis is 1250 square miles.

DETAILS OF STRUCTURE

Giralia Anticline

In outcrop the Giralia Anticline is 80 miles long and is 15 miles wide where the Giralia-Bullara Road crosses it, 19 miles wide across the apex, and 21 miles wide near Cardabia Pool.

The trend of the axis is 15°. North of the apex the structure is asymmetrical along and at right angles to the axis (Plates 3, 4). Cross-section HF (Plate 4) through the apex shows slight asymmetry. Near Miria Well, the profile is symmetrical (cross-section KL, Plate 4), and south of Cardabia Pool the fold is asymmetrical (cross-section MN, Plate 4).

The dip of the west flank increases from $\frac{3}{4}$° near Jubilee Bore, to $2\frac{1}{2}$° at Remarkable Hill and 3° near trig. point A8. High on the flank the dip is low; in the middle it steepens; and towards the base gradually decreases. The east flank dips gently over most of its width, but in a zone roughly parallel to the anticlinal axis and about one and a half miles east of it the dips are generally steeper and range from 3° near Centipede Bore to more than 60° eight miles north-east of Remarkable Hill. This zone is an anticlinal bend. The synclinal bend which adjoins is not exposed. The anticlinal bend is flexured in plan three and a half, eight, 11, and 15 miles south of the Giralia-Bullara Road. South of the apex the anticlinal bend is poorly exposed but it becomes apparent two and a half miles north of Korojon Pool where the Gearle Siltstone dips at 20°. East of the anticlinal and synclinal bends the dip continues very gently to the White Peaks syncline.

The apex is five miles east-north-east of Remarkable Hill. The apical area is flat and elongated in a southward direction.

The crest both to the north and south of the apex is irregular. Immediately to the north of the apex the northerly plunge is 0°55′ for four and a half miles, then 0°8′ for eight miles, 0°19′ for $10\frac{1}{2}$ miles, 1°5′ for three miles and 0°27′ for 12 miles. South of the apex are three small shallow saddles at 11, 12, and $13\frac{3}{4}$ miles, and one large deep saddle at 23 miles. Ignoring these saddles the southern plunge averages 0°27′.

Minor culminations (Billings, 1949) between these saddles are at $11\frac{1}{2}$, 13, 15, and 25 miles south of the apex. Closure on these culminations is 50 feet or less, except the one 25 miles south of the apex with a closure of about 300 feet (Plate 9).

The culminations south of the apex show a progressive shifting of the axis of the Giralia Anticline towards the west. It is thought that the axis is offset by transverse faults.

The closure of the Giralia Anticline on the top of the Boongerooda Greensand is limited by the saddle between the Giralia and Marrilla Anticlines and is 700 feet. The area of closure is 230 square miles. The area of drainage of the Giralia Anticline east of the axis is 500 square miles, and west of the axis 1250 square miles.

Marrilla Anticline

The Marrilla Anticline is 20 miles long and four miles wide across the apex, and extends from two miles south of Deep Bore, Giralia Station, to a point nine miles, bearing 80°, from Remarkable Hill. The width of the Anticline from Hope's Bore to Lamont Well, across the south nose, is three and a half miles.

The axis strikes at 25°. The structure is asymmetrical along, and at right angles to, the axis. Cross-section FG of the anticline (Plate 4) shows the relationship between the steep dips of the east flank and the low dips of the west flank.

The west flanks of the Marrilla and Giralia Anticlines differ in that the minor anticline has a steeper dip; also the dip of the west flank of the Giralia Anticline increases gradually to the south, whereas the dips (1-1½°) on the north-west and south-west flanks of the Marrilla Anticline are the same and the maximum dip (6°) is west of the apex. The dip is gentle on the upper part of the west flank, steepens in the middle portion, and gradually flattens towards the synclinal axis.

Exposures on the east flank are poor, and dips are difficult to obtain. In outcrop pattern, the east flanks of the two anticlines are similar, and the lower part of the east flank of the smaller anticline appears to dip steeply. In profile, the gentle dip of the top of the east flank increases gradually to within one quarter of a mile from the outcrop edge and then suddenly steepens to form an anticlinal bend (cross-section FG, Plate 4). Two prominent flexures occur on the south-east flank. The closures of the culminations formed by the flexures are less than 50 feet.

The apex is eight miles from Lamont Well on a bearing of 175°; the apical area is oval. The crest north of the apex plunges gently towards Giralia Homestead, and although there may have been some minor flexures of the crest, no important reversals of the plunge are evident. There are two shallow saddles on the crest south of the apex.

The closure of the Marrilla Anticline on the top of the Boongerooda Greensand is 250 feet. The closure is limited by the saddle between the Marrilla and Giralia Anticlines. The area of closure is 70 square miles. The area of drainage east of the axis is 100 square miles, and west of the axis is 150 square miles.

Bullara Syncline

The Bullara Syncline (the name is taken from Bullara Homestead) is the name proposed for the syncline which separates the Giralia Anticline from the Cape Range Structure (including the Rough Range Anticline) and the Warroora Anticline. The syncline is about 70 miles long (Exmouth Gulf to the Carnarvon - Warroora Road), and 11 miles wide (Rough Range to Giralia Anticline).

Alluvium adjacent to the west flank of the Giralia Anticline, sand and sand dunes, travertine, and marine muds and sands cover the syncline.

The synclinal axis extends from Exmouth Gulf to Bullara Homestead, Maud Landing Bore, and then southward towards and through Salt Lake. The Bullara Syncline is a slightly asymmetrical structure with a slight structural high near Maud Landing Bore. The dips of the west flank range from 1°-2° near the Rough Range Anticline to 5° east of the north end of the Warroora Anticline. The dips of the east flank range from $\frac{3}{4}$° near Exmouth Gulf to 2° east of Maud Landing Bore to 1° east of Warroora No. 1 Bore.

Nabbawarra Syncline

The name Nabbawarra is derived from the Nabbarawarra Bores, one mile south-south-west of Lamont Well.

Nabbawarra Syncline is the name proposed for the syncline between the Giralia and Marrilla Anticlines. The Nabbawarra Syncline is bordered on the west and south by the northern plunge of the Giralia Anticline, on the east by the Marrilla Anticline, and on the north by Giralia Bay. The syncline extends for 35 miles from 15 miles south-south-west of Lamont Well to Giralia Bay, which is a topographical expression of the northern extension of the syncline. The plan of the syncline is a V the left stroke of which is the east flank of the Giralia Anticline.

Alluvium forms the surface of the axial part of the syncline. North of Giralia Homestead are sand and sand dunes, and south of Giralia Bay are marine muds and sands.

The axis of the Nabbawarra Syncline parallels the east flank of the Giralia Anticline and it is from one to one and a quarter miles east of the edge of the outcrop.

The Nabbawarra Syncline is an asymmetrical structure which plunges northward. The dips on the margin of the west flank range from 3° north of Centipede Bore to 60° on the south-south-west flank of the syncline. The dip on the east flank ranges from 1° east of Nabbawarra Bores to 5° west of the apex of the Marilla Anticline, and 1° on the south-east flank of the syncline. Flexures are prominent on the west flank, whereas the east flank has only a slight flexure.

White Peaks Syncline

The name is taken from the White Peaks one-mile sheet, which is crossed by the syncline.

The White Peaks Syncline is the name proposed for the syncline bounded on the west by the east flank of the Marrilla Anticline and the south-east flank of the Giralia Anticline. The northern extension of the syncline is probably marked by the V of alluvium which extends north-north-east from Gardners Bore. Bore information (cross-section OP, Plate 4) indicates that the southward extension of the White Peaks Syncline possibly passes about one mile east of Mia Mia No. 1 Woolshed.

The syncline is covered by sand, travertine, residual soil, and alluvium.

The approximate position of the axis of the syncline is three miles east of the axis of the Marrilla Anticline, two and a half miles east of Miria Well, and one mile east of Mia Mia No. 1 Woolshed.

The White Peaks Syncline is asymmetrical, the west flank being the steeper. The dips on the margin of the west flank range from 3° upwards and the east flank dips at less than 1°. Near Winning No. 2 Bore is a structural high from which the syncline plunges northward and, more gently, southward.

FAULTS

Except on the north plunge of the Giralia Anticline, faults are few in the Giralia and Marrilla Anticlines. Both longitudinal and transverse faults occur:

1. in the breached crestal area of the Giralia Anticline near the Giralia-Bullara Road;
2. seven miles south-west of Remarkable Hill;
3. three miles east-north-east of Cardabia Pool.

1. Small scale faulting is common in the basal 50 feet of the Wadera Calcarenite, the Boongerooda Greensand, and the top 100 feet of the Korojon Calcarenite. The faults strike at 30° and 70°. Two types of faults can be recognised, viz.

(a) faults associated with the slumping in the Wadera and Korojon Calcarenites; and

(b) faults in the Korojon Calcarenite which are not associated with slumping.

(a) The outcrop pattern and the type of faulting suggest the occurrence of much slumping. The hard beds of the Wadera Calcarenite are buckled and puckered and cut by many small low-angle thrust-faults indicating that the deformation possibly occurred while the sediments of the Wadera Calcarenite were in a semi-consolidated, plastic state. Similar conditions applied to the Korojon Calcarenite. Many small fault-blocks which contain

Korojon Calcarenite, Boongerooda Greensand, and Wadera Calcarenite, outcrop as inliers within the Korojon Calcarenite. The maximum throw of these fault-blocks is about 20 feet.

(b) The two major faults of the area trend at 70° and are one to two miles north of the Giralia-Bullara Road. The faults are probably step-faults The throw of the southernmost fault is about 120 feet, and of the other about 35 feet.

From the nature and size of the throws of the faults of (a) and (b), two ages of faulting are possible. The older faults (a) were pene-contemporaneous with the deposition of the Wadera and Korojon Calcarenites, or after the deposition of the formations but before the deposition of the Pirie Calcarenite. The younger faults (b) may be synchronous with or later than the folding of the Giralia Anticline.

2. The fault seven miles south-west from Remarkable Hill strikes at 20° and is immediately east of the base of the Trealla Limestone. The fault is deduced from physiographical evidence only. A consequent stream which apparently drained the west flank was beheaded by a minor fault which formed a 25-foot scarp. The stream now parallels this scarp and drains to the south. The movement took place in Recent to Sub-recent time.

3. Three miles east-north-east of Cardabia Pool, the attitude of the Korojon Calcarenite indicates a drag. The anticlinal axis through the Windalia Radiolarite, two miles north-west of Cardabia Pool, is displaced and the beds of radiolarite adjacent to the axis are dragged. These facts indicate a fault which trends at 275° and extends from the Windalia Radiolarite to the Korojon Calcarenite on the east flank of the Giralia Anticline. The throw of the fault is small.

