COMMONWEALTH OF AUSTRALIA 10387/54

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 15

PROGRESS REPORT ON THE STRATIGRAPHY and STRUCTURE OF THE CARNARVON BASIN, WESTERN AUSTRALIA;

By

M. A. CONDON

☆

Issued Under The Authority Of Senator the Hon. W. H. Spooner, M.M., Minister For National Development

1954

LIST OF REPORTS

1. Preliminary Report on the Geophysical Survey of the Collie Coal Basin-N.G. Chamberlain, 1948.
2. Observations on the Stratigraphy and Palaeontology of Devonian, Western Portion of Kimberley Division, Western Australia-Curt Teichert, 1949.
3. Preliminary Report on Geology and Coal Resources of Oaklands-Coorabin Coalfield, New South Wales-E. K. Sturmfels, 1950.
4. Geology of the Nerrima Dome, Kimberley Division, Western Australia-D. J. Guppy, J. O. Cuthbert and A. W. Lindner, 1950.
5. Observations of Terrestrial Magnetism at Heard, Kerguelen and Macquarie Island, 1947-1948. (Carried out in co-operation with the Australian National Research Expedition, 1947-1948). N. G. Chamberlain, 1952.
6. Geology of New Occidental, New Cobar and Chesney Mines, Cobar, New South Wales -C. J. Sullivan, 1951.
7. Mount Chalmers Copper and Gold Mine, Queensland-N. H. Fisher and H. B. Owen, 1952.
8. Geological and Geophysical Surveys, Ashford Coal Field, New South Wales-H. B. Owen and L. W. Williams.
9. The Mineral Deposits and Mining Industry of Papua and New Guinea-P. B. Nye and N. H. Fisher
10. Geological Reconnaissance, South-Western portion of Northern Territory-G. F. Joklik.
11. The Nelson Bore, South-Western Victoria; micro-palaeontology and stratigraphical succession-I. Crespin,
12. Stratigraphy and micro-palaeontology of the Marine Tertiary rocks between Adelaide and Aldinga, South Australia-I. Crespin,
13. Geology of Dampier Land-R. O. Brunnschweiller,
14. A Provisional Isogonic Map of Australia and New Guinea Showing Predicted Values for the Epoch 1955·5-F. W. Wood and I. B. Everingham, 1953
15. Progress Report on the Stratigraphy and Structure of the Carnarvon Basin, Western Australia; M. A. Condon.
16. Seismic Reflection Survey at Roma, Queensland; J. C. Dooley.
17. Mount Philp Iron Deposit; E. K. Carter and J. H. Brooks.

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 15

PROGRESS REPORT ON THE STRATIGRAPHY and STRUCTURE OF THE CARNARVON BASIN, WESTERN AUSTRALIA;

By

M. A. CONDON

★

Issued Under The Authority Of Senator the Hon. W. H. Spooner, M.M.,
Minister For National Development

1954

Department Of National Development

Minister - Senator the Hon. W. H. Spooner, M.M.

Secretary - H. G. Raggatt

Bureau Of Mineral Resources, Geology And Geophysics

P. B. NYE - *Director*

J. M. RAYNER - *Deputy Director*

THIS PUBLICATION WAS PREPARED IN THE ADMINISTRATIVE AND GEOLOGICAL SECTIONS

M. A. CONDON - *Acting Chief Geologist*

REPRODUCED AT CENTRAL DRAWING OFFICE, MARIBYRNONG, W.3.

CONTENTS

	Page
SUMMARY	1
INTRODUCTION	2
PHYSICAL CONDITIONS	2
Access	2
Climate	2
Vegetation	2
Development	2
PREVIOUS WORK	3
PHYSIOGRAPHY	5
STRATIGRAPHY	8
Stratigraphical Succession	8
Nomenclature	8
PRE-CAMBRIAN	11
DEVONIAN	11
Nannyarra Greywacke	11
Gneudna Formation	13
Munabia Sandstone	15
Willaraddie Formation	18
Moogooree Limestone	21
Williambury Formation	25
Yindagindy Formation	28
PERMIAN	31
Harris Sandstone	31
Lyons Group	34
Callytharra Formation	47
Cordalia Greywacke	53
Wooramel Sandstone	56
Byro Group	60
Coyrie Formation	60
Mallens Greywacke	63
Bulgadoo Shale	67
Cundlego Formation	72
Quinnanie Shale	75
Wandagee Formation	78

	Page
Norton Greywacke	82
Baker Formation	88
Kennedy Group	90
Coolkilya Greywacke	91
Mungadan Sandstone	95
Binthalya Subgroup	97
JURASSIC	101
Curdamuda Sandstone	101
CRETACEOUS	102
Birdrong Formation	102
Winning Group	105
Muderong Shale	105
Windalia Radiolarite	107
Gearle Siltstone	110
Cardabia Group	113
Miria Marl	
TERTIARY	116
Eocene: Giralia Calcarenite	116
Miocene: Cape Range Group	117
Merlinleigh Sandstone	118
Miocene and ? Pliocene	
Yardie Group	119
QUATERNARY	120
Exmouth Sandstone	121
Joolabroo Formation	121
Walatharra Formation	123
Marine Deposits	123
Bundera Calcarenite	124
Mowbowra Conglomerate	124
Recent Sand	125
Recent Alluvium	127
Recent Wash	127

	Page
Residual Soil	128
Marine Muds and Sands	128
Lake Deposits	129
LATERITE	130
STRUCTURE	133
FAULTS	134
FOLDS	137
Cape Range Anticline	141
Rough Range Anticline	143
Giralia Anticline	144
Marrilla Anticline	146
Chargoo Anticline	147
Gerardi Anticline	148
Chirrida Anticline	148
Minilya Anticline	149
Homestead Anticline	149
Yankie Tank Anticline	149
Grierson Anticline	150
Warroora Anticline	150
Cuvier Anticline	151
ECONOMIC GEOLOGY	152
Oil and Natural Seas	152
Water	154
Gypsum	155
Bentonitic Clay	155
Radiolarite	155
Barytes	155
Phosphates	156
Limestone	156
Salts	156
REFERENCES	157

TABLES

Table 1a: Stratigraphy of the Carnarvon Basin.

1b: Formations of the Carnarvon Basin.

Table 2 : Stratigraphical Nomenclature, Carnarvon Basin.

TEST FIGURES

Fig. 1: "Network Structure" of phosphatic siltstone in shale 70

Fig. 2: Structure of the Cape Range Anticline 143

Fig. 3: Seismic Section, Giralia to Bullara Road 146

PLATES

Plate 1: Geological Map. Northern Part of Carnarvon Basin.

Plate 2: Cross Sections: Carnarvon Basin.

Plate 3: Stratigraphic Columns: Carnarvon Basin.

SUMMARY

This progress report describes the geology of the Carnarvon (or North-West) Basin north of Lat. 25° S.

The Carnarvon Basin is a large epi-continental basin extending from North-West Cape to the Murchison River and from the coast about 130 miles inland. The sedimentational axis of the basin probably runs north-south about 30 miles east of Cape Cuvier.

A conformable sequence of sandstone, greywacke, shale, and limestone, ranging in age from Middle Devonian to Permian (Kungurian), has a maximum compiled thickness, in the outcrop area in the eastern part of the basin, of 19,000 feet. Unconformably above the Palaeozoic sediments is a sequence of siltstone, radiolarite, calcarenite, and limestone ranging in age from Middle Jurassic to possibly Pliocene with several disconformities. The maximum compiled thickness of these sediments is 3,600 feet.

The regional west dip of the Palaeozoic sediments is interrupted by several major thrust faults and many minor faults. Large drag synclines are common on the east side of these faults and in a few places small basin and dome structures have been formed by the drag on the east side of a fault.

The lithology indicates that the sediments were deposited on a shelf area which varied from very stable to moderately unstable. During the Permian, the basin was 'barred' several times so that euxinic shales and evaporites were deposited. A series of glacial and inter-glacial stages is indicated by the formations of the Lyons Group. Lithology and convergence of formations indicate that the shore-line of the basin, from the Devonian onwards, was well to the east of the present edge of outcrop and probably trended in a north-easterly direction. The Cretaceous transgression reached to about the present eastern edge of outcrop of the Palaeozoic sediments.

INTRODUCTION

The Carnarvon or North-West Basin extends from Onslow in the north to the Murchison River in the south and inland for about 130 miles from the coast at Cape Cuvier. This basin of Palaeozoic to Recent sediments is being mapped geologically by geologists of the Bureau of Mineral Resources. The investigation, directed mainly towards determining the possibility of oil accummulation in the basin, was started in 1948 when a small party did a reconnaissance of the Minilya River area. Since then up to seven geologists have been mapping the area in some detail, to determine the stratigraphical sequence and variations, regional structure, and the location and size of closed structures.

The following geologists have mapped the area north of 25° south latitude: M. A. Condon (in charge from 1949 onwards), Dr. C. Teichert (1948-50, in charge 1948), D. Johnstone (1948 onwards), G. A. Thomas (1948-50), C. E. Prichard (1949 onwards), W. J. Perry (1949-50), M. H. Johnstone (1950 onwards), J. G. Best (1950). This report gives the results of the field work up to the end of 1952. Palaeontological, petrological and chemical examination of specimens collected is continuing, but only preliminary, tentative, or incomplete information is available at present.

PHYSICAL CONDITIONS

ACCESS:- The area has a network of mail roads (shown on Plate 1) and station roads which give reasonable access to almost all parts except the very rough areas such as the Cape Range and the western side of the Kennedy Range. These roads are mainly unformed dirt roads which are untrafficable for several days after heavy rain. The supply centre of the area is Carnarvon which is supplied from Perth by regular shipping, air and road services. Onslow is the only other deep-water port in use in the area. Airfields suitable for large aircraft have been established at Carnarvon, Learmonth, Lyndon, Mt. Sandiman, and Gascoyne Junction. Fields suitable only for light planes have been prepared on many of the stations (see Plate 1).

CLIMATE:- The climate of the area is semi-arid in spite of its position on the edge of the tropical zone. Rainfall averages 10 inches at Winning Pool, 9 inches at Carnarvon, 8½ inches at Gascoyne Junction and 9 inches at Onslow (Gardner, 1942, p.lxvi). Most of the rain falls in February-March and May-June. The reliability of rainfall is very low, both in total amount and in month of maximum fall. Frosts are almost unknown except on the inland margin of the area. Winter temperatures are moderate but summer temperatures are very high.

VEGETATION:- The vegetation is generally adapted to the climate, having either small, hard, aromatic leaves and spines or watery, fleshy leaves. Areas of sand have mainly spinifex (Triodia). Areas of outcrop or wash have low scrub mainly of Acacias. River and larger creek channels are lined with eucalypts ("Ghost Gums").

DEVELOPMENT:- The area is subdivided into pastoral leases of large size (averaging about 200,000 acres) all of which are devoted to sheep-raising for wool. Bananas and vegetables are grown along the banks of the Gascoyne near Carnarvon. Whaling stations are established at Carnarvon and Point Cloates.

PREVIOUS WORK

F. T. Gregory (1861) published a section east of Babbage Island (Carnarvon) showing the regional westerly dip of the Palaeozoic sediments which are shown as Devonian (?), Carboniferous (?), and Permian (?), and the overlying "Cretaceous (?)" which was thought to include the sandstones of the Kennedy Range. An editor's note mentions Spirifer from Lyons River in Gregory's collection. There is no discussion of the section in the text of the article.

W. H. Hudleston (1883) described a collection of rock and fossil specimens forwarded by John Forrest. Fossils from the Callytharra Formation between the Gascoyne and Minilya were described and referred to the Lower Carboniferous.

A. Gibb Maitland (1901) discovered the (Lyons) glacial sediments and recognized the possibility of obtaining artesian water in the coastal area of the basin; he was instrumental in having a deep bore drilled near Carnarvon. This bore (Pelican Hill Bore) struck artesian water with a flow of 520,000 gallons a day at a depth of 3,011 feet (Maitland, 1903 and 1904).

Maitland (1909) examined the Palaeozoic sediments in the Gascoyne, Minilya and Lyndon valleys. He described and named the glacial "Lyons Conglomerate" and described (Callytharra) and (Moogooree) limestone, and (Wooramel) and (Kennedy) sandstone. He described sections in the Minilya River at Wandagee, near Moogooloo Peak and in the Kialiwibri Creek (Lyndon River).

F. G. Clapp (1925) did a reconnaissance through the North-West and Desert Basins. He added little to the knowledge of the Palaeozoic stratigraphy or structure but discovered the Cape Range Anticline in Tertiary limestone. His pessimistic view of the oil possibilities of the North-West Basin (Clapp, 1926 a & b) was based mainly on his failure to find any shales which could act as cap rocks - this in spite of the evidence of the artesian bores!