The steep dips of the east flank of the Giralia Anticline were traced in the Korojon Calcarenite, Boongerooda Greensand, and Wadera Calcarenite to the south nose of the Nabbawarra Syncline. South of this point, the aerial photographs show a zone of relatively steep dips, and the zone cuts obliquely across the Korojon Calcarenite and Gearle Siltstone. The outcrop pattern four miles east-south-east of No. 2 Deep Bore suggests that the zone of steep dips is terminated by a fault which trends at 290°. The zone of steep dips (about 20°) reappears in the Korojon Calcarenite two miles south-south-west of Cardabia Pool and disappears under alluvium four miles south-south-west of Korojon Pool.

ORIGIN AND AGE OF FOLDING

In outcrop, the Giralia Anticline is 80 miles long and 14 miles wide, and the Marrilla Anticline is 20 miles long and four miles wide.

The width of the west limb of the Giralia Anticline, from anticlinal axis to synclinal axis, is 15 miles, and the width of the east limb is from two to nine miles. The width of the west limb of the Marrilla Anticline is four and a half and of the east limb about three miles. The dips of the west limb of the Giralia Anticline range up to 3°, and of the east limb (locally) up to 60°. The dip of the west limb of the Marrilla Anticline is up to 6°, and the east limb presumably has dips similar to those on the east limb of the Giralia Anticline.

A sketch isopach map of the Wadera, Pirie, Cashin, Jubilee and Giralia Calcarenites shows a north-west divergence of about half a degree. Provided the erosion at the disconformable contacts was small, the regular divergence of half a degree indicates that differential compaction or deposition over "buried hills" would not be a satisfactory explanation of the origin of the Giralia and Marrilla Anticlines.

Probably vertical forces caused the folding of the Giralia and Marrilla Anticlines. It is suggested that the vertical force or uplift was caused by movement along a fault in the Palaeozoic and basement rocks. The Palaeozoic sediments which crop out in the eastern part of the Carnarvon Basin are not folded except where synclinal drag folds are associated with faults, e.g. Round Hill Well area on Winning Station, Wandagee Hill area on Wandagee Station, and west of the Kennedy Range on Hill Springs Station. Although high-angle normal faults with throws of 100 feet or less are known, the major faults of the Basin are high-angle thrusts, with throws of up to 8,000 feet in the Palaeozoic sediments. Faulting occurred between Permian and Cretaceous deposition and in the late Tertiary in the eastern part of the Carnarvon Basin, and on some faults there were at least two periods of movement.

The west flanks of the Giralia and Marrilla Anticlines dip gently, and the dips of the east flanks increase from the crest and are steep on the outcrop margin. No visible displacement or discontinuity of the trend of the strata, brecciation, or other criteria of faulting, are noticeable on the ground surface on the margin of the east flanks of the two anticlines. The linear trend of the zone of steep dips and the sharp flexures on the east flanks suggest faults which have not broken through to the surface.

The surface folds are drags which resulted either from strike-slip along these main sub-surface faults or from subsidiary faults which cut the main fault. In either case the folds are fault structures and are not due to compression of the strata.

These sub-surface faults are presumed to be high-angle thrusts with the downthrown block to the east. The flexures on the east flanks may be related to small shatter-zones or junctions of a number of sub-surface faults. No evidence exists to determine whether the vertical uplift responsible for the formation of the two anticlines was along old post-Permian fault lines or not (see Results of Geophysical Survey). However, the stratigraphy suggests four periods of movement on the faults in Cainozoic time.

The sediments of the Giralia and Marrilla Anticlines were folded at four different periods, viz. between upper Eocene and lower Miocene, during lower Miocene, between lower Miocene and Pleistocene and in the Pleistocene or post-Pleistocene. After the deposition of the Giralia Calcarenite, the sediments were probably slightly folded, and the crestal area was eroded in the interval between the upper Eocene and lower Miocene. Between lower Miocene and Pleistocene times, the Trealla Limestone and older sediments were folded. The major folding movement occurred during or after the Pleistocene Epoch, because the Walatharra Calcarenite, which is presumed to be Pleistocene in age, dips at ?22° and overlies the Trealla Limestone which dips at 38°.

The sediments of the Cape and Rough Ranges were folded between the Pliocene and Pleistocene, and again in Pleistocene or post-Pleistocene time.

Mesozoic sediments in the eastern part of the Carnarvon Basin overlie Palaeozoic with an angular unconformity which ranges from 1° to 10°.

RELATION TO REGIONAL STRUCTURE

Cretaceous sediments outcrop in the 50 miles which separate the apex of the Giralia Anticline from the Pre-Cambrian rocks. The outcrop of Palaeozoic sediments nearest to the apex of the Giralia Anticline is on Mia Mia Station, 35 miles to the east-south-east.

The Palaeozoic-Mesozoic boundary north of the Gascoyne River is five miles east of Mia Mia Homestead; on the western side of Wandagee Hill; and on the western margin of the Kennedy Range. The westernmost outcrops of Cretaceous rocks, except for those exposed in the breached anticlines near the Salt Lake, are five miles west of Mia Mia Homstead, five miles east of Cooralya Homestead, and 10 miles west of Doorawarrah Homestead.

Along the coast north of Carnarvon is a 40-mile-wide belt of anticlines arranged *en echelon*. The Giralia and Marrilla Anticlines are in the north-east corner of the belt and are the most easterly of the anticlines. The apices of the Cape Range Structure and the Rough Range Anticline are 70 and 40 miles respectively north-north-west of the apex of the Giralia Anticline. Immediately south of the Giralia Anticline and on the same trend are the Chargoo, Chirrida, Gerardi, and Yankie Tank Anticlines. all of which fringe the east shore of the Salt Lake. To the south-south-west of the Giralia Anticline are the Warroora, Gnarraloo and Cape Cuvier Anticlines.

ENVIRONMENT OF SEDIMENTARY DEPOSITION

The sediments which crop out on the Giralia and Marrilla Anticlines are marine and were deposited in a stable shelf area possibly contiguous with the Timor - East Celebes geosyncline.

The Windalia Radiolarite contains mainly a pelagic fauna including foraminifera, radiolaria, belemnites and ammonites and a few pelecypods.

The Gearle Siltstone does not outcrop to the east of the 4 mile Bore, Winning Station, and the sea was probably retreating westward at the close of the deposition of the Windalia Radiolarite.

The Gearle Siltstone contains mainly a micro-fauna of pelagic and benthonic forms: small brachiopods and belemnites are the only mega-fossils recorded. Clayey soils or volcanic ash or tuff were probably the source rocks. The Gearle Siltstone is separated from the Korojon Calcarenite by fine conglomerate; the conglomerate and the Gearle-Korojon contact suggest that the sea was becoming shallower at the close of deposition of the Gearle Siltstone and that there was probably a hiatus in deposition.

The clastic arenite-sized sediments of the Korojon Calcarenite indicate the advent of shallow-water near-shore conditions. The "*Inoceramus* formation" was deposited in a warm sea, probably about 100 fathoms (Clarke and Teichert, 1948, p.43). A fairly rich neritic fauna flourished; it consisted of *Inoceramus* and other pelecypods, small brachiopods, some ammonites, and foraminifera. The thickness of the Korojon Calcarenite indicates that the sediments were possibly distributed on a sea floor which rose gradually towards the west-north-west.

Between the Korojon Calcarenite and Miria Marl is a disconformity which represents non-deposition in lower and middle Campanian times. The conditions of deposition of the Miria Marl were similar to those of the Korojon Calcarenite. The thickness of the Marl is consistent in the Giralia and Marrilla Anticlines and nowhere is the formation absent. Apparently the sea was quiet with no turbulent currents or tide action, and the sea floor was practically level. Marine life of pelagic and benthonic forms flourished. Ammonites were abundant and died out at the close of the deposition of the Miria Marl. The Maestrichtian sea of the Miria Marl is the youngest Cretaceous sea known in the Carnarvon Basin.

Before the deposition of the Boongerooda Greensand the area of deposition was raised above sea level. The contact between the Miria Marl and the Boongerooda Greensand is disconformable and the disconformity represents non-deposition in middle and upper Maestrichtian times at least.

The warm sea at the start of the Cretaceous-Tertiary was shallower — only 10 to 50 fathoms (Twenhofel, 1939, p.403) — than in Maestrichtian time and contained mainly foraminifera and small brachiopods. Conditions were suitable for the formation of glauconite. Probably sediments with biotite were slowly deposited in an anaerobic environment, and the sediments were subjected to the action of sea water for a long time (Twenhofel, loc. cit.).

The Cretaceous-Tertiary sea in which the Wadera Calcarenite and the Pirie-Cashin Calcarenite were deposited was similar in depth and temperature to the sea in which the Korojon Calcarenite was formed. After the deposition of the Boongerooda Greensand the sea became clearer and contained less fine sediment. The fauna of the Wadera Calcarenite comprised foraminifera, corals, echinoids, bryozoa, brachiopods, and molluscs. The Pirie-Cashin Calcarenite fauna included foraminifera, radiolaria, echinoids, bryozoa, small brachiopods, pelecypods, "worms", crabs. The isopach maps of the Wadera Calcarenite and the Pirie-Cashin Calcarenite suggest that the sea-floor was irregular. At the close of the deposition of the Cashin Calcarenite there may have been a break in deposition.

The Jubilee Calcarenite and the Giralia Calcarenite are disconformable, and the hiatus represents non-deposition in the lower Eocene and possibly part of the Cretaceous-Tertiary and middle Eocene times. No sediments with definite lower Eocene fossils outcrop on the Giralia and Marrilla Anticlines.

Ooides were formed in the middle Eocene sea in which the lower part of the Giralia Calcarenite was deposited. Calcareous matter, iron in solution and probably some ooides, fine-grained and medium-grained clastic limestone, and fine-grained clastic argillaceous and quartz material were transported to the sea. The environment of deposition was warm water in which organic matter was abundant and deposition slow. The iron and some ooides were probably derived from a lateritized surface of the land mass: during erosion, laterite fragments were broken down and the iron taken into solution, and, in the form of limonite, hematite, siderite, and possibly other forms, was deposited in the sea as ooides (Twenhofel, 1939, p.575). The close of the deposition of the lower part of the Giralia Calcarenite was marked by a change of conditions. The supply of fine-grained clastic argillaceous sediment decreased, the rate of deposition was not as slow, and the magnesium content of the sea was sufficient to impart a dolomitic composition to the limestones of the upper part of the Giralia Calcarenite. The fauna of the middle to upper Eocene sea included foraminifera, corals, echinoids, bryozoa, brachiopods, molluscs, nautiloids, fish, and crabs.

After the deposition of the Giralia Calcarenite, the sea retreated and the sediments were raised above sea level. Although the dips of the Giralia Calcarenite and the Trealla Limestone are similar, small-scale folding probably accompanied the uplift and the formation of the Giralia and Marrilla Anticlines began. The raised area had a low relief and it was lateritized.

In lower Miocene time a shallow sea transgressed the area but submerged only the lower parts of the land surface. The Lamont Sandstone deposited in this sea is clean, not cross-bedded, and the grain-size is variable. The maximum thickness of the formation is near the Nabbawarra Syncline, and the sandstone exposed on the east flank of the Giralia Anticline and on the west and north flanks of the Marrilla Anticline is much coarser than that on the west and south flanks of the Giralia Anticline. The range in grain-size and the cleanness of the Lamont Sandstone could indicate the existence of turbulent conditions such as those along a beach. The sparse fauna consists mainly of foraminifera.

Between the Trealla Limestone and the Lamont Sandstone is an angular unconformity of less than two degrees. The nature of the unconformity indicates that similar conditions prevailed after the deposition of the Lamont Sandstone to those prevailing after the deposition of the Giralia Calcarenite. Half a mile west of Korojon Pool conglomerate separates the two formations. *Inoceramus* shell fragments in the conglomerate show that some at least of the pre-Trealla Limestone sediments were raised above sea level and that a part of the land surface, probably the crestal area of the Giralia Anticline, was eroded sufficiently to expose the Korojon Calcarenite. The land was then submerged, and the conglomerate deposited. (The thicknesses of the Trealla Limestone outcrops and the stratigraphy suggest that the formation was then deposited over the area now referred to as the Giralia and Marrilla Anticlines.) The Trealla Limestone on the north-east flank of the Giralia Anticline and the basal part of the formation on the west flank is sandy; which suggests that the sea was initially shallow. The sea then deepened, the supply of detrital quartz practically ceased and conditions were favourable for the deposition of limestone. Before the middle Miocene, the area was raised above sea level. During uplift or after, the sediments were again folded.

In ?Pleistocene time the Walatharra Formation was rapidly deposited, in probably only a small area. In ?Pleistocene time or later, the sediments of the Giralia and Marrilla Anticlines were uplifted and folded to their present form.

GEOMORPHOLOGY

The Giralia Range area may be divided into eight geomorphological units:

(a) The north nose, west flank, and south nose of the Giralia and Marrilla Anticlines;
(b) Remarkable Hill area;
(c) The east flanks of the anticlines;
(d) The breached apical areas of the anticlines;
(e) Nabbawarra Syncline;
(f) Sand dunes;
(g) Region of centripetal drainage;
(h) Alluvium south of Korojon Pool;
(i) The northern extension of Salt Lake.

The north nose, west flank and south nose of the Giralia and Marrilla Anticlines

This unit consists of two separate areas — one on the Giralia Anticline, the other on the Marrilla Anticline. Each area is like an arcuate wedge with the steep edge facing east.

Giralia Anticline

The area on the Giralia Anticline consists of a series of cuestas, with long gentle dip slopes to the west and prominent escarpments with scalloped margins to the east. The limestone beds of the Korojon and Jubilee Calcarenites and the basal limestone beds of the lower part of the Giralia Calcarenite and the Trealla Limestone cap the cuestas, and the soft calcarenite beds form the steep slopes of the scarps and valley sides. Outliers capped by the resistant beds of these four formations occur on the north and south noses and the south-west flank of the Giralia Anticline.

The main drainage is consequent and has a dendritic pattern, although the short subsequent and obsequent streams impart a rectangular arrangement. The streams are mature, and only in the upper reaches is bedrock eroded. North of Remarkable Hill the cuesta formed by the limestone beds of the Jubilee Calcarenite constricts the main tributaries to a braided consequent stream. South-west of Korojon Pool, drainage is poorly developed.

Marrilla Anticline

The Marrilla Anticline area contains two cuestas the dip slopes of which are the limestone beds of the Korojon and Jubilee Calcarenites in the north, and the Korojon and Pirie Calcarenites in the south. North of the apical area outliers of the Wadera and Pirie Calcarenites fringe the scarp of the more western cuesta.

The drainage is consequent, and the drainage pattern is dendritic.

The Remarkable Hill Area

The Remarkable Hill area is bounded by the Cardabia - Winning Road on the south and an east-west line three miles north of Remarkable Hill. The unit has the most rugged topography of the Giralia and Marrilla Anticlines because the hard limestone beds in the Wadera Calcarenite resist the erosion of the obsequent streams of the scarp. Adjacent to and to the north of Remarkable Hill are prominent conical hills which are outliers of the Wadera, Pirie, and Cashin Calcarenites. Outliers of the Giralia Calcarenite and Trealla Limestone dot the lower slopes of the west flank.

The drainage is consequent and has a fine closely-spaced dendritic pattern in the eastern half of the unit. The streams are youthful with sharp V-shaped valleys and are cutting rock. The drainage of the western half, one and a half miles from the scarp, is consequent but more mature. The main drainage pattern is dendritic, but in some places the subsequent and obsequent streams form a rectangular pattern. The main tributaries join the consequent streams before they flow through the lower part of the Giralia Calcarenite.

The east flanks of the anticlines

Giralia Anticline

West of the anticlinal bend on the northern part of the east flank, the limestone beds of the Korojon Calcarenite and the Wadera Calcarenite form cuestas. Within the anticlinal bend, the other Cretaceous-Tertiary and Eocene formations form homoclinal ridges, and the Trealla Limestone forms a hogback. From the source of Cardabia Creek to the northernmost outcrop of the Windalia Radiolarite, the Eocene sediments form a homoclinal ridge. South to Miria Well is a homoclinal ridge of soft Korojon Calcarenite capped by travertine. From Miria Well to Korojon Pool the eastern part of the east flank is a surface half a mile to two miles wide which rises gently to the east, where it is capped by travertine.

North of the head of C-Y Creek, the drainage of the east flank is consequent and the pattern is dendritic; the watershed is the scarp formed by the Korojon Calcarenite of the west flank. The tributaries flow into each initial consequent stream west of the anticlinal bend. Because the gradient is low and the volume of water small, the streams north of Lamont Well fan out and distribute into the alluvium and sand. South of Lamont Well, the streams are more active and have joined the longitudinal consequent stream which drains the Nabbawarra Syncline. From the head of C-Y Creek to Korojon Pool, Cardabia Creek has captured the consequent streams which initially drained the east flank. The streams now rise on the south nose of the Nabbawarra Syncline and in the saddle between the Giralia and Marrilla Anticlines, and flow westward across the east flank and join Cardabia Creek as reversed consequent streams.

Marrilla Anticline

North and east of the apex the anticlinal bend consists of poorly developed low hogbacks capped by travertine. On the south-east limb are two homoclinal ridges each formed by the limestone beds of the Korojon Calcarenite and travertine.

The drainage is consequent and flows eastward. The streams which rise on the scarp of the west flank and flow across the apical area are constricted by a ridge formed by the steeply dipping sediments. East of this ridge the consequent streams fan out and distribute into the alluvium and sand.

The breached apical areas of the anticlines

Giralia Anticline

The apical area is a depression 30 miles long and up to eight miles wide. One large and three small hills of Windalia Radiolarite occupy the central part of the depression formed in the Gearle Siltstone.

Cardabia Creek and its main southward-flowing tributaries have wide shallow valleys in the soft Gearle Siltstone. North of No. 2 Deep Bore Cardabia Creek is deepening its channel. South of No. 2 Deep Bore the Creek develops meanders and its course is graded.

From three miles north of the Giralia-Bullara Road to C-Y Creek, the crestal region is breached and three small basins have been formed in the Gearle Siltstone and Korojon Calcarenite. The main drainage is consequent, and the streams are mature.

Marrilla Anticline

The breached apical area is 13 miles long and three miles wide. Two streams rise on the south nose of the Nabbawarra Syncline and flow across the south plunge of the Anticline. Two streams rise on the more western escarpment of the west flank and meander across the soft Gearle Siltstone. The streams of the Marrilla Anticline are youthful and have a high gradient until the base of the escarpment formed by the limestone beds of the Korojon Calcarenite is reached. Then the gradient is low and the streams are mature.

Nabbawarra Syncline

The Nabbawarra Syncline is a depression, which is V-shaped in plan. Travertine and the Miocene, Eocene, and Cretaceous-Tertiary formations outcrop at the south end of the synclinal trough. The remainder of the area is covered by sand and alluvium.

A longitudinal consequent stream rises at the south end of the syncline and is joined by consequent streams from the adjacent anticlines. The stream parallels the west flank of the Marrilla Anticline, swings east around the north nose, and fades out one mile east of Giralia Homestead.

Sand Dunes

Longitudinal dunes of red sand parallel the western outcrop edge of the Giralia Range from Exmouth Gulf to Warroora No. 1 Bore. The eastern limit of the sand dunes is a line which joins Warroora Homestead, Warroora No. 1 Bore, Centenary Bore, and Bullara Homestead, and the western edge is the coast-line of the Indian Ocean. Individual dunes are up to two miles long and the bearing of their long axes is 10°-20°.

Between Korojon Pool and Mia Mia Woolshed No. 1 is a small area of red sand dunes.

Red sand dunes extend from six miles east of the south nose of the Marrilla Anticline to five miles south of Giralia Bay. A plain of alluvium, one to two miles wide, separates the dunes from the east flank of the Marrilla Anticline except east of the apical area.

Parallel to and close to the coast line are reticulate or interlaced white dunes of carbonate sand which form a strip about half a mile wide. The maximum development is near points or headlands. Similar dunes are north-east of Sandalwood Landing and south of Giralia Landing, Exmouth Gulf.

No important streams drain the sand dune areas.

Region of centripetal drainage

To the east of Miria Well is an area, 10 miles long and five miles wide, of centripetal drainage. The nearly flat surface of travertine and sand probably overlies permeable calcareous strata. Surface water has dissolved some of the calcareous beds and caused the travertine surface to subside and form narrow shallow sink-holes.

Alluvium south of Korojon Pool

From Korojon Pool to the south end of the Giralia Anticline is a flat plain of alluvium in which the braided channel of Cardabia Creek is incised for seven miles. Then the Creek splits into many small meandering and anastomosing channels that form a distributory fan. Farther south, these channels rejoin to form with the Lyndon River a braided channel around the south end of the west flank of the Giralia Anticline.

The northern extension of the Salt Lake

The northern extension of the Salt Lake refers to a triangular-shaped basin bounded by the south-west flank of the Giralia Anticline to the north-east, the Warroora and Chargoo Anticlines and the Salt Lake to the south, and sand and sand dunes to the north-west.