W. G. Woolnough (1933) in the course of an Australia-wide aerial reconnaissance confirmed the anticlinal structure of the North-West Cape Range and of other coastal hills southward to Salt Lake. He observed faults and anticlinal structures in the Palaeozoic sediments along the Gascoyne River.

The first really systematic stratigraphical work done in this basin was done between 1932 and 1935 by geologists of Oil Search Ltd. Condit (1935) gave a brief summary of the results, indicating that there were at least 7,000 feet of Permo-Carboniferous marine sediments - including substantial thicknesses of richly organic shales and other potential source beds - shaly beds which should serve as seals, and mild structural deformation and absence of metamorphism. Raggatt (1936) and Condit, Raggatt and Rudd (1936) presented the details of the stratigraphy of the area north of the Gascoyne. The main outlines of the Permian stratigraphy were established but the presence of Lower Carboniferous and Devonian sediments was not realised. The presence of definite Cretaceous and Eocene strata was established for the first time.

H. G. Raggatt and H. O. Fletcher (1937) listed the species then known from the North-West Basin and examined the problem of the Carboniferous-Permian boundary in Australia and the Indian Ocean area generally. They concluded that the Speckled Sandstone and Agglomeratic Slate of India, the 'Lower Marine series' of New South Wales and the Lyons 'Series' of the North-West Basin are Lower Permian, assuming the base of the Permian is at the base of the Schwagerina-Uddenites Zone.

C. Teichert examined the stratigraphy and palaeontology of the Wandagee area from 1939 onwards and added much to the detailed knowledge of this part of the section. In 1948 he directed the reconnaissance which initiated the present investigation and from 1949 to 1951 co-operated actively in the investigation.

A large number of investigators have worked on details of the palaeontology and sedimentary petrology. These will be referred to where necessary in the body of the report.

PHYSIOGRAPHY

The Carnarvon Basin area consists of coastal plains at two levels separated by a steep scarp generally more than 100 and less than 400 feet high. Both plains slope very gently westward towards the coast. The main rivers are inherited consequent streams, rising in the higher Pre-Cambrian country to the east.

The high-level plain, the largest area of which is the Kennedy Range, is largely formed by the lateritized surface of the Miocene Merlinleigh Sandstone, a thin marine sand deposited on a peneplain surface of Permian sediments. It slopes very gently westward and is terminated abruptly on all sides by a precipitous erosion scarp up to 400 feet high. The surface of this plain reached 1,195 feet above sea level (at trig. K-38) and is generally more than 1,000 feet above sea level. Remnants of this plain include Moogooloo and the Pleiades. Smaller remnants close to the main areas form the flat-topped mesas and buttes which are one of the characteristic features of this area. The surfaces of the Kennedy Range and the Pleiades are covered by long ridges or dunes of red sand.

The low-level plain occupies the greater part of the area. It is probably mainly an erosional plain, in contrast to the depositional high-level plain. It may be divided into two main types - the sand plain and the outcrop plain. The sand plain extends from near Glenroy Station in the north through Winnemia on the Gascoyne River and from the coast inland for about 60 miles. The highest areas on this plain are probably west of Moogooloo and near Mardathuna Homestead where the elevation is probably close to 400 feet above sea level. The sand of this plain is a thin veneer resting on an erosion surface of Cretaceous and Permian sediments. The nature of this erosion surface and the uniformity of the sand type on very variable underlying rock may indicate that the erosion surface was wave-cut and the sand deposited in a shallow sea. No fossils have been found to support this though it is doubtful if fossils would be preserved in this type of sediment.

The outcrop plain extends from the apical area of the Giralia Anticline to Winning Pool and from there southward in the area bounded by Wandagee Hill, Mardathuna, and Winnemia, on the west, and Lyndon, Williambury, Eudamulla, and Dairy Creek, on the east. This plain has been formed by stream erosion and is generally above the level of the sand plain except close to the river channels, which are somewhat entrenched. Drainage is mainly by sheet flow which in many places deposits a thin veneer of sand and gravel.

Standing up above the low-level plain are a number of outcrop ridges consisting generally of a steep east-facing scarp and a more gently sloping western dip-slope. The Giralia Range (in Cretaceous and Tertiary sediments), the Moogooloo Range, the ridge between K-52 and K-35 (Permian Callytharra Formation), and the ridges between Williambury and Moogooree (Devonian and Carboniferous sediments) are the main outcrop ridges. These ridges were developed by differential erosion after the formation of the high-level plain and before the deposition of the sand on the low-level plain.

In the coastal area south of North-West Cape are several young fold ridges formed by the folding, probably in Pleistocene time, of Tertiary limestone. The largest of these is the Cape Range, which reaches 1033 feet above sea level. The others, on the north-west and eastern sides of the Salt Lake, are much smaller and lower than the Cape Range.

The Salt Lake originated as a synclinal gulf between the anticlinal ridges. The opening to the sea at the south end was closed by sand, probably first as a spit and then by the building of beach dunes on this spit. Marine shell beds are preserved around the present margin of the lake. These, because of their elevation above sea level, are probably Pleistocene. The Lyndon and Minilya Rivers empty their flood flows into the lake. The floor of the lake is covered by a saliferous deposit consisting of alternating clay and salts (mainly gypsum and halite). On the west side of the lake, north and south of the peninsula, are permanent salt water pools in which fish are reported by local residents. These pools are probably in contact with the Indian Ocean by means of subterranean passages through the Tertiary limestone of the Gnarraloo isthmus.

The Gascoyne River has formed a large alluvial cone delta, the head of which is 30 miles upstream from the mouth. This cone extends into Shark Bay, where its extent may be seen in bathymetric contours.

The coastline in this area is almost entirely structural and of the Pacific type. The coast from North-West Cape to Quobba is determined by the west flank of the young anticlines, modified very slightly by marine erosion. Along this coast, probably at the outer edge of the wave-cut platform, is a growing coral reef. Exmouth Gulf is synclinal. The coast from Point Locker eastward is probably formed by the regional dip of Cretaceous sediments in that area.

The continental shelf varies greatly in width in this area, from 40 miles off Point Locker and Quobba to 4 miles off Yardie Creek. Although the soundings available are few and not very well placed there is good indication of a ridge (probably caused by folding) rising to 38 fathoms beyond the main continental slope off the mouth of Yardie Creek (Admiralty Chart, 1901). Although no indication of anticlinal structure was found on Bernier Island this and Dorre Island are almost certainly on an anticlinal ridge.

STRATIGRAPHY

STRATIGRAPHICAL SUCCESSION:-

Table 1 sets out the main features of the stratigraphy of the northern part of the Carnarvon Basin, and Plate 2 shows the variations in the succession and in formation thicknesses in the Palaeozoic sediments.

On the eastern edge of the area of outcrop of the sediments of the Carnarvon Basin, the sediments lie unconformably on or are faulted against Pre-Cambrian schists, gneisses, granite, and sediments. The oldest Palaeozoic sediments (Devonian Nannyarra Greywacke) rest unconformably on the Pre-Cambrian rocks which are assumed to form the floor of the Basin. The Palaeozoic sequence is conformable except in two places: possibly at the base of the Harris Sandstone and certainly above the Callytharra Formation there are disconformities. There is a major unconformity (angular and erosional) between the Palaeozoic sediments and the Mesozoic sediments. Minor disconformities are common in the otherwise conformable Mesozoic-Tertiary section.

NOMENCLATURE:-

Stratigraphical: Stratigraphical nomenclature follows the Australian Code and has been approved by the State Committee on Stratigraphic Nomenclature. (Glaessner, Raggatt, Teichert and Thomas, 1948; Raggatt, 1950).

Lithological: Lithological names are used with the meanings set out in the following glossary:

ARENITE — Grain-size class name (Grabau, 1904, p.242) for fragmental sedimentary rocks having a grain-size between 0.06 and 4.0 mm. (Dapples, Krumbein and Sloss, 1950). Sub-classes are: very coarse - 2.0 to 4.0 mm.; coarse - 1.0 to 2.0 mm.; medium - ¼ to 1.0 mm.; fine - ⅛ to ¼ mm.; very fine - 1/16 to ⅛ mm.

ARKOSE — Arenite composed of felspar (20 to 60%), quartz (20 to 78%) and heavy minerals of the granitic suite (2 to 4%) with up to 30% kaolinitic clay, 20% mica and/or 40% fragments of slate quartzite, graphitic rock and/or schist (Oriel, 1949).

BENTONITE — A lutite consisting mainly of the clay minerals montmorillonite and/or beidellite.

CALCARENITE Fragmental carbonate rock composed of fragments (between 0.06 and 4.0 mm.) of carbonate organic tests, crystalline limestone, dolomite or siderite, cleavage fragments of carbonates, and/or calcareous ooides.

CALCILUTITE Fragmental limestone of particle size less than 0.06 mm. consisting mainly of carbonate fragments. (Grabau, 1904).

CLAYSTONE Massive lutite of grain-size less than 0.004 mm.

COQUINITE A bedded organic rock consisting mainly of tests of benthonic organisms. The proportion of fossils may be relatively small but if they form the frame-work of the rock it may be considered a coquinite. (A new word derived from 'coquina' and proposed as the name of the rock type constituting a biostrome).

COQUINOID Adjective applied to rocks which contain a moderate but not dominant proportion of benthonic fossils.

GREYWACKE Arenite consisting of angular and/or rounded quartz and rock fragments, with or without felspar, and with a fine-grained matrix which is mainly micaceous and/or chloritic (Condon, 1952).

LATERITE Mature soil profile developed by weathering probably under humid tropical conditions.

LIMESTONE Dense, crystalline calcium carbonate sedimentary rocks.

LUTITE Grain-size class name for fragmental rocks of grain-size smaller than 0.06 mm. (Grabau, 1904).

OILSAND Any rock containing petroleum recoverable by drainage or other hydraulic methods.

OOLITIC Containing ooliths in less than dominant proportions.

OOLITH Spherical or ovoid inorganic particles smaller than 2 mm. with concentric laminated structure (Twenhofel, 1932, p. 757).

QUARTZ SANDSTONE Arenite composed predominantly of fragments of quartz (Condon, 1952).

QUARTZITE Quartz sandstone with siliceous cement.

RADIOLARITE Siliceous organic rock consisting mainly of the tests and fragments of radiolaria with or without diatoms, foraminifera, sponge spicules, other pelagic fossils, clay sand, and organic residues. (Murray and Renard, 1891, p. 203).

SHALE Laminated lutite of fine grain (grain-size less than 0.004 mm.).

SILTSTONE Lutite of grain-size between 0.004 and 0.06 mm. consisting mainly of fragmental silica and silicates.

TILLITE Consolidated rock-flour clay with or without sand with scattered pebbles, cobbles and boulders, deposited by ice.

TRAVERTINE Dense fine-grained to medium-grained crystalline calcium carbonate deposited from solution in ground and/or surface waters (Fay, 1920).

VARVE Sediment deposited during one year. Distinguished by graded bedding related to seasonal deposition (sand to silt or silt to clay) and regular repetition with minor fluctuations in thickness. May be up to 2 metres thick but is generally thin. Mainly but not necessarily fluvio-glacial. (Rice, 1940).

Place Names: Place names on Western Australia Lands Department plans are accepted except where there is obvious inconsistency or duplication.

Where Lands Department names are not available, use has been made of station bore, well, and paddock names.

There are several cases of the use of the same name for different features of the same type, e.g. Binthabooka Creek is, on Lands Department plans, south-west of Kennedy Range, and is also in local use for the creek flowing south to the east of the east scarp of the Kennedy Range. Enquiry has been made for local alternatives and where one is available it is applied to the feature unnamed in Lands Department plans. There is confusion in the use of 'Davis Creek' and 'Davies Creek' for two of the creeks flowing west into Lyons River north and south of Lyons River Homestead. On Lands Department Litho. No. X/800 'Davis Creek North' and 'Davis Creek South' are shown flowing south-west from near K-41, and 'Davis Creek' is shown flowing south-west from the direction of K-34. It is proposed to apply the local name 'Grays Creek' to the creek flowing south-westward from near K-34, and 'Davis Creek' for the creek flowing south-west from K-41.

Pronunciation:

Where there may be some doubt about the pronunciation of place names, the local pronunciation is indicated. The symbols used are those employed in the Concise Oxford Dictionary, 4th Edition, 1951, with the following differences:

The short vowel is unmarked; the indeterminate vowel is underlined; and the syllables are separated by hyphens.

PRE-CAMBRIAN:

Pre-Cambrian rocks crop out in the area to the east of the Palaeozoic sediments and in several small fault blocks in the eastern part of the Palaeozoic basin. It is assumed that rocks of similar type form the floor of the Palaeozoic sedimentary basin.