An arm of the sea occupied the Salt Lake and its northern extension after the Giralia, Marrilla, Warroora, and Chargoo Anticlines were folded.

The basin is characterized by beach ridges, which, at the northern end, parallel the south-west flank of the Giralia Anticline. The southern limit of the ridges is east of the northern end of the Warroora Anticline, where the beach ridges are concave southward and lie parallel to the northern shore of the Salt Lake.

The sediment of the basin is a soft puffy soil, with, in places, marine pelecypod shells. The area is flat with no important streams. Two outliers of Trealla Limestone break the low relief of the basin.

STAGES OF EROSION OF GIRALIA AND MARRILLA ANTICLINES

When erosion started, the Giralia Anticline was an asymmetrical closed anticline with a wide west limb that sloped gently and a short east limb with steep dips.

In the initial stage of drainage development, consequent streams flowed down inequalities on the flanks and noses of the Giralia and Marrilla Anticlines, and a longitudinal consequent stream developed in the Nabbawarra Syncline. A consequent stream (Cardabia Creek) began to form in an inequality on the south-east flank of the Giralia Anticline, and the creek where the Cardabia-Winning Road crosses the west flank was consequent and drained the first saddle south of the apex.

In the next stage of drainage development the consequent streams cut deeper into the flanks, and streams eroded laterally along the saddles and formed subsequent tributaries.

On both anticlines the east flanks were subjected to a greater erosive attack than the west flanks, because the stream gradient was higher. The easterly-flowing consequent streams eroded faster than the westerly-flowing streams, and captured their headwaters. This happened in the Marrilla Anticline and in the Giralia Anticline north of Toothawarra Creek. The easterly-flowing streams now rise on the east-facing escarpment formed by the hard limestone beds of the Korojon Calcarenite. In the Giralia Anticline the strata of the axial regions were weakened by folding and Cardabia Creek eroded more quickly than the consequents on the east and west flanks, and captured the headwaters of these consequent streams. The stream near the Cardabia-Winning road was beheaded and left an area of alluvium. Cardabia Creek continued to deepen its channel, and headward erosion of the creek attacked the scarps. Meanwhile the easterly-flowing consequent, insequent, and subsequent streams reduced the east flank from a homoclinal ridge to a hogback. Cardabia Creek eventually confined its headward erosion to the soft Gearle Siltstone and continued to enlarge the subsequent valley. The east flank was reduced to its present form and Cardabia Creek captured, and so reversed, the drainage of this flank.

The lower reaches of Cardabia Creek were in a state of equilibrium. However south of Korojon Pool the gradient gradually decreased until the stream was unable to transport the material in suspension, and Cardabia Creek deposited the sediments in suspension as an alluvial fan and aggraded its channel. When a suitable gradient was reached, the stream carried its load farther until the gradient was critical and again deposited its load and thereby extended the fan.

During erosion of the Giralia Anticline, the consequent streams on the east flank probably distributed and lost their identity in the White Peaks Syncline. In the early stages of development of erosion, when the stream gradient was high, limestone conglomerate and finer-grained sediments were deposited in this syncline. A heterogeneous deposit of limestone conglomerate and fine-grained sediments formed a mantle over the syncline. Such calcareous terrestrial sediments had areas of high permeability and were ideal for the development of centripetal drainage.

SUBSURFACE GEOLOGY

RESULTS OF GEOPHYSICAL SURVEY

In 1950 and 1951 the Geophysical Section of the Bureau of Mineral Resources carried out gravity (Thyer, 1951a) and seismic (Vale, 1951) traverses along the Giralia-Bullara Road, and made a gravity reconnaissance of the Carnarvon Basin north of the Gascoyne River (Thyer, 1951b).

Gravity Surveys

The detailed gravity traverse on the Giralia-Bullara Road indicates a trough, the axis of which is two and three-quarter miles west of the surface axis of the Giralia Anticline (Thyer, 1951a).

The gravity reconnaissance of the Carnarvon Basin (Thyer, 1951b) showed the following (see Plate 2):

(a) A trough (of gravity deficiency) 120 miles long and 40 miles wide, the axis of which extends from near Mia Mia, through Middalya and Lyons River Homesteads, to the Gascoyne River. The eastern edge of the trough is generally close to the eastern margin of the outcropping Palaeozoic rocks. The maximum gravity deficiency of 44 milligals suggests more than 15,000 feet of sediments at the low point of the trough (near Merlinleigh Station). This agrees with the known thickness of sediments at this place.

(b) The axis of a ridge (of relatively small gravity deficiency) extends from two miles west of Mia Mia Homestead to three miles west of Wandagee Hill and from there to twelve miles west of Gascoyne Junction. The high point of the ridge is about five miles south-south-west of Wandagee Hill.

(c) The axis of a trough extends from 12 miles east of Carnarvon through the east side of Salt Lake to Exmouth Gulf. The low point of the trough appears to be immediately south-east of Carnarvon where the anomaly (-50 milligals) probably corresponds to a thickness of sediments of about 20,000 feet. About one mile east of Maud Landing Bore and on the axis of the trough, which parallels the axis of the Giralia Anticline, is a low point (-30 milligals) which may contain 12,000 feet of sediments. It is possible that this gravity trough, confirmed by the Seismic Survey, indicates the sedimentational axis of the Carnarvon Basin, and that west of this trough the regional dip is to the east.

(d) The axis of a ridge extends south-westward from a point three miles west of Bullara Homestead to the Indian Ocean. The high point of the ridge is west of Bullara Homestead.

(e) The axis of a trough connects Point Cloates and Exmouth Gulf Homestead. The low point is at Point Cloates, where a gravity deficiency of 30 milligals suggests 12,000 feet of sediments. The axis of the Rough Range Anticline meets the axis of the trough at Exmouth Gulf Homestead. The angle between the two axes is about 20°.

(f) The gravity anomaly increases in a north-westerly direction from -12 milligals at Exmouth Gulf Homestead to +10 milligals near Yardie Creek. This may mean that the basement is approaching the surface in this direction, but positive gravity anomalies due to deep-seated features are common near continental margins and the increase is not necessarily related to decrease in the thickness of the sediments. There are at least 1000 feet of Tertiary Limestone in this area and much of it is hard and crystalline. The high density of the limestone however would be sufficient to explain only a small part of the positive gravity anomaly. This limestone covers the whole North West Cape Peninsula and its occurrence does not explain the gravity contours in the Cape Range area.

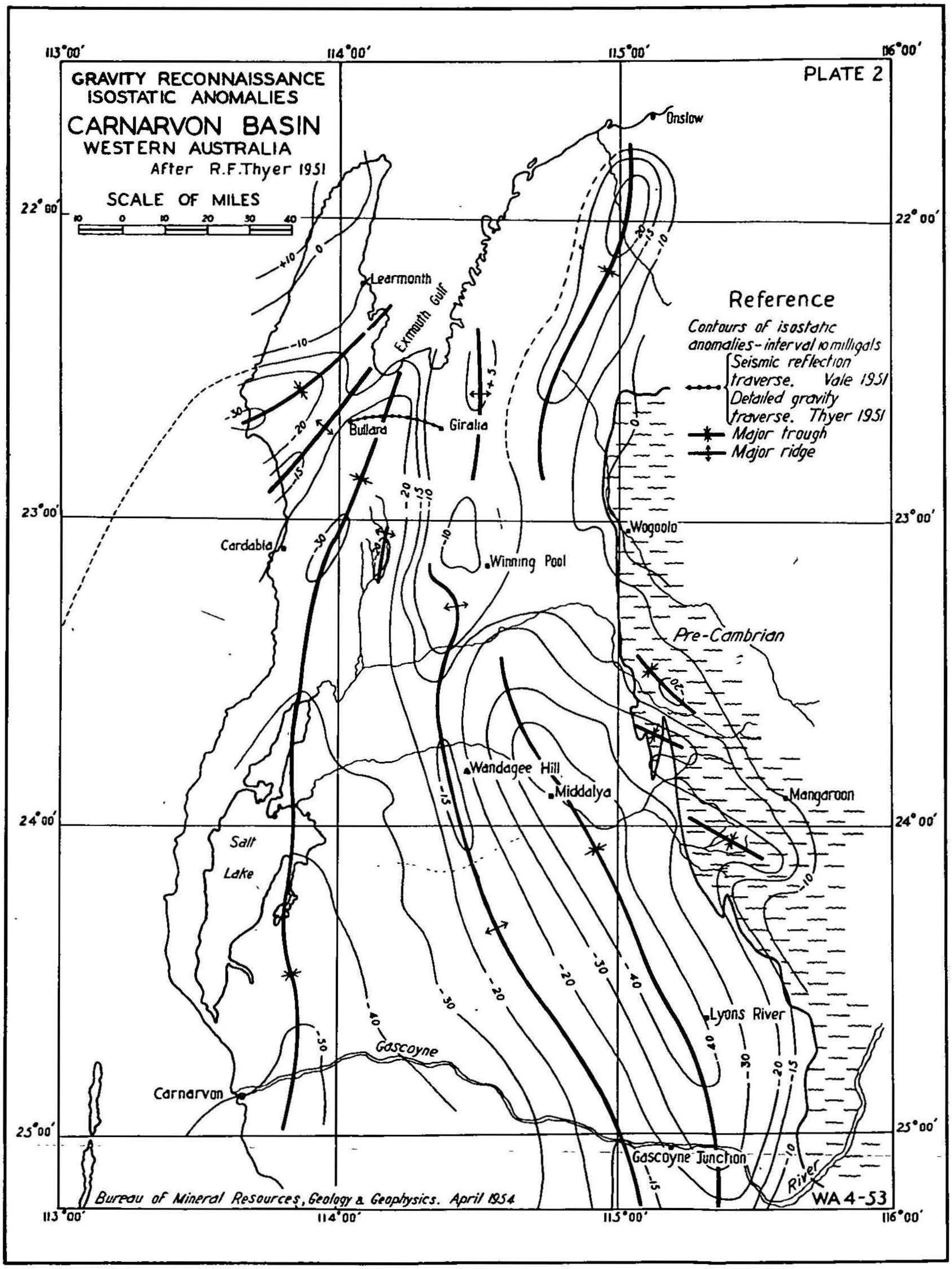

PLATE 2
GRAVITY RECONNAISSANCE
ISOSTATIC ANOMALIES
CARNARVON BASIN
WESTERN AUSTRALIA
After R.F.Thyer 1951
SCALE OF MILES
10 0 10 20 30 40
113°00'
114°00'
115°00'
116°00'
22°00'
23°00'
24°00'
25°00'
Reference
Contours of isostatic anomalies - interval 10 milligals
Seismic reflection traverse. Vale 1951
Detailed gravity traverse. Thyer 1951
Major trough
Major ridge
Onslow
Learmonth
Exmouth Gulf
Bullara
Giralia
Cardabia
Winning Pool
Wogoola
Pre-Cambrian
Wandagee Hill
Middalya
Mangaroon
Salt
Lake
Lyons River
Gascoyne
Carnarvon
Gascoyne Junction
River
Bureau of Mineral Resources, Geology & Geophysics. April 1954
WA 4-53

Seismic Survey

A seismic reflection traverse along the Giralia-Bullara Road indicated the following features (Vale, 1951):

(a) a shallow anticline which corresponds to the Giralia Anticline and is conformable with the surface geology to a depth of about 3,000 feet;

(b) an unconformity at about 3,000 feet;

(c) below the unconformity a syncline which underlies the shallow anticline of (a);

(d) an absence of reflections beneath the surface zone of steep dips, which probably indicates a fault.

In outcrop only one major unconformity (Permian-Mesozoic) and one major disconformity (at the top of the Callytharra Formation) are known in the sequence which may occur beneath the Giralia-Bullara Road. The depth to the Permian-Mesozoic unconformity on the axis of the Giralia anticline is not likely to be more than 2,000 feet, although it may be up to 3,500 feet in the Bullara Syncline. On Vale's section the unconformity is most likely at 2,800 feet beneath the surface axis of the Giralia Anticline, 3,000 feet three to six miles east of the axis and 3,200 feet 4 miles west of the axis. The authors think it is possible that the velocity used to calculate the depth of the events above the unconformity was too great.

The subsurface syncline (c), the axis of which is about half a mile west of the axis of the Giralia Anticline, has flank dips of 3° to 4° west and 2° east. A small anticline is immediately west of the fault zone.

BORE LOGS (also refer to Water Supply, p. 10).

Dozens of bores have been drilled in the Giralia Range area in the search for subsurface water.

Drillers compiled the logs and the lithological terms are sometimes incorrect, and different drillers use the same term with different meanings.

Logs are available of the Centenary or Cardabia No. 2, Maud Landing or Government, Warroora No. 1, Cardabia No. 1 Deep, Cardabia No. 2 Deep, Cardabia No. 37 (or 38), Cardabia No. 38 (or 39), Mia Mia No. 1 Shed, Mia Mia No. 2, Mia Mia No. 4, Mia Mia No. 5, Winning No. 1, and Winning No. 2 Bores. The bore logs have been divided into formations as known in outcrop although it is realized that the interpretations so obtained should be regarded with reserve. During the seismic survey in 1951 two bores were sunk and the holes were logged by a geologist. A 392 foot hole — Seismic Water Bore — was sunk on the Giralia-Bullara Road near the boundary gate, and "Shot hole" D, on the Giralia-Bullara Road in the Nabbawarra Syncline, was 200 feet deep. In 1951 a bore was drilled to 80 feet at Giralia Homestead, and potable water in sufficient quantity to supply the homestead was struck. A rock sample at 60 feet below the bore collar is from the lower part of the Giralia Calcarenite.

The following are interpretations of the logs of the above mentioned bores.

Centenary or Cardabia No. 2 Bore

Depth 2436 feet

Formations	*Thickness (feet)*
Soil	4
Trealla Limestone	36
Giralia Calcarenite, Jubilee Calcarenite, Cashin Calcarenite and Pirie Calcarenite	380
Wadera Calcarenite, Boongerooda Greensand and Miria Marl	70
Korojon Calcarenite	135
Gearle Siltstone	575
Windalia Radiolarite, Muderong Shale	1094
Sandstone (?Birdrong Formation)	17
?Permian strata	125+

Maud Landing or Government Bore

Depth 2359 feet — Completed 1909

Trealla Limestone	35
Lamont Sandstone	15
Giralia Calcarenite	63
Jubilee Calcarenite, Cashin Calcarenite and Pirie Calcarenite	211
Wadera Calcarenite, Boongerooda Greensand, Miria Marl and Korojon Calcarenite	256
Gearle Siltstone	680
Windalia Radiolarite, Muderong Shale	1015
Sandstone (?Birdrong Formation)	75
?Permian strata	9+

Warroora No. 1 Bore

Depth 1774 feet

Soil	2½
Trealla Limestone	60½
Giralia Calcarenite and Cardabia Group	296
Gearle Siltstone	611
Windalia Radiolarite, Muderong Shale	790
Sandstone (?Birdrong Formation)	10
?Permain strata	4+

Cardabia No. 1 Deep Bore

Depth 4013 feet. Completed at 2161 feet in 1909, deepened to 4013 feet in 1911.

Korojon Calcarenite	100
Winning Group	1100
Permian strata	2813

Cardabia No. 2 Deep Bore

Depth 2506 feet.

Gearle Siltstone, Windalia Radiolarite, Muderong Shale	1000
Sandstone (?Birdrong Formation)	10
Permian strata	1496+

Cardabia No. 37 (or 38) Bore.

Depth 275 feet. Completed October, 1950

Giralia Calcarenite and Jubilee Calcarenite	120
Cashin Calcarenite and Pirie Calcarenite	28
Wadera Calcarenite	32
Boongerooda Greensand and Miria Marl	10
Korojon Calcarenite	70
Gearle Siltstone	15+

A salt water horizon which yielded 200 gallons per day was struck at 155 feet. The bore has been abandoned.

Cardabia No. 38 (or 39) Bore.

Depth 300 feet. Completed October, 1950

Soil	2
Cashin Calcarenite and Pirie Calcarenite	78
Wadera Calcarenite	46
Boongerooda Greensand	6
Miria Marl	6
Korojon Calcarenite	63
Gearle Siltstone	99+

50 gallons of salt water per day were obtained from a one-foot bed at 81 feet. The bore has been abandoned.

Mia Mia No. 1 Shed Bore

Depth 1364 feet. Completed 1939

Sub-soil	30
Korojon Calcarenite	135
Gearle Siltstone, Windalia Radiolarite, and Muderong Shale	1151
Sandstone (Birdrong Formation)	20
?Permian strata	28

An artesian bore which yields 317,000 gallons daily. The aquifer is the 20 feet of Sandstone.

Mia Mia No. 2 Bore

Depth 1320 feet.

Gearle Siltstone, Windalia Radiolarite and Muderong Shale	780
Sandstone (?Birdrong Formation)	15
Permian strata	525+

Small supplies of salt water were struck at 35 and 398 feet. At 789 feet 20,000 gallons of good stock water per day were tapped, and the flow increased to 80,000 gallons daily at 795 feet. The bore is artesian.

Mia Mia No. 4 Bore

Depth 1197 feet. Completed 1928

Sub-soil	15
Korojon Calcarenite	93
Gearle Siltstone, Windalia Radiolarite, and Muderong Shale	1085
Sandstone (?Birdrong Formation)	4½+

The artesian aquifer is at 1193 feet and yields 400,000 gallons of good stock water daily.

Mia Mia No. 5 Bore

Depth 1281 feet. Completed 1929

Gearle Siltstone, Windalia Radiolarite and Muderong Shale	655
Permian strata	626

Apart from "a supply of salt water" at 250 feet no aquifer was cut.

Winning No. 1 or "12 Mile" Bore

Depth 1043 feet. Completed 1926

Gearle Siltstone	315
Windalia Radiolarite, Muderong Shale	725
Sandstone (?Birdrong Formation)	3+

At 1040 feet a "good supply of first class stock water" was struck.

Winning No. 2 Bore

Depth 2009 feet.

Sub-soil	4
Korojon Calcarenite	26
Gearle Siltstone	410
Windalia Radiolarite, Muderong Shale	605
Permian strata	964+

At 670 feet a "small supply" of salt water was struck.

TABLE II.