The Pre-Cambrian rocks may be subdivided lithologically into the following groups: schists, granite, sediments, and dyke rocks. Schists predominate in the area near the margin of the Carnarvon Basin. Many types, including some indicating high-grade metamorphism, outcrop in this area. Mica schist and quartz schist are common. Granitic rocks extend in a fault block from 10 miles north of Mt. Sandiman to north of Wogoola. Small areas of granitic rock are common within the area of schist. Sediments which have been altered only by low-grade to very low-grade metamorphism outcrop in a belt running north-west between Lyndon and Maroonah, in a belt running south from Eudamullah, and in small outliers close to the margin of the Palaeozoic sediments. Quartzites are common, limestone, slate and greywacke less so. Pegmatites and basic dykes, some of great length and moderate thickness, cut through the schists and granite but appear not to cut the sediments.

DEVONIAN:

The Devonian is the oldest system represented in the outcropping Palaeozoic sediments of the Carnarvon Basin. In the area of outcrop it comprises the Nannyarra Greywacke, Gneudna Formation, Munabia Sandstone and Willaraddie Formation. The outcrop extends from near Mt. Sandiman Homestead almost to Lyndon Homestead.

<u>Nannyarra Greywacke</u>

The Nannyarra Greywacke is the oldest Palaeozoic formation exposed in the Carnarvon Basin. It is a thin formation consisting of greywacke and siltstone resting unconformably on a mature erosion surface of Pre-Cambrian rocks and conformably beneath the Gneudna Formation.

The name (pronounced nan'-e-a'-ra) is taken from Nannyarra Paddock (on Moogooree Station) the north-west corner of which is 4¾ miles S-S-E of the homestead (Teichert, 1949b).

The type section of the formation is at the south end of Gneudna Paddock, Williambury, at Lat. 23°58' S., Long. 115°14' E. In descending order the type section consists of:

GNEUDNA FORMATION conformable above

72 feet of	friable pale green siltstone possibly calcareous;
61 feet of	firm to friable, light grey-green, medium to fine-grained greywacke, some beds laminated (Specimen TP/157);
22 feet of	friable laminated fine-grained greywacke (poor outcrop);
14 feet of	friable, light greenish grey, medium-grained greywacke; few fine-grained beds to 6 inches thick;
22 feet of	friable, light greenish grey, medium-grained greywacke (TP/156);
2 feet of	firm light-grey very coarse grained greywacke;
42 feet of	firm light-grey medium-grained greywacke with few beds to 1 foot thick of very coarse grained greywacke;
30 feet of	firm light-grey coarse to very coarse grained greywacke; some sub-angular quartz pebbles up to 1 inch (TP/154,155).
265 feet	- type thickness of Nannyarra Greywacke.

Red brown decomposed coarse granite (Pre-Cambrian) unconformably below.

The basal beds are rather arkosic in appearance but contain too little felspar to be classified as such (Edwards, 1952). The greywackes are composed dominantly of quartz (40% to 60%) with from 10% to 50% of rock fragments (slate, chert, quartzite, phyllite, granitic rock), 5% to 10% felspar, up to 5% mica (biotite, muscovite, sericite) and up to 25% fine-grained matrix. The grains are sub-angular to angular and poorly sorted. The thickness and lithology of the formation vary considerably from place to place. Eleven miles E-N-E. of Mt. Sandiman Homestead, the thickness is 170 feet; $4\frac{1}{2}$ miles E-N-E. of Williambury Homestead it is about 200 feet and 2 miles north-west of Williambury it is about 150 feet. The junction between the Pre-Cambrian and the Nannyarra Greywacke is very rarely exposed, but in aerial photographs it shows up well in some places and shows that, particularly in detail, the junction is irregular, causing rapid variations in thickness.

The Nannyarra Greywacke generally forms reduced topography between the Pre-Cambrian hills and the strike ridges of the Gneudna Formation. It is usually covered by soil and outcrop is rare.

No fossils have been found in the Nannyarra Greywacke but as the age of the lower part of the conformable Gneudna Formation is Middle Devonian (Teichert, 1949b; Hill, 1953) the Nannyarra Greywacke is probably Middle Devonian. The variations in the Pre-Cambrian lithology and thickness and the absence of marked erosion effects on the surface of the Pre-Cambrian indicate that it is a rapidly transgressive formation.

Gneudna Formation

The Gneudna Formation (Teichert, 1949b) is a thick formation of greywacke, limestone, and siltstone, generally very fossiliferous. It rests conformably between the Nannyarra Greywacke below and the Munabia Sandstone above.

The name (pronounced nū'd-na) is taken from Gneudna Paddock on Williambury Station, immediately south-east of the homestead. The type section is at the south end of Gneudna Paddock, 3¼ miles south of Gneudna Well, at Lat. 23°58' S., Long. 115°13' E. and is contiguous with the type section of the Nannyarra Greywacke. In descending order, the type section consists of:

MUNABIA SANDSTONE conformably overlying

35 feet of friable grey-green medium to fine-grained greywacke (50%), hard brownish-grey sandy fine-grained crystalline limestone (45%) and hard white calcareous quartz sandstone (5%);

10 feet of hard grey sandy medium-grained crystalline limestone;

48 feet of medium-hard to friable white fine-grained sandstone;

15 feet of friable green fine-grained greywacke;

7 feet of hard grey medium-grained crystalline limestone;

63 feet of friable green fine-grained greywacke;

30 feet of friable greenish-grey laminated fine to medium-grained greywacke and hard crystalline limestone;

20 feet of hard grey medium-grained crystalline limestone with solitary tabulate corals and stromatoporoids (TP/208);

80 feet of medium-hard grey-green laminated fine-grained greywacke and thin-bedded crystalline limestone;

110 feet of friable greenish-grey medium-grained to fine-grained and coarse-grained greywacke (90%) and hard grey medium-grained to fine-grained crystalline limestone both containing brachiopods, tabulate corals and stromatoporoids (TP/205,206,207);

170 feet of friable to firm greenish-grey fine-grained to medium-grained shelly greywacke and hard brownish-grey medium-grained to coarse-grained crystalline limestone (10%) with many brachiopods (TP/194 to 204);

105 feet of friable greenish-grey fine-grained to medium-grained shelly greywacke in beds up to 10 feet thick and hard brownish-grey medium-grained shelly crystalline limestone in beds to 2 feet thick, both containing brachiopods, pectinids, and few straight nautiloids (TP/186 to 193);

63 feet of friable yellow-brown shelly calcarenite, medium-hard grey laminated fine-grained crystalline limestone, and thin-bedded hard grey coarse-grained crystalline limestone (TP/181 to 185);

40 feet of medium-hard brown-grey medium-grained to coarse-grained crystalline limestone, some beds sandy (TP/178 to 180);

5 feet of soft grey-green laminated siltstone (TP/177);

50 feet of medium-hard green-grey medium-grained crystalline limestone with many lamellibranchs and brachiopods;

35 feet of friable yellow-brown calcarenite with brachiopods and straight nautiloids (TP/176);

80 feet of thin-bedded medium-hard medium-grained to coarse-grained grey crystalline limestone with many nautiloids and brachiopods (TP/174,175);

25 feet of friable yellow-brown calcarenite;
25 feet of thin-bedded medium-hard grey medium-grained crystalline limestone (TP/173,175B);
25 feet of friable yellow-brown calcarenite and hard grey fine-grained crystalline limestone crowded with lamellibranchs (TP/172);
50 feet of thin-bedded, medium-hard to friable, light-grey fine-grained to medium-grained crystalline limestone crowded with brachiopods and lamellibranchs (TP/171);
75 feet of thin-bedded to thick-bedded, hard to medium-hard, medium-grained to fine-grained crystalline limestone (TP/170);
43 feet of friable yellow-brown laminated calcarenite and hard light-grey laminated fine-grained crystalline limestone with small brachiopods and crinoid stems (TP/169);
30 feet of thin-bedded, hard to medium-hard, grey crystalline limestone and medium-hard to friable yellow-brown crinoidal calcarenite (TP/168);
60 feet of massive to laminated hard grey crystalline limestone, some sandy, and friable yellow-brown calcarenite (TP/162 to 167);
20 feet of medium-hard laminated sandy limestone, ferruginous at the surface (TP/160,161);
65 feet of medium-hard grey laminated fine-grained crystalline limestone, some beds containing brachiopods, nautiloids and crinoid stems (TP/159);
237 feet of poorly outcropping friable greywacke and calcarenite with few thin beds of hard crystalline limestone (TP/158);
25 feet of hard green-grey crystalline limestone with small gastropods and small crinoid stem ossicles;

conformably overlying the NANNYARRA GREYWACKE

1646 feet - type thickness of the Gneudna Formation.

The base of the Gneudna Formation is the bottom of the lowermost hard limestone bed and the top of the formation is the uppermost hard limestone bed overlain by friable quartz sandstone. There are many beds of Munabia type in the upper 100 feet but there are no beds of Gneudna type above the top hard limestone bed. Teichert (1949b), in announcing the discovery of Devonian and Carboniferous sediments in the Carnarvon Basin, named this formation 'Gneudna Limestone' but as there is only 45% of limestone in the type section the sequence is better named 'Formation'. The Gneudna Formation forms plains with low strike ridges of limestone which appear in aerial photographs as fine parallel dark lines on a light ground. The vegetation is sparse acacia scrub and small herbaceous plants.

Except in the type section, dips are unreliable because of weathering but it seems possible that the type section is the thickest section exposed of the Gneudna Formation, although a greater thickness has been calculated at Williambury. The thickness is 930 feet eleven miles E.-N.-E. of Mt. Sandiman Homestead, approximately 1250 feet 10½ miles east of Moogooree Homestead; about 1170 feet 11½ miles S.-S.-E. of Moogooree Homestead; 1600 feet 6 miles north-east of Williambury Homestead; possibly 1750 feet 4 miles N.-N.-W. of Williambury Homestead and possibly 1670 feet 4½ miles west of Williambury Homestead. This indicates thickening northward and westward towards Williambury but the dip evidence is so doubtful that the thicknesses are not reliable as an indication of convergence. The only two measured sections where the dips are reasonably reliable (the type section and the 930-foot thickness) indicate thickening northerly along the strike.

The Gneudna Formation outcrops in a continuous belt from 5 miles south-west of Lyndon Homestead to 2 miles north of Mt. Sandiman Homestead and in fault blocks 4½ and 1½ miles west of Williambury Homestead, 10½ miles east of Moogooree Homestead and 11 miles north-north-east of Mt. Sandiman Homestead. J. M. Dickins found Gneudna-type spiriferids (cf. Cyrtospirifer) in core from 1446 feet in the Pelican Hill Bore, Carnarvon. This discovery is important in giving definite evidence of the extension of the Gneudna Formation in similar but somewhat finer-grained facies at least as far west as Carnarvon particularly as thickness measurements in the Devonian-Carboniferous seem to indicate convergence westward.

The Gneudna Formation probably ranges in age from Middle Devonian (Givetian) to Upper Devonian (Frasnian), (Hill, 1953). The fauna contains relatively few species but many individuals. Camarotoechia sp. is common in the lower part of the formation, Atrypa, Nautiloidea, Cyrtospirifer and Rhynchonellids characterize the middle part of the formation and stromatoporoids and corals the upper part. In some parts of the sequence the fauna is noticeably dwarfed.

Munabia Sandstone

The name Munabia Sandstone was given by Teichert (1949b) to the sequence between the Gneudna Formation and the Moogooree Limestone before any detailed section had been surveyed. As a result of the field work of G.A. Thomas and C.E. Prichard, it is evident that this sequence should be subdivided into two formations and it is proposed to restrict the name 'Munabia Sandstone' to the lower quartz sandstone formation of this sequence (Thomas and Prichard, 1953). The Munabia Sandstone is defined as the quartz sandstone formation conformable between Gneudna Formation below and Willaraddie Formation above.

The name (pronounced mū'-na-bī-a) is taken from Munabia Paddock, Williambury Station, which is immediately north-east of the homestead. The formation outcrops across the middle of this paddock.

The type section is in Gneudna Paddock, 5 miles south-east of Williambury Homestead and one mile north-west of Gneudna Well, at Lat. $23^{o}55'$S., Long. $115^{o}12'$E. The type section, measured by G.A. Thomas and C.E. Prichard, in descending order consists of:

WILLARADDIE FORMATION conformably above

46 feet of friable white fine-grained to medium-grained quartz sandstone with beds of fine-grained quartz conglomerate;

23 feet of medium to coarse-grained quartz sandstone;

19 feet of friable white fine-grained 'sparkling' sandstone (Sample TP/34);

15 feet of white fine-grained quartz conglomerate;

240 feet of friable white fine to medium grained cross-bedded quartz sandstone with coarser beds towards the base;

112 feet of soft grey sandy siltstone with thin beds of friable greywacke and thin hard beds of yellow crystalline limestone (Sample TP/32);

26 feet not outcropping;

204 feet of friable white fine-grained to medium-grained quartz-sandstone with thin coarse to very coarse grained beds (Sample TP/30);

6 feet of soft sandy siltstone;

76 feet of friable white medium-grained quartz sandstone with thin hard silicified beds and thin pebbly beds;

66 feet of friable white fine-grained quartz sandstone with thin siltstone beds;

341 feet of friable white fine-grained to medium-grained quartz sandstone with thin hard silicified beds, thin siltstone beds and thin pebble beds (Sample TP/28);

106 feet of friable white fine-grained sandstone with thin hard silicified beds;

86 feet of friable white fine-grained to medium-grained quartz sandstone with hard silicified bands and beds of clay galls;

60 feet of friable and hard white fine-grained quartz sandstone;

110 feet of friable white to pale brown fine-grained to medium-grained cross-bedded quartz sandstone with some mica;

235 feet of thin-bedded white to pale brown fine-grained to medium-grained cross-bedded quartz sandstone with some mica and with pebbly coarse beds and silicified beds (few Lepidodendroid plant remains near base);

Conformably above uppermost hard limestone bed of Gneudna Formation.