STRATIGRAPHY OF THE CARNARVON BASIN

	Age	Group	Formation: Cape Range	Formation: Giralia Range	Formation: Eastern part of Basin	Max. Thickness (Feet)	Lithology	Common Fossils
QUATERNARY	Recent (Condon, Johnstone and Perry, 1953)						Alluvial clays and sand; Aeolian sand; Travertine; Marine muds and sands	
			Bundera Limestone			16+	Clastic limestone	Foraminifera, corals, bryozoa, mollusca
			CONTACT NOT EXPOSED					
			Mowbowra Conglomerate			25+	Limestone conglomerate and clastic limestone	Corals, mollusca
	?Pleistocene			Walatharra Formation		91	Calcarenite and limestone pebble conglomerate	
					Joolabroo Formation	20	Pebbly sand and travertine	
			Exmouth Sandstone			*400+	Calcareous sandstone	Foraminifera
		NONCONFORMITY						
TERTIARY	?Pliocene and lower Miocene	Yardie Group				340	Calcareous sandstone and sandy limestone	Foraminifera, bryozoa, gastropods, algae
	lower Miocene (Condon, et al., 1953)		Trealla Limestone	Trealla Limestone		180+	Crystalline limestone	Foraminifera, corals, mollusca
				NONCONFORMITY				
		Cape Range Group		Lamont Sandstone		30	Calcareous sandstone, sandstone	Foraminifera
			Tulki Limestone			420	Crystalline limestone	Foraminifera, corals, echinoids, bryozoa, molluscs, algae
			Mandu Calcarenite			*550+	Foraminiferal clastic limestone (calcarenite)	Foraminifera, echinoids, molluscs, ostracods
	Middle to Upper Eocene		?	Giralia Calcarenite		200	Glauconitic calcarenite and glauconitic limestone, with limonite oolites	Foraminifera, echinoids, bryozoa, brachiopods, mollusca, nautiloids
				DISCONFORMITY				
CRETACEOUS	Upper Cretaceous to Cretaceous-Tertiary	Cardabia Group	?			375	See Table I.	
		DISCONFORMITY						
	Lower Cretaceous to Upper Cretaceous	Winning Group	?			675+	See Table I.	
	?Lower Cretaceous				Birdrong Formation	97		
					DISCONFORMITY			
	Middle Jurassic (Teichert, 1940)		?		Curdamuda Sandstone	20	Calcareous sandstone	Pelecypods, algae
					NONCONFORMITY			
PERMIAN	Kungurian (Teichert, 1941) (———, 1950a) (Dickins, 1954)	Kennedy Group				2370	Quartz greywacke and quartz sandstone	Spiriferids *?cleiothyridina*, *chonetes*, molluscs
					Baker Formation	200	Carbonaceous siltstone and quartz greywacke	Spiriferids, small productids, pectenids
					Norton Greywacke	230	Quartz greywacke	*Strophalosia*, *chonetes* pelecypods
					Wandagee Formation	760	Siltstone, quartz greywacke	Large spirifers and productids, foraminifera, bryozoa, *Strophalosia*, *Calceolispongia*, *Linoproductus*, gastropods, *Chonetes*
	Artinskian (Dickins, 1954)	Byro Group			Quinnanie Shale	410	Carbonaceous shale	Foraminifera, spiriferids, productids, *Calceolispongia* *Lingula*, gastropods
					Cundlego Formation	1090	Quartz greywacke, siltstone, calcareous sandstone	Small corals, *Chonetes*, spiriferids, pelecypods, gastropods
					Bulgadoo Shale	580	Carbonaceous shale	Foraminifera, ostracods Chonetes Calceolispongia
					Mallens Greywacke	520	Quartz, greywacke, calcareous beds	Spiriferids, pelecypods, small gastropods
					Coyrie Formation	860	Carbonaceous siltstone, quartz greywacke, calcareous sandstone	Foraminifera, bryozoa, spiriferids, productids, chonetes, gastropods, cephalopods, trilobites, *?Gangamopteris*, *Glossopteris*, fossil wood
					Wooramel Sandstone	250	Quartz sandstone	Worm burrows, fossil wood
					Cordalia Greywacke	180	Quartz greywacke	Bryozoa
					DISCONFORMITY			
					Callytharra Formation	760	Crystalline limestone, calcarenaceous quartz, greywacke, siltstone	Foraminifera, corals, bryozoa, brachiopods, spiriferids, productids, crinoids, molluscs
					DISCONFORMITY			
	Sakmarian (Teichert, 1941)	Lyons Group				4600	Greywacke, quartz greywacke, siltstone, boulder beds, calcareous sandstone, marine glacial	Corals, bryozoa, brachiopods, *Calceolispongia*, gastropods, pectinids
					Harris Sandstone	270	Ferruginous quartz sandstone	*Lepidophloem* flora
					DISCONFORMITY			
CARBONIFEROUS					Yindaginely Formation	260	Crystalline limstone, arkose.	Brachiopods, ostracods
	Upper Carboniferous (Teichert, 1950b)				Williambury Formation	1080	Greywacke, pebbly greywacke, siltstone, limestone	
	Lower Carboniferous (Teichert, 1950b)				Moogooree Limestone	900	Crystalline limestone	*Syringothyris*, *Rhipidomella*, spiriferids, productids
DEVONIAN	Upper Devonian (Teichert, 1950b)				Willaraddie Formation	1100	Greywacke, siltstone, conglomerate	
					Munabia Sandstone	1900	Quartz sandstone	Lepidodendron — like plants
	Middle Devonian to Upper Devonian (Teichert, 1950b)				Gneudna Formation	1720	Calcareous greywacke, siltstone, limestone	Corals, brachiopods, (productids spiriferids, etc.), crinoids (stems), nautiloids, molluscs, stromatoporoids
					Nannyarra Greywacke	400	Greywacke, siltstone	——
					UNCONFORMITY			
PRE-CAMBRIAN								Quartzite, slate and limestone, schists, gneiss, granite

* Includes thickness from bore information.

Seismic Water Bore

Depth 392 feet. Completed July, 1951

Giralia Calcarenite, Jubilee Calcarenite	155
Cashin Calcarenite	40
Pirie Calcarenite	62
Wadera Calcarenite	135+

No water horizons were noticed during drilling. On lithological evidence, drilling finished practically at the base of the Wadera Calcarenite.

"Shot Hole" D

Depth 200 feet. Completed July, 1951

Sediments above Trealla Limestone	120
Trealla Limestone	80+

No water horizons were observed.

ECONOMIC GEOLOGY

POSSIBILITIES OF OIL ACCUMULATION

Summary of Regional Geology.

Table II sets out the formations known to outcrop in the Carnarvon Basin and shows the relationships between them.

The Devonian and Carboniferous formations converge to the west and south, and whether Devonian and Carboniferous sediments underlie the Giralia Range is debatable. The Permian formations, with the possible exception of the Wooramel Sandstone, diverge north-westward. Tertiary sediments diverge north-westward, and bore logs indicate that the Cretaceous formations also diverge north-westward.

The closest outcrop of Palaeozoic sediments to the Giralia Range is 35 miles to the east-south-east. The Palaeozoic sequence under the Giralia Range may differ from that in outcrop, as the Giralia Range area is farther from the old shore-line and the Devonian, Carboniferous, and Permian sediments indicate deposition on an unstable continental shelf.

Source Beds.

Because the Mesozoic and Tertiary sediments are not as suitable as source, cap, and reservoir formations as the Palaeozoic sediments, oil is more likely to be found in Palaeozoic sediments or in the permeable Lower Cretaceous Birdrong Formation overlying the unconformity above the Palaeozoic sediments.

Lithologically, the formations of the Byro Group and the Callytharra Formation are the most likely source beds. Except for the Mallens and

Norton Greywackes, the Byro Group is characterised by black carbonaceous shales and siltstones, gypsum deposits, pyrites, and abundant marine life. The gypsum is mainly secondary; the Bulgadoo Shale and the Wandagee Formation contain primary gypsum. The repetition of lithological types in the Byro Group suggests that sedimentation was rhythmic. Slow sedimentation of siltstone or shale alternated with relatively rapid sedimentation of quartz greywacke. Usually the units of quartz greywacke are thinner than those of siltstone or shale.

Of the Cretaceous sediments, the Winning Group is a possible oil source.

Reservoir Beds.

The most likely reservoir beds for oil in the Carnarvon Basin are the permeable sandstone formations.

Of the Palaeozoic sequence, the Munabia Sandstone, the Wooramel Sandstone and the Kennedy Group are permeable, and consist of fine-grained and medium-grained quartz sandstone.

Artesian water was obtained from "sandstone" beds (assumed to be Permian in age) in the Centenary and Maud Landing Bores and sub-artesian water was obtained in what are thought to be the same beds at Cardabia No. 1 and 2 Deep Bores. This indicates that some beds of the Permian sequence are sufficiently permeable for fluid migration.

In the deep bores of the Giralia Range a sandstone aquifer which ranges in thickness from 10 to 75 feet was struck. This aquifer is thought to be within the Birdrong Formation. The aquifer yields 95,000 gallons of artesian water daily at Maud Landing Bore, 1½ million gallons of artesian water daily at Warroora No. 1 Bore, and 2 million gallons of water daily at Pelican Hill Bore (eight miles north of Carnarvon). No traces of oil-gas or oil have been noted. The permeability of this aquifer and its probable overlapping of the potential oil source beds of the Byro Group and older formations indicate its potentiality as a reservoir for oil accumulation.

Sediments of the Cardabia Group and the Mandu Limestone would be suitable as reservoirs, but their worth as such would depend upon the presence of source and cap rocks.

The authors think that no structural (jointing) or secondary (solution) features of the Palaeozoic formations in the Carnarvon Basin would convert impermeable beds or formations into reservoirs for oil accumulation. Widely spaced jointing is known in some limestone outcrops of the Callytharra Formation (east of Moogooloo Range) but it is not interconnected and closely knit enough to form a prospective reservoir for oil accumulation.

Cap Rock.

The Gneudna Formation, Willaraddie Formation, Lyons Group, Callytharra Formation, Coyrie Formation, Bulgadoo Shale, Quinnanie Shale, Baker

Formation, and probably the Williambury, Cundlego, and Wandagee Formations are sufficiently impermeable to act as cap rocks to prevent the vertical escape of fluids.

The siltstones and shales of the Winning Group are effective cap rocks to the artesian aquifer.

Location of Test Bore.

As preliminary seismic work (Vale, 1951) has indicated that the surface structure does not reflect the structure at depth, choice of a site for a test bore should await a complete seismic survey. Scout drilling would help, by determining the stratigraphical sequence below the Permian-Mesozoic unconformity.

NON-METALLIC MINERALS

Barytes.

Barytes mainly occurs as nodules in the top third of the Gearle Siltstone, but a one-foot bed of red-brown barytes sandstone in the lower part of the Gearle Siltstone is exposed in the bank of Cardabia Creek three and a half miles north-north-east from Cardabia Pool. The nodules range in size up to 9 inches in diameter, and because of the poor exposures of the Gearle Siltstone the occurrence of the nodules, whether sporadically or in particular beds, is uncertain. The one bed of barytes sandstone may indicate that the nodules are secondary development from primary evaporite beds.

Bentonitic Siltstone and Claystone.

The bentonite content of the Gearle Siltstone on the Giralia Anticline was first proved when the Government Chemical Laboratories of Perth analysed a one-ton sample collected from lat. 22°54′S., long. 114°09′E., on C-Y Creek. Sadler's Test yielded 24 percent "bentonite" (Reid, pers. comm.).

Three other samples of the Gearle Siltstone were examined from the same locality. Two samples taken from 11 and 12 feet below a creek bed contained 26 and 23 percent "bentonite," and a sample eight feet below the surface of a nearby outcrop yielded 15 percent "bentonite." After the clay in a sample was washed out the residue mainly consisted of limonite-stained clay, together with calcite fragments, angular quartz, a few grains of chalcedony, sub-rounded gypsum grains, zircon, garnet, sericite, and possibly felspar. The quartz content is about 0.001 percent by weight of the sample (Glover, pers. comm.)*

Only samples from the above-mentioned locality were examined. The bentonitic properties of the Gearle Siltstone are likely to vary considerably, both vertically and laterally.

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* J. J. E. Glover, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

The Gearle Siltstone is soft and forms a slightly undulating terrain which is cut by Cardabia Creek and its tributaries. In places Cardabia Creek has steep banks. The siltstone weathers easily, and, except in the creeks, the formation is covered by three to five feet of gypseous soil (gypsite). In wet weather the siltstone becomes boggy and access is difficult; normally, the Gearle Siltstone outcrops are easily accessible. The outcrop is such that open-cut methods could be applied.

The main outcrop of the Gearle Siltstone is in the breached apical area of the Giralia Anticline, where about 150 square miles of the formation are exposed. Other outcrops are: the apical area of the Marrilla Anticline (about 8 square miles), $11\frac{1}{2}$ miles south of the Giralia-Bullara Road ($\frac{1}{4}$ square mile), eight miles south of the Giralia-Bullara Road ($1\frac{3}{4}$ square miles), four miles south of the road ($1\frac{3}{4}$ square miles).

The Government Chemical Laboratories, Perth, tested the properties of the Gearle Siltstone as a drilling mud. The crushed bentonite was soaked in water or brine for 24 hours and the suspension was then "gunned" to a required viscosity. The experiment yielded a 75lb. mud with only moderate stability, and poor wall-building properties. After repeated "gunning" the viscosity of the mud increased and the stability improved.

The salt content of the Gearle Siltstone is high (Boan, Sydney, pers. comm.); and to forestall corrosive action soda ash should be added to make the mud alkaline. In 1951 the seismic party of the Bureau of Mineral Resources used Gearle Siltstone (from four miles south of the Giralia-Bullará Road) as a drilling mud to bore "shot holes". A rotary bit was used and the drilling mud consisted of two parts of water to one of siltstone.

Glauconite.

C. R. Le Mesurier analysed samples of the Boongerooda Greensand collected by J. Sofoulis of the Geological Survey of Western Australia in 1949.

Analyses of Samples

Laboratory No.	Locality	Percent of K_2O	Equivalent percent of Glauconite
4180	29 miles north-north-east from Remarkable Hill	2.62	37 approx.
4181	Do.	2.73	39 approx.
4183	3 miles north of Remarkable Hill	2.91	41 approx.

An analysis of the Lower Greensand (Feldtmann, 1934; Teichert, 1946) at Gingin, 50 miles north of Perth, shows the following:

K_2O	3 percent
P_2O_5	1 percent
$CaCO_3$	15 percent

The outcrop area of the Boongerooda Greensand is stated in the section on this formation (p. 11). The best outcrops of the greensand are on the Giralia Anticline on the west flank north of the Cardabia-Winning Road, the north nose and the north-east flank. The thickness ranges from two to eight feet with an average of three feet. The outcrop is soft and friable and is capped by the Wadera Calcarenite. The overburden on the outcropping greensand ranges from 130 feet near Remarkable Hill to five to fifteen feet on the northern plunge of the anticline.

Access to the Boongerooda Greensand is not difficult, especially on the northern plunge. Roads and tracks which traverse the area are described on p. 9.

Glauconite is also disseminated in the Wadera, Pirie, Cashin, Jubilee, and Giralia Calcarenites, but the mineral is most abundant in the Boongerooda Greensand.

Glauconite from the Lower Greensand at Gingin has been used for the last 20 years for softening water at Midland Junction, near Perth. At present sufficient supplies of glauconite are produced at Gingin for this process.

CONCLUSIONS

The completion of palaeontological studies of the Upper Cretaceous and Lower Tertiary sediments should reveal data that would be valuable to the knowledge of the contact between Cretaceous and Tertiary sediments.

The structure of the Giralia Anticline and the Marrilla Anticline is probably due to deposition over a mature erosion surface in Palaeozoic (possibly Permian) sediments and to up-thrusting along a fault plane which dips west at about 60°. As the surface structure is not a reflection of the structure in depth, detailed seismic surveys are necessary to determine sites for test drilling for oil.

The lithology of the Permian sediments in outcrop 50 to 200 miles to the south-east indicates that source, reservoir, and cap rocks could exist beneath the Mesozoic sediments of the Giralia Anticline. However, the stratigraphy of the Permian sediments beneath the unconformity at a depth of about 3,000 feet is not known. Valuable stratigraphical information on the Permian-Mesozoic unconformity and structures in the Palaeozoic sediments could be obtained from relatively shallow scout bores producing cores.

To define the subsurface structure of the closed anticlines of the western part of the Basin, further geophysical surveys must be made. Bores are required for stratigraphical interpretations of these surveys.

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Plate 3
GEOLOGICAL MAP
GIRALIA AND MARRILLA ANTICLINES
WESTERN AUSTRALIA
Geological Mapping by: M.A.Condon, D.Johnstone, W.J.Perry, C.E.Prichard, J.G.Best & M.H.Johnstone
Slotted Templet Layout of Air-Photos by Dept. of Lands & Surveys W.A. & National Mapping Section, Dept. of the Interior, Canberra
SCALE
2 0 2 4 6 Miles
REFERENCE
MAP
SECTION
QUATERNARY
Recent
Qra Alluvium
Qrs Sand
Qrw Wash
Qrr Residual soil
Qrm Marine deposits
Qrl Lake deposits
Qrt Travertine
Pleistocene
Qpm Marine deposits
Qpe Exmouth Sandstone
Qpw Walatharra Formation
Q
TERTIARY
Miocene
Tmt Trealla Limestone
Tml Lamont Sandstone
Tmk Tulki Limestone
Eocene
Teg Giralia Calcarenite
CRETACEOUS-TERTIARY
K-Tj Jubilee Calcarenite
K-Tc Cashin Calcarenite
K-Tp Pirie Calcarenite
K-Tw Wadera Calcarenite
K-T
CRETACEOUS
K/K-T Boongerooda Greensand Miria Marl
Upper
Kuk Korojon Calcarenite
Kug Gearle Siltstone
Kuw Windalia Radiolarite
Lower
Muderong Shale Birdrong Formation
Kuw Kl
Geological boundaries - Position accurate
Position approximate
Probable boundary (by bore logs)
Established fault - position accurate
Probable fault - position approximate
Established anticlinal crest (showing plunge of fold)
Established synclinal trough (showing plunge of fold) Position approximate
Dip and measured strike
Dip with approximate strike
Type section of formation
Dune
Coral reef
Swamp and mangrove
Bore
Well
Windpump
Trig station
Highway
Road
Vehicle Track
Boundary fence
Fence
Telephone line
Building
ELG Emergency landing ground
EXMOUTH GULF
GIRALIA BAY
INDIAN OCEAN
MARRILLA STATION
WINNING STATION
MIA MIA STATION
MINILYA STATION
CARDABIA
Section A-B-C
Vertical exaggeration 10.56 to 1
Bureau of Mineral Resources
Geology and Geophysics 1953
W.A. 46B-10
Reproduced by Royal Australian Survey Corps 1954

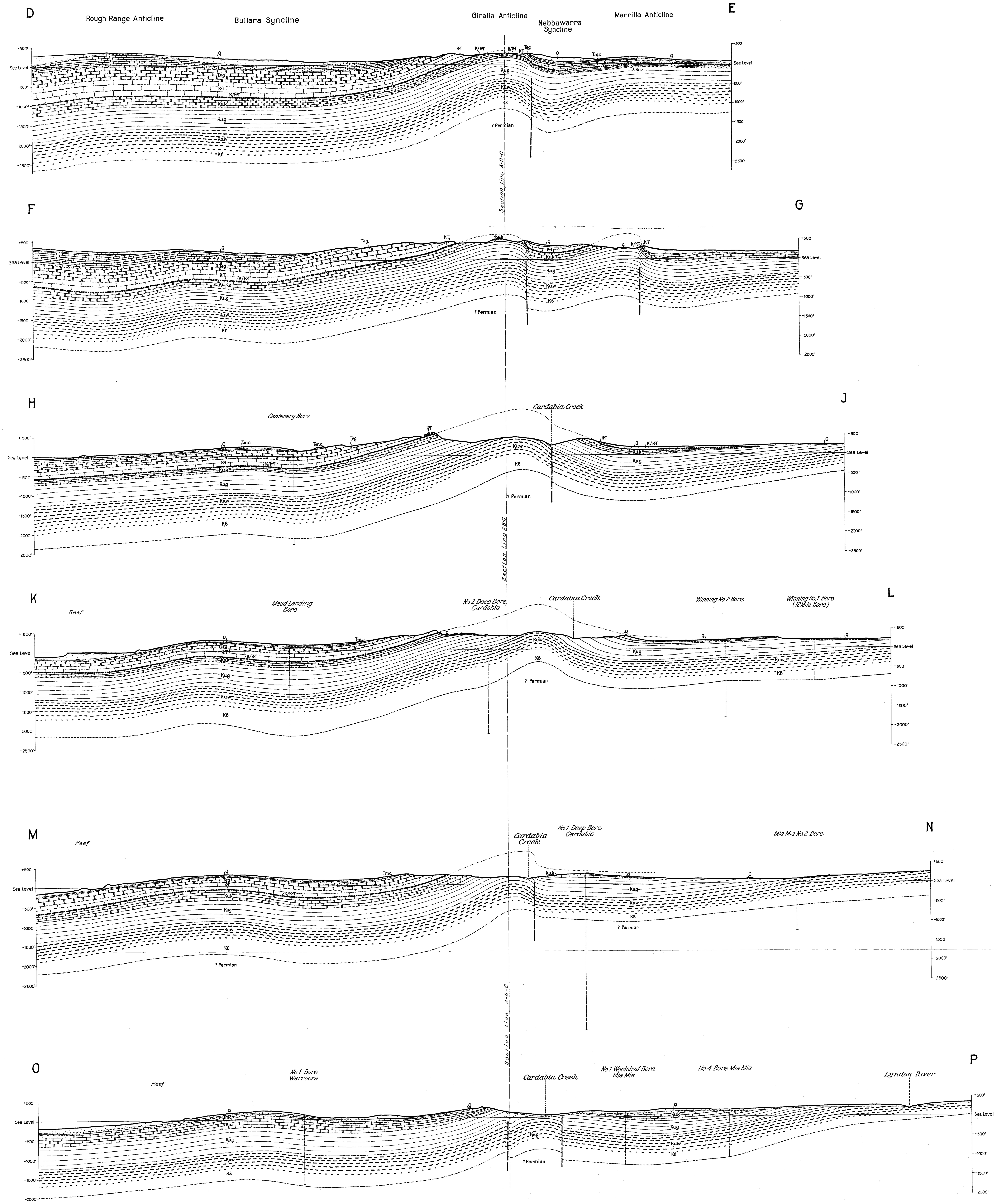
CROSS SECTIONS
GIRALIA AND MARRILLA ANTICLINES W.A.

Compiled by: M.A.Condon, D.Johnstone, C.E.Prichard and M.H.Johnstone

Horizontal Scale

2 0 2 4 6 Miles

Vertical exaggeration 10.66 to 1



Legend

Quaternary	Tertiary		Cretaceous-Tertiary		Cretaceous		
Q	Tmc	Tcg	K-T	K/KT	Kuk	Kug	Kuw / Kℓ
Recent deposits	*Cape Range Group*	*Giralia Calcarenite*	*Jubilee Calcarenite, Cashin ", Pirie ", Wadera "*	*Boongerooda Greensand, Miria Marl*	*Korojon Calcarenite*	*Gearle Siltstone*	*Windalia Radiolarite, Muderong Shale, Birdrong Formation*

Bureau of Mineral Resources, Geology & Geophysics 1953

WA.46B-11
H.F.3.