1820 feet - type thickness of Munabia Sandstone.

The base of the Munabia Sandstone is placed at the top of the uppermost hard limestone bed of the Gneudna Formation and the top of the Munabia Sandstone at the base of the lowest pebbly greywacke of the Willaraddie Formation.

The Munabia Sandstone is dominantly clean quartz sandstone consisting of 90% quartz, 5% felspars, 2.5% fragments of chert and quartzite and 2.5% clay matrix. The quartz is commonly overgrown and the resulting crystal faces give sparkle to much of the rock. White mica is common in some beds but almost absent in others. The grain-size is variable from bed to bed but within each bed the sorting is good and porosity is about 10%. In the upper part of the formation there is a thin member consisting of siltstone, greywacke, and thin hard limestone. Cross-bedding is common in the sandstone members. Examination of recorded dips indicates that, in addition to the small-scale cross-bedding, there is cross-bedding on a scale large enough to give the appearance of normal bedding and it is probable that some of the beds which do not show cross-bedding are themselves large foreset beds. Because of this, thicknesses based entirely on recorded dips may be incorrect. A check on the total thickness of the Munabia Sandstone and Willaraddie Formation was made by drawing a section using only dips obtained in the top part of the Gneudna Formation and in the Moogooree Limestone. This agreed well with the thickness obtained using only dips selected as conforming to a regular sequence. Some of the 'foreset beds' were thus shown to be as much as 10 degrees different in dip from the true bedding planes.

The Munabia Sandstone outcrops in a continuous belt about $\frac{3}{4}$ mile wide extending from eight miles north of Williambury Homestead to seventeen miles south-south-east of Moogooree

Homestead, and in fault blocks three miles west of Williambury Homestead, 11 miles east-south-east of Moogooree Homestead, and 12 miles north of Mt. Sandiman Homestead.

In the main outcrop belt the thickness varies from about 1700 feet at the south end to about 1900 feet at the north end - a divergence of 7 feet per mile northward. A complete section of the formation is not present in the eastern fault blocks and in the western fault block the thickness is about 1000 feet: it is probable that the top part of the formation is faulted out.

The only fossils known from the Munabia Sandstone are Lepidodendroid plant fragments. At the base of the formation, at a locality 7¾ miles north-north-west of Williambury Homestead, a small fragment of stem with leaf-scars and several small thin leaf impressions was found (Sample M-23).

Age determination of the Munabia Sandstone depends on its position immediately above the Upper Devonian Gneudna Formation and below the Willaraddie Formation which is conformable beneath the Lower Carboniferous Moogooree Limestone. As the upper part of the Gneudna Formation is probably Frasnian in age the Munabia Sandstone may be referred to the Upper Devonian.

There is very little variation in lithology along the main outcrop belt but in the fault block west of Williambury Homestead there are several thin limestone beds developed within the lowermost sandstone member.

Willaraddie Formation

The Willaraddie Formation is defined as the sequence of greywacke, siltstone, sandstone, and conglomerate conformably between the Munabia Sandstone below and the Moogooree Limestone above.

The name (pronounced will'-a-rad'-dē) is taken from Willaraddie Creek which flows south-westward through Munabia Paddock, Williambury Station, and joins the Minilya River three miles eastward of Williambury Homestead. The formation outcrops immediately west of the mouth of Willaraddie Creek.

Willaraddie Formation outcrops in a belt about ½ mile wide from 8 miles north-north-east to 6 miles south-south-east of Williambury Homestead and in another belt from 7½ miles north-north-west to 3½ miles north-west of Williambury Homestead.

The type section is in Gneudna Paddock, four miles south-east of Williambury Homestead and 1¾ mile north-west of Gneudna Well, at Lat. 23°54'S., Long. 115°11¾'E. The type section, measured by G.A. Thomas and C.E. Prichard, in descending order consists of:

	MOOGOOREE LIMESTONE conformably above
34 feet of	friable white fine-grained to medium-grained silty quartz sandstone with some white mica;
56 feet of	friable pale brown medium-grained kaolinitic quartz sandstone, cross-bedded, with few quartzite pebbles (Sample TP/318);
67 feet of	friable pale yellow fine-grained to very fine-grained micaceous quartz sandstone;
28 feet of	friable sandy pebble conglomerate (pebbles of chert, quartz, quartzite);
8 feet of	hard yellow very-fine-grained micaceous sandstone;
27 feet of	friable fine-grained red sandstone with hard calcareous beds, and thin pebbly coarse-grained greywacke beds;
92 feet of	friable grey coarse-grained to medium-grained greywacke with pebbles and clay galls;
14 feet of	thin-bedded friable micaceous sandstone with kaolinitic matrix;
1 foot of	friable fine conglomerate with pebbles to 4" of dark chert and quartz;
13 feet of	friable grey coarse-grained greywacke;
17 feet of	soft very-fine-grained micaceous sandstone;
48 feet of	friable medium-grained greywacke and soft very-fine-grained micaceous sandstone;
29 feet of	friable medium-grained greywacke;
31 feet of	friable to soft fine-grained sandstone with ferruginous (? calcareous) beds and hard pebbly beds 2 to 3 feet thick;
8 feet of	friable pebbly coarse-grained greywacke;
32 feet of	soft pale grey siltstone (Sample TP/317);
32 feet of	friable fine-grained sandstone with thin beds of ferruginous pebbly greywacke;
11 feet of	soft red-brown very-fine-grained sandstone;
30 feet of	dark coarse-grained pebbly greywacke;
45 feet of	thin-bedded friable pale-brown fine-grained micaceous quartz sandstone with thin hard ferruginous beds;
60 feet of	friable pale yellow-brown coarse-grained to medium-grained pebbly greywacke with ferruginous beds, and thin soft siltstone beds (Sample TP/143);
9 feet of	soft reddish very-fine-grained micaceous sandstone (Sample TP/144);

39 feet of friable pale brown pebbly coarse-grained greywacke with medium-hard ferruginous beds and beds of pebble conglomerate;
58 feet of friable yellow-brown pebbly coarse-grained greywacke with pebble beds (Sample TP/36);
32 feet of friable very-coarse-grained greywacke with pebbles;
24 feet of soft very-fine-grained sandstone (Sample TP/145);
20 feet of friable coarse-grained cherty sandstone and quartz greywacke - cross-bedded;
23 feet of soft fine-grained micaceous greywacke containing poorly preserved bryozoa and Athyrid brachiopods (Sample TP/146);
45 feet of friable coarse-grained pebbly sandstone and reddish fine-grained sandstone;
16 feet of friable coarse-grained greywacke with pebbles (Sample TP/35);
20 feet of soft reddish fine-grained to very-fine-grained sparkling quartz sandstone;
12 feet of friable medium-grained greywacke, pebbly at base; conformable above friable white quartz sandstone of MUNABIA SANDSTONE.

980 feet - type thickness of Willaraddie Sandstone.

The base of the Willaraddie Formation is placed at the bottom of the lowermost bed of greywacke overlying the top sandstone member of the Munabia Sandstone. Above this bed there are beds of quartz sandstone but although they have the same 'sparkle' as the Munabia Sandstone they are mainly of finer grain-size and more reddish than the Munabia Sandstone. The top of the Willaraddie Formation is placed at the bottom of the lowermost bed of limestone of the Moogooree Limestone.

The pebbly greywacke beds of the formation - the dominant lithological type - consist of rounded to subangular pebbles of black chert, light grey chert, milky quartz, quartzite, and jasper, up to 10 cm. in intermediate diameter and mainly ovoid in shape, in a poorly sorted arenite consisting of subangular milky and clear quartz, quartzite, quartz schist, chert, muscovite, and phyllite with interstitial clay but little or no felspar and few heavy minerals (leucoxene and blue tourmaline). The sandstone beds of the formation are mainly 'cleaned-up' greywacke. They consist of poorly sorted angular grains of quartz (50 to 70%) and felspar (5 to 10%), coarse muscovite flakes, and numerous angular fragments of quartzite, chert and phyllite, and little mica schist, with a matrix, amounting to about 15%, consisting of clay and sericite.

The siltstone beds of the formation are 'greywacke siltstone' consisting of angular quartz, mica, little felspar of silt size, with clay and a relatively large proportion (up to about 40%) of sand-size angular grains of quartz and mica and a little chert, quartzite, mica schist, and blue tourmaline.

As the full thickness of the formation is exposed over such a small area nothing is known about the regional convergence of the formation although in the belt east of Williambury there is apparently a very slight thickening northward. For the same reason, the regional variations in lithology are not known.

The only fossils found in this formation are poorly preserved bryozoa and Athyrid brachiopods. These do not help in the determination of the age of the formation which, because of its conformable position immediately beneath the Lower Carboniferous Moogooree Limestone and above the Munabia Sandstone and the Frasnian Gneudna Formation, is referred tentatively to the uppermost Devonian (Famennian Stage).

The lithology suggests very rapid accumulation of sediment of very mixed grain-size probably deriving from an elevated terrain of sedimentary rocks. It suggests that at this time Pre-Cambrian sediments including conglomerates still covered the source area (probably to the east). The sediments are mainly second-cycle greywackes from which most of the felspar has been removed, possibly by disintegration within the Pre-Cambrian sediments before erosion. This formation and the Williambury Formation were deposited during periods of relatively great instability when the source areas were elevated and the areas of deposition were sinking rapidly and accumulating sediment which was not worked by wave action. It is probable that this formation thins appreciably towards the basin (westward).

Moogooree Limestone

The Moogooree Limestone, named by Teichert (1949b), is defined as the formation, consisting almost entirely of crystalline limestone with beds containing Lower Carboniferous marine fossils, conformable between the Willaraddie Formation below and the Williambury Formation above.

It outcrops in a belt about 2000 feet wide from four miles north-north-east of Williambury Homestead to eight miles south-south-east of Moogooree Homestead, in a meridional belt about eight miles long two miles west of Williambury Homestead, and in scattered outcrops in the sand plain seven miles west of Williambury Homestead.

The name (pronounced moog'$\overline{\text{oo}}$-ree, first oo short) is taken from Moogooree Homestead and Station. The formation crops out in a ridge to the east of the creek which flows north past Moogooree Homestead.

The type section of the Moogooree Limestone is in Gneudna Paddock, Williambury Station, $3\frac{1}{2}$ miles south-east of Williambury Homestead and $2\frac{1}{2}$ miles north-west of Gneudna Well, at Lat. $23^{\circ}53\frac{1}{2}$'S., Long. $115^{\circ}11$'E. The type section, measured by G.A. Thomas, consists in descending order of:

	Friable light greyish-green calcareous siltstone and thin hard silty limestone beds of the WILLIAMBURY FORMATION conformably overlying
235 feet of	hard thick-bedded, grey to yellow-brown, fine-grained crystalline limestone (Sample TP/44);
1 foot of	hard light grey coquinoid fine-grained crystalline limestone, the fossils silicified (Sample TP/45); fossils include *Fenestella*, *Camarotoechia*, *Linoproductus*, *Krotovia*, *Spirifer* and *Tylothyris*;
114 feet of	hard thick-bedded light grey fine crystalline limestone;
60 feet of	hard thick-bedded light grey fine crystalline limestone with scattered poorly-preserved fossils;
1 foot of	hard light grey fine-grained crystalline limestone with many crinoid stem ossicles (Sample TP/43);
59 feet of	hard thick-bedded light grey fine-grained crystalline limestone;
1 foot of	hard light grey coquinoid limestone with silicified fossils including *Syringothyris*, *Rhipidomella* and athyrids;
25 feet of	thick-bedded hard light grey fine-grained crystalline limestone;
4 feet of	hard light grey coquinoid limestone with silicified fossils including *Pleurodictyum*, *Syringopora*, *Syringothyris*, *Rhipidomella*, *Spirifer*, *Tylothyris*, *Streptorhynchus*, *Camarotoechia*, and *Athyris* (Samples TP/38, 42, 216-A);

50 feet of	hard thick-bedded light grey fine-grained crystalline limestone;
400 feet of	hard bedded (6"), light grey to brownish yellow, fine-grained crystalline limestone possibly with clastic sediments intercalated - outcrop generally poor (Sample TP/37);
20 feet of	hard thin-bedded laminated yellowish sandy or silty fine-grained crystalline limestone, friable calcareous siltstone, and friable silty sandstone; conformably overlying friable white silty quartz sandstone of the WILLARADDIE FORMATION.
970 feet -	type thickness of MOOGOOREE LIMESTONE.

The Moogooree Limestone has two members - the lower consisting of thin-bedded limestone possibly with clastic intercalations, the upper of thick-bedded limestone with few beds containing silicified fossils and much nodular chalcedony. Its base is placed at the bottom of the lowermost thin hard limestone bed conformably above the Willaraddie Formation and its top is placed at the top of the thick-bedded massive limestone. There is a gradational sequence at each boundary and the base and top are defined where they can be recognized in the field even in relatively poor outcrop areas.

The lower member of the Moogooree Limestone outcrops as a series of low parallel ridges of limestone in a belt of reduced flat topography. It shows in aerial photographs as closely-spaced parallel dark lines, similar to the appearance of the Gneudna Formation. The upper member outcrops as a low rounded ridge with sparse low scrub vegetation. It appears in aerial photographs as a nearly uniform dark colour with very little sign of bedding.

Because of its poor outcrop, little is known of the details of the lithology of the lower member, but the thin limestones of the base are either sandy or silty. The upper member is the only thick lithological unit in the Palaeozoic sediments of the Carnarvon Basin which consists predominantly of limestone. Generally the limestone is finely crystalline (crystal grains less than 1 mm. in diameter). There is a relatively large amount of chalcedonic silica, as nodules and replacing the shell material of the fossils, scattered through the limestone of this member. There has been a suggestion that this limestone may be dolomitic (Teichert, 1949), but its complete and rapid solution in cold acid (except for chalcedonic silica residues), its specific gravity (near 2.65) and its appearance on weathered surfaces confirm that it is not dolomitic but siliceous. The bedding is thick and massive; beds are from six inches to about two feet thick and the bedding planes are generally undulatory. Some of the beds have the appearance of having been coquinoid or calcarenites but the main part of this member is probably a precipitated limestone deposited on a shelf, as indicated by the undulatory bedding (Rich, 1951). This shelf limestone with very little clastic material, lying as it does conformably between two formations of coarse clastics, introduces a problem in plaeogeography. The lithology and sedimentary structures of the upper member of the Moogooree Limestone require a stable shelf environment of deposition and an extremely reduced or extremely distant hinterland, whereas the formations below and above require a very unstable shelf area of deposition and a strongly positive area of erosion. The probability is that after the initiation of deposition in the Devonian a cyclical epeirogenic movement began, resulting in alternating conditions of relative stability and instability. The climax of this movement occurred during the early Permian glaciation, and from then on the scale of the movement decreased.

The thickness of the Moogooree Limestone increases from 940 feet immediately east of Moogooree Homestead to 1180 feet 3 miles north-east of Williambury Homestead, a divergence of 15 feet per mile northward. Four miles north-west of Williambury the thickness is about 1000 feet; but as this figure is very doubtful because of the unreliability of dip readings in this area it cannot be used to indicate regional convergence.

No fossils have been found in the lower member of the Moogooree Limestone but the poor outcrop may account for this. In the upper member, there are only four known fossiliferous beds. The two lower fossiliferous beds, 470 and 500 feet respectively above the base of the type section of the formation, have similar faunas which are rich in numbers of specimens but relatively poor in number of species. The main genera, identified by C. Teichert (personal communication), are Pleurodictyum, Syringopora, Syringothyris, Rhipidomella, Spirifer, Tylothyris, Streptorhynchus, Camarotoechia, and Athyris. The bed at 560 feet above the base contains only crinoid stem ossicles. The top fossiliferous bed, at 735 feet above the base, contains Fenestella, Camarotoechia, Linoproductus, Krotovia, Spirifer and Tylothyris. Athyris ranges from Middle Devonian to Lower Carboniferous, Spirifer from Lower to Upper Carboniferous, Syringothyris from Upper Devonian to Permian and Camarotoechia from Silurian to Lower Carboniferous. The overlap of these generic ranges indicates that the Moogooree Limestone may be referred to the Lower Carboniferous with some certainty. It probably may be correlated with the Burindi Limestone of New South Wales, which contains Syringothyris, Athyris and Rhipidomella (Benson, 1921).

Williambury Formation

The Williambury Formation, named "Williambury Sandstone" by Teichert (1949b), is defined as the formation, consisting of pebbly greywacke, siltstones and conglomerate, conformable between the Moogooree Limestone below and the Yindagindy Formation above. As the sequence contains beds of several lithologies the term 'Formation' is preferred to a lithological term.

The Williambury Formation outcrops in a belt about ½ mile wide extending from 3½ miles north-north-east of Williambury Homestead to 5 miles south-east of Williambury Homestead; and in a belt about 1000 feet wide from 2½ miles west to 6 miles north-west of Williambury Homestead.

The name is taken from Williambury Station, which is 120 miles north-eastward from Carnarvon. The formation outcrops mainly on Williambury Station.

The type section of the Williambury Formation is in Gneudna Paddock, 2¼ miles south-eastward from Williambury Homestead, at Lat. $23^{\circ}52\frac{1}{2}$'S., Long. $115^{\circ}10\frac{3}{4}$'E. The type section, measured along the north side of a small mesa, consists in descending order of:

	Basal hard limestone of the YINDAGINDY FORMATION conformably overlying
85 feet of	friable fine-grained to medium-grained quartz-chert greywacke, poorly exposed (Sample TP/312);
37 feet of	friable grey medium-grained greywacke with pebble beds;
108 feet of	friable grey medium-grained to coarse-grained quartz-chert greywacke in beds to 5 feet thick and friable pebbly greywacke in beds to 3 feet thick (Sample TP/138A);
115 feet of	friable grey medium-grained to coarse-grained greywacke and thin soft dark red-brown siltstone, few pebble beds (Sample TP/137A);
30 feet of	friable greywacke, pebbly greywacke, and pebble conglomerate showing large scale cross-bedding;
15 feet of	soft dark-brown siltstone;
55 feet of	friable medium-grained greywacke and thin beds of pebble conglomerate; few thin beds of siltstone;
40 feet of	friable pebble conglomerate with small cobbles of dark chert and quartz and thin beds of medium-grained greywacke;
25 feet of	medium-hard pebble conglomerate; thin beds of greywacke;
50 feet of	firm dark red-brown siltstone, possibly calcareous;
23 feet of	pebbly greywacke and pebble conglomerate;
15 feet of	medium-hard red-brown calcareous siltstone;
27 feet of	pebbly greywacke and pebble conglomerate;
25 feet of	medium-hard red-brown sandy calcareous siltstone;
15 feet of	friable greywacke and red-brown calcareous siltstone (Sample TP/138);
15 feet of	medium-hard red-brown sandy calcareous siltstone;
60 feet of	friable to medium-hard grey medium-grained to coarse-grained greywacke with few beds to 7 feet thick of pebble conglomerate and few beds to 2 feet thick of red-brown siltstone (Sample TP/137);
25 feet of	friable grey laminated medium-grainedto fine-grained greywacke (TP/136);
44 feet of	friable grey pebbly medium-grained greywacke;
1 foot of	hard brown silty limestone;
10 feet of	friable grey pebbly greywacke;
140 feet of	thin-bedded friable grey medium-grained to coarse-grained greywacke with scattered pebbles of quartzite, black chert, and quartz (Samples TP/134,135);
20 feet of	friable medium-grained to coarse-grained greywacke and pebble conglomerate;
100 feet of	friable light grey-green calcareous siltstone with thin beds of silty limestone (G/226);
	conformably overlying bedded hard light grey fine-grained crystalline limestone (MOOGOOREE LIMESTONE).
1080 feet -	type thickness of Williambury Formation.

The base of the Williambury Formation is placed at the top of the bedded hard limestone of the Moogooree Limestone; its top is placed at the base of the lowermost thin hard sandy limestone of the Yindagindy Formation.

The outstanding lithological characteristic of the

Williambury Formation is the large proportion of black chert which is present in the greywacke and conglomerate of the formation. The greywacke and the arenaceous matrix of the conglomerate consist of from 30 to 60% angular quartz grains, 20 to 40% angular to rounded gragments of black chert, up to 10% angular to sub-round fragments of quartzite and 20 to 30% fine matrix consisting of clay and fine quartz. Sorting is poor and porosity low. The pebbles of the conglomerate and pebbly greywacke are mainly black chert and white quartz with few quartzite and phyllite pebbles. The pebbles are rounded to sub-round and mainly ovoid with few sub-spherical. The siltstone is mainly bedded but not laminated, coarse-grained (0.02 to 0.06 mm.), and probably generally somewhat calcareous. Some at least of the siltstone beds are bottom-set beds related genetically to the pebbly foreset beds.

Because of the small area of outcrop of the formation, little can be discovered of the regional convergence of the Williambury Formation. It shows appreciable thickening northward along the strike, from 1080 feet at the type section to about 1200 feet 3 miles to the north. The thickness 4½ miles north-west of the Williambury Homestead is only about 600 feet. This indication of rapid thinning westward is perhaps an indication that in the area of outcrop the formation is near the seaward edge of a deltaic deposit and that father west the formation as such changes to a different facies, perhaps more like the siltstone beds of the type section.

No fossils have been found in the formation: their absence is perhaps related to the deltaic environment of deposition of the formation.

Its conformable position above the Lower Carboniferous Moogooree Limestone is the only evidence for the age of the formation, which is referred tentatively to the Middle Carboniferous (Moscovian).

The Williambury Formation is a deltaic deposit the detrital material of which almost certainly was derived from pre-existing (probably Proterozoic) conglomeratic sediments. In this it is similar to the Willaraddie Formation. The difference in the mineralogy of the detrital material is probably due to regional differences in the stratigraphical level to which erosion had proceeded.

The Williambury Formation outcrops only in the scarps of mesas the tops of which are protected by a cap of resistant laterite. Elsewhere the formation produces a pebble-strewn plain which appears moderately dark on aerial photographs with very little sign of bedding. Vegetation is generally sparse.

Yindagindy Formation

The Yindagindy Formation, informally named 'Yindagindy Limestone' by Teichert (1950), is defined as the formation, consisting of coarse to medium-grained greywacke with intercalated thin hard oolitic limestone beds, conformably overlying the Williambury Formation and disconformably underlying the Harris Sandstone. As the sequence contains beds of several lithologies, of which limestone is a minor type, the term 'Formation' is preferrred to 'Limestone' in the formation name.

The Yindagindy Formation outcrops in a narrow belt from 2½ miles west to 5½ miles north-west of Williambury Homestead, in a small area 2½ miles south-east of Williambury Homestead, and in several small fault blocks between 1½ and 6 miles north of Moogooree Homestead. Outcrop generally is very poor. The area of outcrop forms a plain with parallel impersistant low strike ridges of limestone; between the limestone beds the surface is strewn with pebbles of quartz and black chert. Vegetative cover is somewhat denser than on the Williambury Formation and is mainly acacia scrub. On aerial photographs, the tone of the Yindagindy outcrop area is slightly lighter than that of the Moogooree Limestone and darker than the Williambury; it is lighter than the outcrop areas of the Harris Sandstone but darker than the areas where the Harris is covered by sand.

The name (pronounced yi'n-da-gi'n-dē) is taken from Yindagindy Creek, the local name for the creek flowing south into the Minilya River 4 miles south-west of Williambury Homestead. The outcrop belt which includes the type section is in the eastern drainage area of this creek.

The type section of the Yindagindy Formation is immediately north of the Williambury to Middalya road, 2½ miles west of Williambury Homestead, at Lat 23 51'S., Long. 115 6½'E. The type section in descending order consists of:

	Friable white clean quartz sandstone of the HARRIS SANDSTONE
	DISCONFORMITY
12 feet of	medium-hard dark brown ferruginous sandstone and greywacke;
80 feet of	friable to medium-hard (calcareous) medium-grained quartz greywacke with coarse grains (to 4 mm.) of quartz and chert; thin beds of hard light-grey fine-grained oolitic limestone (Sample G/314 from near the base of this unit);
30 feet of	hard light-grey oolitic fine-grained limestone with fine quartz sand and fossils - brachiopods, crinoids, gastropods and ostracods (Samples G/286 near top, G/285 at base of this unit);
35 feet of	friable very coarse greywacke (Sample G/313) and fine-grained greywacke conglomerate (pebbles of quartz, black chert);
100 feet of	friable light-greenish-grey medium-grained greywacke (G/221) and thin beds of hard light-grey fine-grained limestone with fine to coarse sand and fossils - brachiopods, ostracods, small crinoid stem ossicles (Samples G/222, 223, 249);
	conformably overlying friable pebbly greywacke of the WILLIAMBURY FORMATION.
257 feet -	type thickness of the YINDAGINDY FORMATION

The base of the Yindagindy Formation is placed at the base of the lowermost hard sandy limestone bed, the top at the base of the clean quartz sandstone of the Harris Sandstone.