Plate 5
STRUCTURE CONTOUR MAP
GIRALIA AND MARRILLA ANTICLINES
WESTERN AUSTRALIA
Based on top of Boongerooda Greensand
Compiled by M.A. Condon, D. Johnstone, C.E. Prichard and M.H. Johnstone
Scale
Dip-Scale
Horizontal separation of 100' contours equivalent to dip
Bullara Syncline
Giralia Anticline
Marrilla Anticline
Nabbawarra Syncline
Whitepeaks Syncline
Legend
Accurate surface contours (Elevation in feet above sea level)
Approximate surface or subsurface contours
Reconstructed contours
Zone of steep dips
Established anticlinal crest (showing plunge or pitch of fold)
Established synclinal trough-position approximate
Probable fault
W.A. 46B-12
H.F.B.
Bureau of Mineral Resources, Geology & Geophysics 1953

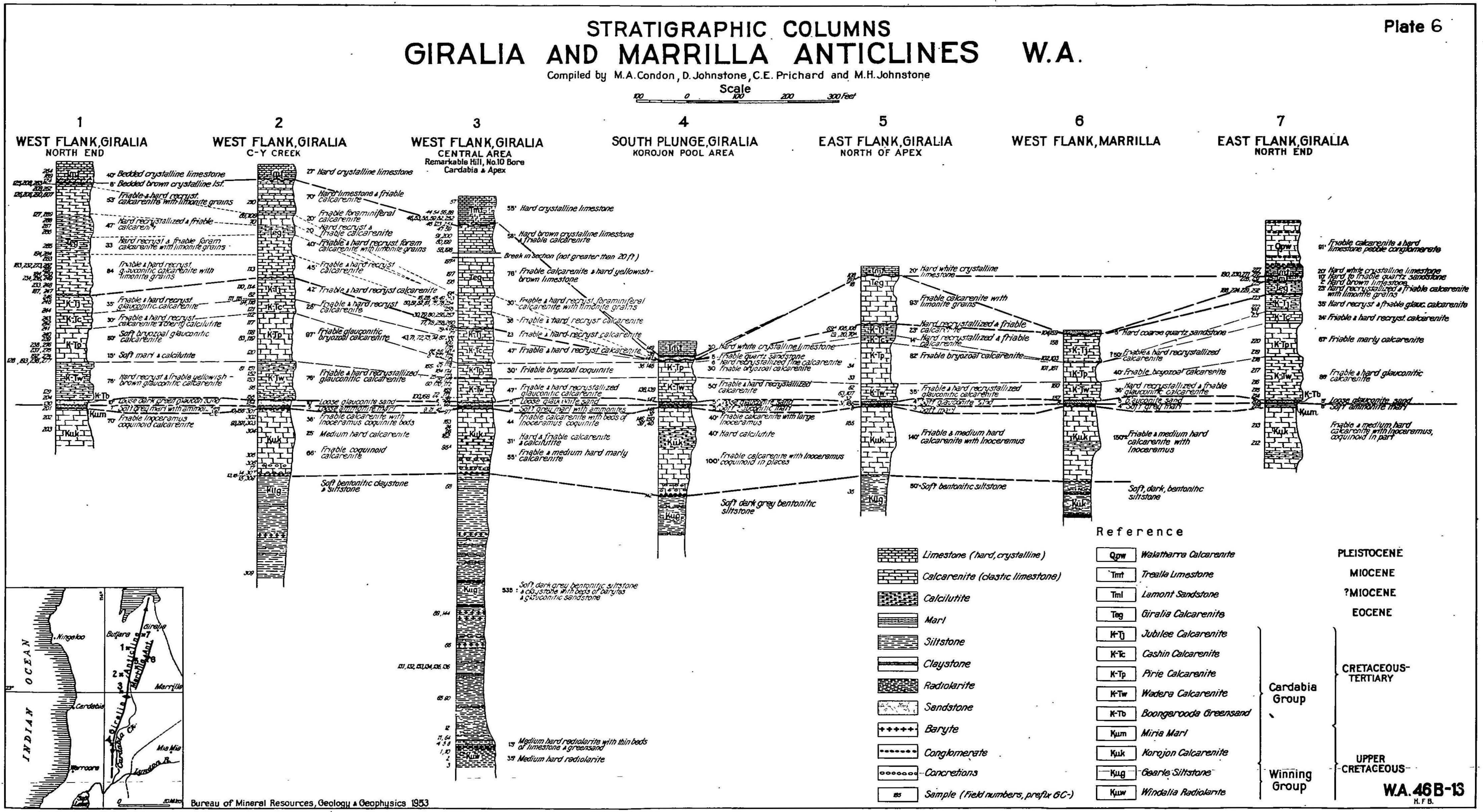


Plate 6
STRATIGRAPHIC COLUMNS
GIRALIA AND MARRILLA ANTICLINES W.A.
Compiled by M.A.Condon, D.Johnstone, C.E.Prichard and M.H.Johnstone
Scale
100 0 100 200 300 Feet
1 WEST FLANK, GIRALIA NORTH END
2 WEST FLANK, GIRALIA C-Y CREEK
3 WEST FLANK, GIRALIA CENTRAL AREA Remarkable Hill, No.10 Bore Cardabia & Apex
4 SOUTH PLUNGE, GIRALIA KOROJON POOL AREA
5 EAST FLANK, GIRALIA NORTH OF APEX
6 WEST FLANK, MARRILLA
7 EAST FLANK, GIRALIA NORTH END
Break in section (not greater than 20 ft)
Reference
Limestone (hard, crystalline)
Calcarenite (clastic limestone)
Calcilutite
Marl
Siltstone
Claystone
Radiolarite
Sandstone
Baryte
Conglomerate
Concretions
Sample (Field numbers, prefix 6C-)
Qpw Walatharra Calcarenite
Tmt Trealla Limestone
Tml Lamont Sandstone
Teg Giralia Calcarenite
K-Tj Jubilee Calcarenite
K-Tc Cashin Calcarenite
K-Tp Pirie Calcarenite
K-Tw Wadera Calcarenite
K-Tb Boongerooda Greensand
Kum Miria Marl
Kuk Korojon Calcarenite
Kug Gearle Siltstone
Kuw Windalia Radiolarite
Cardabia Group
Winning Group
PLEISTOCENE
MIOCENE
?MIOCENE
EOCENE
CRETACEOUS-TERTIARY
UPPER CRETACEOUS
INDIAN OCEAN
Ningaloo
Cardabia
Giralia
Marrilla
Bullara
Mia Mia
Warroora
Bureau of Mineral Resources, Geology & Geophysics 1953
W.A. 46 B-13
H.F.B.

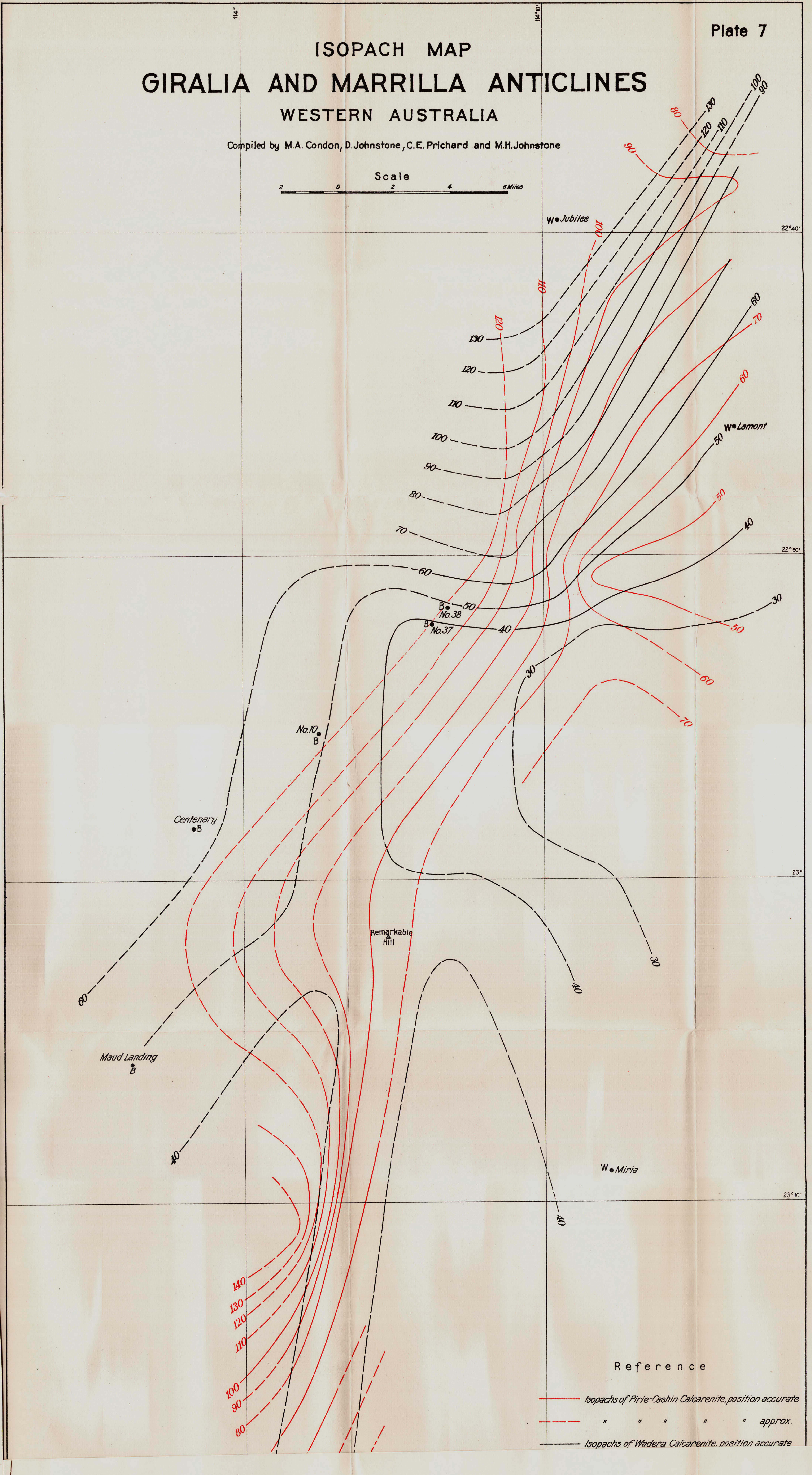


Plate 7
ISOPACH MAP
GIRALIA AND MARRILLA ANTICLINES
WESTERN AUSTRALIA
Compiled by M.A. Condon, D. Johnstone, C.E. Prichard and M.H. Johnstone
Scale
2 0 2 4 6 Miles
114°
114°10'
22°40'
22°50'
23°
23°10'
W Jubilee
W Lamont
W Miria
B No. 38
B No. 37
No. 10 B
Centenary B
Maud Landing B
Remarkable Hill
Reference
Isopachs of Pirie-Cashin Calcarenite, position accurate
" " " " " approx.
Isopachs of Wadera Calcarenite, position accurate