The greywacke of the Yindagindy Formation is similar to the greywacke of the Williambury Formation but there are several important distinctions - there is a lower proportion of pebbles and the pebbles are smaller but of the same types; there is more felspar and mica in the Yindagindy greywacke; the proportion of black chert is lower than in the Williambury greywacke; and, at least in the upper part of the formation, garnet is a noticeable minor constituent. The limestone beds are distinctive in that most of them are oolitic. They are of very fine crystal grain-size and break with a smooth fracture. The lower beds are sandy with rounded grains up to ½" of quartz, black chert, and quartzite. The fossils mainly do not weather out of the rock although some beds are packed with brachiopod valves.

Because of the limited outcrop no indication of regional convergence of the formation can be given. The thickness of the formation 2½ miles south-east of Williambury Homestead is about the same as in the type section.

Few of the fossils have been determined but it is known from field observations that the fauna includes crinoids, athyrid, rhynchonellid and spiriferid brachiopods, gastropods, nautiloids, and ostracods. The only genera identified to date are Composita, Camarotoehia, Bythocypris and Paraparchites.

None of the fossils so far identified is of diagnostic value for determining the precise age of the Yindagindy Formation. The specific identity of the Composita and of the crinoids may fix the age fairly closely. Tentatively, the age of the Yindagindy Formation is referred to the Upper Carboniferous mainly by reason of its position relative to the Lower Carboniferous Moogooree Limestone.

The reduction in the average grain-size of the greywacke probably indicates a reduction in the elevation of the source area and the intercalation of fossiliferous limestone beds possibly indicates increasing stability in the area of deposition. The strongly ferruginous top of the formation and the sharp change of lithology from the Yindagindy to the Harris probably indicates a disconformity, although, as this part of the sequence was seen well-exposed in only one place, there is some doubt as to the regional significance of this disconformity. Although it is realised that it is not necessary that a disconformity or other regional discontinuity mark the boundary of a system, it is proposed that because the transgressive Harris Sandstone marks the beginning of a new cycle of deposition during which deposition was very much faster than before, the system boundary between the Carboniferous and Permian be drawn at the base of the Harris Sandstone, at least in the area of outcrop.

PERMIAN:

The Permian System of the Carnarvon Basin comprises, in ascending order, Harris Sandstone (doubtfully Permian); Lyons Group (Sakmarian); Callytharra Formation, Cordalia Greywacke, Wooramel Sandstone, Coyrie Formation, Mallens Greywacke, Bulgadoo Shale, Cundlego Formation, Quinnanie Shale, Wandagee Formation, Norton Greywacke, Baker Formation, and Coolkilya Greywacke (Artinskian); and the Mungadan Sandstone and Binthalya Sub-group (possibly Kingurian).

Harris Sandstone

The Harris Sandstone is defined as the clean quartz sandstone formation resting probably disconformably on the Yindagindy Formation and conformably underlying the Lyons Group. It usually contains some Lepidodendroid plant fossils. For the sandstone containing plant fossils occurring in small fault blocks near Moogooree Homestead Teichert (1950) informally proposed the name 'Red Hill Sandstone'. These sandstones are now known to belong in the formation between the Yindagindy Formation and the Lyons Group, but the name Harris Sandstone is proposed for the following reasons: the type section where the relationships with the Yindagindy Formation and the Lyons Group were established is close to Harris Well and Harris Well penetrates Harris Sandstone; 'Red Hill' is a poor geographical name; the sandstone in fault blocks is exposed in Red Hill paddock, Moogooree Station, but Red Hill Well is sunk in Munabia Sandstone and Red Hill is in the Pre-Cambrian.

The Harris Sandstone outcrops in a narrow belt from 2½ miles west to $5\frac{1}{2}$ miles north-west of Williambury Homestead and in fault blocks from about six miles north to about $2\frac{1}{2}$ miles south of Moogooree Homestead. The Harris Sandstone generally stands up as a strike ridge or, in small fault blocks, as relatively resistant hills. On aerial photographs, the formation outcrop shows a very dark tone in areas of rock outcrop, but a very light tone where there is a sand cover over it. The resistance of the formation to erosion is caused by surface silicification.

The name is taken from Harris Well, Williambury Station, four miles west of Williambury Homestead on the Williambury to Middalya road.

The type section of the Harris Sandstone is $3\frac{1}{2}$ miles north of the Williambury to Middalya road, 5 miles north-west of Williambury Homestead, at Lat. $23^{\circ}48\frac{1}{4}$'S., Long. $115^{\circ}5\frac{3}{4}$'E. There the sequence in descending order is as follows:

	Friable light brown quartz greywacke with pebbles and few cobbles, at the base of the LYONS GROUP, conformably overlying
80 feet of	friable light-brown medium-grained quartz sandstone with pebbles to 3" of quartz and quartzite;
47 feet of	friable white medium-grained to coarse-grained clean quartz sandstone with hard red-brown silicified skin;
13 feet of	soft yellow-brown calcareous siltstone;
90 feet of	friable white medium to coarse clean quartz sandstone, thin-bedded, cross-bedded (Sample MG/166);
50 feet of	friable white medium-grained to coarse-grained clean quartz sandstone with chert lenses to 1'6" thick and lepidodendroid plant fossils (Sample G/225); disconformably over hard dark-brown ferruginous greywacke at the top of YINDAGINDY FORMATION.
280 feet -	type thickness of HARRIS SANDSTONE.

The base of the Harris Sandstone is placed at the bottom of the clean quartz sandstone above the ferruginous top of the Yindagindy Formation; the top is placed at the change in lithology from quartz sandstone to quartz greywacke. This boundary is reasonably sharp but can be distinguished only where outcrop is very good; however it is 90 feet below the lowermost boulder bed of the Lyons Group which forms a useful marker for mapping.

The Harris Sandstone consists predominantly of clean quartz sandstone, mainly in thin beds up to 3" thick or in cross-bedded beds up to one foot thick. The sandstone varies in grain-size from bed to bed but within each bed the sorting is good to very good, and the grains are round to sub-round and mainly sub-spherical. The sandstone consists predominantly of grains of quartz generally round to sub-round but in many cases with quartz overgrowths developing crystal form. Minor constituents, which individually or together rarely exceed 5% of the rock, include chert (black and grey), fine-grained quartzite, muscovite, felspar, and blue or brown tourmaline. In some specimens the quartz grains are covered by iron oxide films produced by weathering. The porosity is high (probably near 20%) and although it is generally out of easy reach of the surface the formation is the best aquifer in the basin. Pebbles are generally concentrated in beds, although there are a few scattered through the sandstone. The pebbles are mainly quartz with some chert and quartzite; they are generally well-rounded and ovoid to spherical.

Very little information is available on the thickness of the formation. Apart from the type section the only place where a thickness could be measured is $1\frac{1}{4}$ mile north of Moogooree Homestead where the thickness is about 300 feet.

The only fossils found to date are cortical impressions of lepidodendroid stems which have not been examined critically. These fossils are much more plentiful in the fault blocks near Moogooree Homestead than in the type locality, where only poorly preserved fragments and one trunk have been found. This may indicate an approach to the shoreline in the Moogooree area.

The lithology of the Harris Sandstone indicates that it was deposited under stable conditions with a very feeble supply of detrital material and adequate working by wave and current action. The formation is probably transgressive but the rate of transgression must have been very slow. Although nothing precise can be known about the position of the shoreline the relative abundance of the fossil plant material in the Moogooree area as compared with the Harris Well area may indicate that the shoreline was only a short distance to the east of Moogooree.

Lyons Group

The term 'Lyons Group' was used by Teichert (1950) in place of Raggatt's (1936) 'Lyons Series' to conform to the Australian Code of Stratigraphical Nomenclature. In terms of Raggatt's definition the Lyons Group "includes all the Permo-Carboniferous beds below the base of the Callytharra (Stage). The (Series) consists of more than 2000 feet of strata, most of which show evidence of having been deposited under glacial conditions. The basal beds of the Lyons (Series) rest with marked angular unconformity upon (Pre-Cambrian) basement". Even if the term 'Permian' is substituted for 'Permo-Carboniferous' (Raggatt and Fletcher, 1937) this definition has been shown to be in need of revision: the Harris Sandstone is part of the same sedimentary cycle as the Lyons Group and is therefore referred tentatively to the Permian but, as it is different lithologically and genetically from any part of the sequence between it and the Callytharra Formation, it should not be included in the Lyons Group; the group has a maximum measured thickness of 4600 feet; and it is conformable on the Harris Sandstone and unconformable on the Pre-Cambrian only in the Arthur River Woolshed Area.

Therefore, the LYONS GROUP is redefined as the sequence of formations, related genetically to glaciation and consisting of tillite, greywacke, siltstone and quartz greywacke with thin calcareous beds containing marine fossils, conformable above the Harris Sandstone and beneath the Callytharra Formation. The only place where this complete relationship is exposed is in the area in the north western part of Williambury Station and the north-eastern part of Middalya Station.

The Lyons Group outcrops, in a broad belt averaging about five miles wide, from north of the Lyndon River (12 miles south-east of Winning Pool) to the Gascoyne River 33 miles east of Gascoyne Junction. Between Mt. Sandiman and Wyndham River there is duplication of the outcrop belt by faulting. The best exposed outcrops are northeast of K-52, along the Lyndon River and its tributary Kialiwibri Creek, and along the Arthur and Wyndham Rivers. The outcrop areas of the Lyons Group almost invariably form areas of reduced topography with a few small flat-topped hills. The wide, nearly flat, plain is strewn with pebbles and boulders and supports a very sparse scrub vegetation. In all but a few places the drainage over its surface is of the sheet-flow type. In aerial photographs the outcrop area of the Lyons shows a very light to moderately dark tone with some sign of bedding and some indication of the formations in the differences in tone. Black patches indicate swamps which are common in the siltstone formations. Although the formations comprised in the group are readily separated in a well-exposed section they are not easily followed on the aerial photographs and therefore have not been mapped or named separately.

The name, first used by Maitland (1909), is taken from the Lyons River, main northern tributary of the Gascoyne River.

The only place where the full section is exposed is in the area east and west of the Vermin-Proof fence north of the Williambury to Middalya road and therefore this is proposed as the amended type section of the Lyons Group. The base, including the contact with the Harris Sandstone, is exposed only in the area north-east of Harris Well. The main part of the section, from the Callytharra Formation downwards, extends from Lat. 23°49'S., Long. 114°57'E. (4 miles north-north-east of K-52) to Lat. 23°46¼'S., Long. 114°58¾'E. (8 miles north-north-east of K-52). The lowermost part of the section is five miles north-west of Williambury Homestead, at Lat. 23°49½'S., Long. 115°05¼'E. The two sections overlap by 1400 feet and within that thickness there is very good correlation of boulder beds and of other lithology where it is exposed in both sections. The upper part of the lower section is faulted off and the basal part of the upper section is covered by thick sand.

The type section of the Lyons Group, in descending order, consists of:

Friable grey fossiliferous calcarenaceous fine-grained quartz greywacke at the base of the CALLYTHARRA FORMATION, conformably overlying

30 feet of friable fine-grained greywacke with few pebbles and cobbles (Sample MG/137);
5 feet of medium-hard greenish grey greywacke with cobbles and boulders of granite, limestone, gneiss, quartzite, and hornfels; thin bed of hard grey calcareous pebbly greywacke with bryozoa and brachiopods (Sample MG/136);
5 feet of firm grey siltstone (Sample MG/135);

FORMATION BOUNDARY

40 feet of thin-bedded to laminated fine-grained quartz greywacke with thin hard calcareous beds;
10 feet of soft light-grey siltstone with well-rounded pebbles;
20 feet of friable grey quartz greywacke with few thin beds of hard calcareous quartz greywacke (Sample MG/124);
10 feet of firm grey shale (? varve);
25 feet of friable grey quartz greywacke and hard grey calcareous quartz greywacke; few cobbles of granite, gneiss, and laminated limestone at the top;
10 feet of firm grey shale (? varve); (Sample MG/134);
40 feet of thin-bedded light grey siltstone with pebbles, cobbles and boulders and thin beds of quartz greywacke;
10 feet of friable pebbly quartz greywacke;

FORMATION BOUNDARY

105 feet of friable and medium-hard, grey to brown, medium-grained to fine-grained quartz greywacke with thin beds of coarse-grained quartz greywacke and of siltstone; few pebbles of quartz and quartzite (Sample MG/122,123);
70 feet of soft greenish-grey coarse-grained and medium-grained siltstone with beds of fine-grained quartz greywacke (Sample MG/121) and few thin beds of fossiliferous limestone containing bryozoa, small crinoid stem ossicles, and brachiopods (Sample MG/161);
65 feet of friable greenish-grey medium-grained to fine-grained quartz greywacke with hard calcareous beds and thin-bedded soft grey siltstone; strongly contorted in places;
105 feet of soft greenish grey coarse-grained to medium-grained sandy siltstone with few thin beds of fossiliferous (MG/160) and cone-in-cone limestone; fossils include bryozoa, small brachiopods, and crinoids;

FORMATION BOUNDARY

5 feet of hard grey calcareous pebbly greywacke with few boulders;
40 feet of friable to medium-hard light-brown medium-grained sparkling quartz greywacke;

30 feet of friable sandy siltstone with pebbles cobbles and boulders of granite, quartzite, and quartz;
40 feet of medium-hard to friable brown quartz greywacke and soft light greenish-grey siltstone;
40 feet of friable greenish-grey siltstone with few small pebbles of quartzite, quartz, and chert;
5 feet of hard grey calcareous greywacke with few granite boulders;
95 feet of friable greenish-grey siltstone with small pebbles of quartzite, quartz, and chert, and one hard calcareous greywacke bed with few fossils;
5 feet of hard grey calcareous pebbly greywacke with few cobbles and boulders of granite, quartzite, limestone, and slate, and fossils including bryozoa, pectenids, gastropods and brachiopods (Sample MG/159);
85 feet of soft greenish-grey siltstone with few small pebbles and few thin beds of calcareous greywacke;
10 feet of friable and hard calcareous pebbly greywacke with few cobbles of granite and quartzite and fossils including bryozoa, pectinids and corals (Sample MG/157,158);
50 feet of soft greenish-grey siltstone with quartz grains and pebbles;
5 feet of hard grey calcareous pebbly greywacke with pectenids;
75 feet of friable light greenish-grey sandy siltstone, friable grey greywacke and thin hard calcareous greywacke;
5 feet of medium-hard pebbly greywacke with few cobbles and very few boulders;
15 feet of firm greenish-grey sandy siltstone with few small pebbles;
10 feet of friable greenish-grey sandy siltstone with pebbles and few cobbles;
15 feet of friable greenish-grey sandy siltstone with very few pebbles;
5 feet of friable greenish-grey sandy siltstone with few pebbles and cobbles and very few boulders; the pebbles etc. are of quartzite, granite, schist, quartzitic conglomerate, banded limestone and chalcedony, and laminated ironstone;
100 feet of soft grey sandy siltstone with few pebbles, friable grey greywacke and hard calcareous pebbly greywacke; few cobbles at the base;

FORMATION BOUNDARY

30 feet of friable grey greywacke with few pebbles;
15 feet of friable sandy siltstone and friable greywacke with few small pebbles;
30 feet of friable greenish-grey greywacke with a 'boulder bed' containing pebbles, cobbles and few boulders of quartzite granite and limestone;
40 feet of friable greywacke without pebbles;
5 feet of medium-hard pebbly greywacke with boulders and cobbles of medium-grained granite, sandy limestone, dark quartzite, hornfels, biotite schist;
10 feet of friable grey greywacke;
10 feet of soft white siltstone;
50 feet of friable grey greywacke with small pebbles;
5 feet of medium-hard calcareous pebbly greywacke;
25 feet of friable greenish-grey sandy siltstone with few small pebbles;
5 feet of pebbly greywacke with pebbles and boulders;
15 feet of friable grey quartz greywacke;
5 feet of medium-hard to hard grey calcareous quartz greywacke with pebbles cobbles and few small boulders;

90 feet of friable grey greywacke with few small pebbles;
5 feet of pebbly quartz greywacke with few boulders of granite;
80 feet of friable medium-grained to coarse-grained greywacke with few pebbles;

FORMATION BOUNDARY

170 feet of friable dark greenish-grey sandy siltstone, dark shale and fraible grey quartz greywacke; few small pebbles;
5 feet of pebbly greywacke with cobbles and boulders;
65 feet of soft greenish-grey siltstone with few small pebbles;
10 feet of friable grey pebbly greywacke (Sample MG/131);
5 feet of medium-hard grey calcareous pebbly greywacke with cobbles and few boulders and marine fossils - bryozoa, pectinids (Sample MG/156);
55 feet of friable grey sandy siltstone with few small pebbles;
10 feet of friable grey greywacke with pebbles;
5 feet of pebbly fine-grained to coarse-grained greywacke with cobbles and few boulders (pebbles of quartzite, granite, reef quartz, and hornfels; cobbles of the same plus limestone, schist and banded hematite; boulders of medium and coarse-grained granite, pegmatite, and hornfels);
25 feet of friable grey siltstone with pebbles and sand;
15 feet of friable fine-grained to coarse-grained greywacke with boulders and cobbles of granite, dark quartzite, biotite schist, gneiss, slate, laminated ironstone, reef quartz, banded limestone with chalcedony, amphibolite;
40 feet of friable grey fine-grained to coarse-grained greywacke pebbly at bottom;
15 feet of friable grey fine-grained to coarse-grained greywacke with boulders, cobbles, and pebbles, and some thin hard calcareous greywacke beds;
10 feet of friable greenish-grey sandy siltstone with few small pebbles and few thin hard calcareous beds (Sample MG/155);
40 feet of thin-bedded friable grey greywacke with lenses of hard grey calcareous greywacke, few pebbles;
30 feet of friable greenish-grey sandy siltstone with few pebbles;

FORMATION BOUNDARY

20 feet of friable grey greywacke with pebbles of quartzite and quartz;
10 feet of friable grey pebbly greywacke with few boulders of granite and quartzite;
175 feet of friable grey quartz greywacke with small pebbles of quartz and quartzite in the upper part;
40 feet of soft yellow-brown siltstone (? varve); (Sample MG/154);
40 feet of friable grey pebbly greywacke with few boulders;
35 feet of friable greenish-grey sandy siltstone;
35 feet of friable light grey laminated quartz greywacke, severely contorted;
40 feet of friable grey greywacke medium-grained to fine-grained with lenticular thin beds of hard calcareous quartz greywacke;
80 feet of friable grey greywacke with small pebbles of quartz, quartzite and chert;
130 feet of friable greenish-grey fine-grained greywacke with no pebbles;
40 feet of friable grey greywacke with few small pebbles of quartz;
75 feet of no outcrop;
35 feet of friable grey medium-grained quartz greywacke (Sample MG/153);
30 feet of soft grey fine-grained siltstone (? varve);

20 feet of friable pale brown quartz greywacke;
70 feet of friable greenish-grey greywacke with scattered boulders and cobbles;
40 feet of friable grey greywacke and dark greenish grey sandy siltstone;
30 feet of friable grey greywacke;
20 feet of friable grey pebbly greywacke with cobbles and boulders of quartzite, quartz, pegmatite, mica schist, granite, limestone, calcareous slate;
60 feet of friable grey greywacke with few pebbles of quartz and quartzite;
10 feet of friable grey pebbly quartzite with cobbles and boulders of biotite schist, dark quartzite, granite, limestone, reef quartz, laminated chert;
80 feet of friable greenish-grey greywacke with few pebbles of quartz and quartzite;
5 feet of friable grey greywacke with cobbles, pebbles, and few boulders;
145 feet of friable greenish-grey greywacke with few pebbles of quartzite and quartz;
10 feet of friable grey greywacke with pebbles and boulders of granite, dark quartzite, hematite, slate;
45 feet of friable grey greywacke with pebbles of quartzite and quartz;

FORMATION BOUNDARY

25 feet of friable greenish-grey sandy siltstone with few pebbles;
60 feet of friable grey greywacke with few pebbles;
5 feet of friable grey greywacke with boulders;
25 feet of friable grey greywacke;
5 feet of friable grey greywacke with boulders of granite and quartzite and cobbles and pebbles of quartzite, granite and quartz;
15 feet of friable grey greywacke;
40 feet of friable greenish-grey sandy siltstone with small pebbles of quartzite, granite, and quartz;
30 feet of friable greenish-grey greywacke with boulders of quartzite and granite and pebbles of quartzite, granite, and quartz (Sample MG/152);
25 feet of soft greenish-grey sandy siltstone with small pebbles of quartz and quartzite (Sample MG/151);
45 feet of friable greenish-grey fine-grained to medium-grained quartz greywacke with small pebbles of quartz and quartzite.

This is the bottom of the exposed section in the north-western locality. The lower part of the south-eastern section continues from this horizon as follows:

100 feet of poorly exposed sandy siltstone with small pebbles of quartz and quartzite;
100 feet of poorly exposed quartz greywacke and pebbly quartz greywacke;
100 feet of poorly exposed sandy siltstone with small pebbles of quartz and quartzite;

FORMATION BOUNDARY

490 feet of no outcrop; sandy soil with pebbles of quartzite, quartz and granite;
20 feet of friable light-brown greywacke with pebbles, cobbles, and boulders of quartzite, granite, limestone, hematite and quartz; (this 'boulder bed' also outcrops through the sand in similar stratigraphical position to the east of the main section);

90 feet of friable light-brown quartz greywacke with pebbles and few cobbles of quartzite, quartz, and granite; conformably overlies friable light-brown quartz sandstone with pebbles of quartzite and quartz (HARRIS SANDSTONE).

4600 feet - type thickness of LYONS GROUP.

The base of the Lyons Group is placed at the change in lithology from clean quartz sandstone to silty quartz greywacke, about 90 feet below the lowermost 'boulder bed'. The top of the group is placed at the change in lithology from unfossiliferous silty quartz greywacke to fossiliferous calcarenaceous quartz greywacke about 30 feet above the uppermost boulder bed and about 10 to 30 feet below the lowermost hard limestone bed of the Callytharra Formation.

There are eight easily separated formations in the Lyons Group, the boundaries of which are indicated in the above section. In terms of genesis there are five marine tillites and four sequences representing the inter-glacial stages if the tillites represent the glacial stages of the Lower Permian ice age.

In such a big thickness containing so many rock types description of only the main types can be given. The most characteristic lithology of the Lyons Group is the tillite of which there are two main types - one with a siltstone matrix the other with a greywacke (arenaceous) matrix. The siltstone is poorly sorted and almost invariably contains an appreciable proportion of larger grains. The colour of fresh material is dark greenish-grey and the fresh rock is moderately indurated. The siltstone consists of angular grains of quartz, chert, felspar in a fine-grained rock-flour of the same minerals. There is generally very little of the clay minerals except a little sericite which may be authigenic. Mica, both muscovite and biotite, is fairly common and tourmaline and garnet are common accessory minerals. The larger grains consist of angular to subangular sand grains of quartz, quartzite and chert and small pebbles of quartzite, chert and quartz. The silty boulder beds have the same matrix but contain also pebbles, cobbles and boulders of very diverse lithology - in approximate order of abundance quartzite (dark and light types of a wide range in grain size) granitic rocks (ranging from medium-grained to very coarse-grained) chert (black, grey, laminated and jasper), limestone (laminated, sandy, and interlaminated with chalcedony), gneiss of various types, schist of several types (mica, quartz and talc schists), ironstone (laminated and massive hematite) and amphibolite. Generally very few of these larger fragments show direct evidence of glaciation but a small proportion show facetting and striation with chatter marks. These larger fragments usually have produced impact distortion of the underlying siltstone in the few places where vertical sections of a silty boulder bed are available. This is regarded as evidence that the whole sequence was deposited under water although there are large parts of the sequence which are not known to contain marine fossils.

The greywacke tillites are distinguished from the silty tillites mainly by the grain-size of the matrix. In the greywackes the larger part of the rock is of sand size (between 0.06 and 4.0 mm.) but as in the siltstone the sorting is very poor and in some specimens there are significant proportions of size grades ranging from 256 down to 0.01 mm. The mineralogy of the greywackes is similar to that of the siltstones but there is generally less felspar, and more mica and quartzite grains. As in the siltstone the smaller fragments are angular but the larger fragments are round to subangular.

Commonly, with the boulder beds there are thin beds of hard calcareous siltstone or greywacke. These are similar in the constitution of the fragmental portion of the rock to the non-calcareous types with which they are associated but contain up to about 40% of calcite which in many cases is recrystallized into large crystals enclosing the detrital grains and giving to the rock in hand specimen the schiller of 'Fontainebleu structure'. Most of the fossils are contained in beds of this type.

There are two main rock types in the non-tillitic parts of the sequence - quartz greywacke and finely-laminated siltstone or shale. The quartz greywacke is better sorted than the tillitic greywacke but covers a fairly wide range of grain-size and in many cases is noticeably composed of a sand-size main fraction and an appreciable fraction of much finer grain, generally within the fine silt or clay range. There is a variation in the mineralogy of this type which ranges from a kaolinitic sandstone, through felspathic sandstone and quartz greywacke to greywacke. The kaolinitic sandstones consist of angular to subround quartz with interstitial white kaolin (20 to 40% of the rock) and fresh felspar (up to about 10%) with minor amounts of muscovite, tourmaline and garnet. The felspathic sandstones are similar but contain more felspar (10 to 20%) and less kaolin matrix (15 to 20%). The quartz greywacke consists of angular to sub-rounded quartz (50% to about 70%), fresh felspar (up to 10%), chert, quartzite, slate, and phyllite fragments, (10% to about 30%) muscovite and little biotite (1% to 3%) and clayey matrix which is generally white in weathered rock but consists mainly of a fine rock flour containing only minor amounts of kaolin (15% to about 30%) and minor accessory heavy minerals (garnet, tourmaline, staurolite, zircon, epidote). The greywackes are in minor proportion in this suite but are generally similar to the tillitic greywackes except that sorting is somewhat better and the grain-size distribution more commonly bi-modal. Some of these rock types have a fairly high porosity (up to about 15%) and form good aquifers. The non-tillitic siltstones are generally not well exposed. They are soft, well-laminated, fine-grained siltstones and shales which weather readily. In the few small outcrops where they are well exposed it is probable that they are varves as the lamination is very even (although of different thickness in different outcrops) and the grainsize is graded from coarser to finer in each lamination. Within members of this type thin beds of hard fine-grained limestone, in some cases with fossils, are not uncommon.

As the full thickness of the Lyons Group is exposed only in the above type section locality, details of variation in thickness for the full group cannot be given except to mention that west of Moogooree Homestead, where close to the full section is probably present in outcrop, the thickness, using very few observed dips and an outcrop width scaled off aerial photographs, is about 4150 feet.

The thickness of the upper part of the group from the base of the Callytharra Formation to the base of the main tillite formation is 2100 feet in the type section. This part of the section is exposed in most parts of the outcrop belt but in many places measurements cannot be made because of strike faulting. Sections of this part of the group, probably without significant faulting, have thicknesses of about 1700 feet 9 to 13 miles east of Lyons River Homestead and 2600 feet 17 to 20 miles east of Mia Mia Homestead. Although these thicknesses are not reliable enough for computation of convergence, they do indicate a thickening northward.

Fossils have been found only in calcareous beds in the tillite formations and in limestone beds in the other formations. Marine fossils including foraminifera, bryozoa, brachiopods, pectenids, gastropods, crinoids including <u>Calceolispongia</u>, and few solitary corals have been found mainly in the upper part of the group (above the base of the main tillite formation). A fossiliferous bed about 2 miles north of Moogooree Homestead is probably very low in the group and a calcareous pebbly greywacke bed about one mile south-west of K-34 containing bryozoa, large <u>Neospirifer</u>, productids, and corals probably belongs in the tillite which, in the type section, is 1000 to 1600 feet above the base. No ammonoids or fusulines have been found in this group.

The only fossils so far found which are of some value for determining the age of the Lyons Group are the Neospirifer and the gastropod cf. Keenia. Neospirifer has a range from Upper Carboniferous to Permian in North America, Australia, and India. Keenia is reported from the 'Upper Marine' of Eastern Australia. The main evidence for the age determination is by correlation with the Nangetty Formation of the Irwin Basin which underlies the Holmwood Shale containing Metalegoceras jacksoni which Teichert (1941, p.404) believed to be of Sakmarian age.

The Lyons Group includes all the sediments which may be considered as deposited in the glacial environment. The presence of maring fossils throughout the sequence and the evidence of dumping of boulders into the sediment show that the sediments of the group were all deposited in a marine environment but the influence of the Lower Permian continental glaciation is so pronounced as to mask the normal features of marine deposition. Thus although there are greywackes and fine shales in the sequence these are related to the conditions of erosion of the hinterland and not to its elevation or to the rapidity of burial of the material. The lowermost tillite, representing the first glacial stage, is relatively thin but indicates that the hinterland had been eroded down to the metamorphic and igneous rocks because a small proportion of the larger fragments in this tillite are of igneous and metamorphic rocks. This is in sharp contrast to the pebbles of the Williambury Formation which are almost entirely of chert, quartzite, and quartz. It seems likely that, during the glacial stages, an ice sheet carrying the moraine material within it produced icebergs which travelled far out to sea from the edge of the continent and deposited the moraine material in widespread beds as the icebergs melted. During the interglacial stages the ice sheet retreated onto the continent and fluvio-glacial material was carried out to sea by rivers and only few erratics were carried out to sea by icebergs which broke off the end of valley glaciers. The first interglacial stage is marked by very thick sedimentation of siltstone and quartz greywacke probably deriving from the fluvial erosion of the moraine materials left by the retreating ice sheet. The sediments are characterized by the presence of a fine rock flour in the arenites and by small pebbles of quartz and quartzite throughout. The second glaciation resulted in a thick sequence of arenaceous tillite with at least six boulder beds indicating the seaward advance of the ice sheet (as icebergs). The mainly arenaceous nature of the matrix of this tillite is perhaps an indication that the ice sheet was not of great thickness so that it was eroding the Proterozoic sediments and older Pre-Cambrian in valleys without severe crushing and pulverisation.

The sediments of the second interglacial stage are much more typical of the deposits of this environment than are those of the first interglacial stage. Fine-grained quartz greywacke and laminated siltstone and shale are the common sedimentary types. The quartz greywacke has the fine rock-flour matrix which is typical of the whole group but it is more quartzose than in the tillites. In places these quartz greywackes are severely contorted, probably by the action of large icebergs running aground on the unconsolidated sea-floor. The laminated siltstone and shale are probably varves although the laminae may not represent annual deposits. Pebbles are very rare in this sequence although at a few horizons there are scattered pebbles and few boulders.

The third and main glacial stage, from 2460 to 4010 feet above the base of the group in the type section, comprises three formations - the bottom and top formations are silty tillites and the middle formation is a tillite with greywacke matrix. There are at least six boulder beds in the bottom, one boulder bed and six pebble beds with few boulders in the middle and one boulder bed and eleven pebble beds with few cobbles and boulders in the upper formation. These three formations are probably related to variations in climate which produced first a very thick, then a thinner, finally a thick ice sheet. The thicker icesheets severely pulverized the rock surface over which they flowed and plucked large blocks of the bed rock; the thinner sheet could not erode the crystalline basement but was able to erode the softer Proterozoic sedimentary rocks. Some of the erratic boulders in the lower formation of this main tillite are very large. One, beside the Williambury to Moogooree road on the north side of the South Branch, Minilya River near the crossing, is now broken by weathering into many parts but the original boulder must have been of the order of 10 x 12 x 15 feet. Another big erratic is on the Mt. Sandiman Airfield. Most of the very large erratics are of granitic rock. Calcareous beds, some containing fossils, are fairly common in the upper formation. These probably indicate the introduction of the environment which, at the end of the glaciation, caused the deposition of the calcareous Callytharra Formation.

The third and last interglacial stage, from 4010 to 4400 feet above the base of the type section, consists of quartz greywacke and siltstone with few small pebbles. The quartz greywacke is contorted in some places, probably by grounding icebergs, and the siltstone is varve-like in places. There are a few fossiliferous beds in this sequence.

The last glacial stage is not so well marked as the others and shows alternation between glacial and inter-glacial stage types. There are several boulder beds all of which are rather lenticular in development and several varve-like shales and siltstones. This probably is caused by the alternate advance and retread of valley glaciers which at some times reached the sea to form icebergs carrying morainic material.

Terrestrial tillite is known capping the Pre-Cambrian rocks in the area around Lake Carnegie (Lat. $26\frac{1}{2}^{o}$S. Long. $122\frac{1}{2}^{o}$E.) about 400 miles east of the outcrop of the Lyons Group. This tillite is believed to be Permian although it is shown as Cretaceous on the latest official geological map of Western Australia. It was originally correlated on lithological grounds with the tillite of the Irwin Basin which, because it was associated with beds containing 'ammonites' (in fact Metalegocerass, were called Cretaceous. (Streich, 1893). During the Lower Permian glaciation the continental margin was somewhere between the present outcrop area of the Lyons Group and Lake Carnegie. The thick Holmwood Shale between the Nangetty Formation tillite and the Fossil Cliff Formation (correlative of the Callytharra Formation) possibly indicates that the Irwin Basin at this time was further removed from the shoreline than was the Carnarvon Basin and that the continental margin at that time trended north-westerly.

The Lyons Group is correlated lithologically with the Nangetty Formation (tillites etc.) and the Holmwood Shale of the Irwin Basin, with the Grant Formation of the Fitzroy Basin (Western Australia), with the Hunter Group ('Lower Marine') of New South Wales and by reference to its stratigraphical position possibly with the Talchir and Blaini Tillites of India and the Dwyka Tillite of South Africa and the Itarare Tillite of South America.

Callytharra Formation

This formation was originally defined as 'Callytharra Stage' by Raggatt (1936, p.123). Teichert (1950, p.1792) renamed the formation 'Callytharra Limestone' despite Raggatt's definition of the unit as consisting of "rather argillaceous limestone or highly calcareous mudstone" and his own description (Teichert, 1946, p.100) of the formation as consisting of "calcareous shales and limestones". In view of the mixed lithology of the formation it is proposed to re-name it the Callytharra Formation, which is re-defined as the sequence of thin-bedded calcarenaceous quartz greywacke and siltstone and hard limestone, generally very fossiliferous, resting conformably on the Lyons Group and separated from the overlying Cordalia Greywacke or Wooramel Sandstone by a disconformity.

The Callytharra Formation outcrops in a narrow belt from the Lyndon River 13 miles east of Mia Mia Homestead to K-55, in a parallel belt from 7 miles north-east of Moogooloo to 12 miles west of Moogooree Homestead, in a narrow belt from 8 miles south-west of Williambury Homestead to K-35, and in a discontinuous belt from 8 miles east of Lyons River Homestead to the Wyndham River 22 miles east of Gascoyne Junction. The Callytharra Formation and the Wooramel Sandstone form a prominent strike ridge with an east-facing scarp and west-sloping dip-slope. Where the scarp has been eroded back, the formation forms prominent cuestas. The vegetation is noticeably denser and healthier than on the adjoining Lyons Group. Tall acacia scrub but very little herbaceous vegetation grows on this formation.

The name (pronounced ca'l-lē-thar'-ra) is taken from Callytharra Spring on Wooramel River (at Lat. 25°52'S., Long 115° 30'E.), the type locality of the formation.

The Callytharra Formation has not been examined at the type locality. Within the area covered by this report, several sections were measured in detail. Of these the two following are typical, the first of the outcrop between the Gascoyne and Lyons Rivers, the second of the outcrop between Moogooloo and the Lyndon River. The section at Lat. 24°39¼'S., Long. 115°29'E. in descending order consists of:

	Friable white medium-grained to coarse-grained quartz sandstone of the WOORAMEL SANDSTONE, disconformably overlying
25 feet of	friable greenish grey calcarenaceous quartz greywacke with very few thin beds of hard brownish grey limestone and few fossils (Sample G/336);
50 feet of	friable light greenish-grey calcarenaceous quartz greywacke with many thin beds of hard brownish-grey medium-grained to fine-grained crystalline limestone containing fossils - <u>Aulosteges</u>, bryozoa, large pectenid, <u>Strophalosia</u>, <u>Cleiothyridina</u>, chonetids, spiriferids, crinoid stem ossicles, pelecypod cf. <u>Astatartes</u> (Sample G/335); some beds ferruginous and silicified; (hard limestone makes up 25% of the thickness);

90 feet of friable light greenish-grey fine-grained to medium-grained calcarenaceous quartz greywacke and thin beds, some lenticular, of hard grey medium-grained to fine-grained crystalline limestone (10%); fossils include bryozoa including Hexagonella, crinoid stem ossicles, spiriferids (large), large pectenid, chonetid, Linoproductus, Syringothyris, Dictyoclostus, Streptorhynchid, Phricidothyris, Cleiothyridina, and solitary corals (Samples G/332,333,334);

45 feet of friable light-grey fine-grained to medium-grained calcarenaceous quartz greywacke and thin hard medium-grained to fine-grained crystalline limestone both fossiliferous; fossils include those in the above 90 feet except pectenids (Sample G/331);

25 feet of poorly outcropping friable calcarenaceous quartz greywacke with few fossils;
Conformably overlying friable light grey quartz greywacke with pebbles and cobbles, of the LYONS GROUP.

235 feet - thickness of Callytharra Formation.

In the Moogooloo - Lyndon River area (at Lat. 23°20¾'S., Long. 114 40¼'E.) the sequence in descending order is as follows:

Hard calcareous medium-grained to coarse-grained quartz greywacke of the CORDALIA GREYWACKE, disconformably overlying

30 feet of friable light-grey fine-grained calcarenaceous quartz greywacke with few fossils (bryozoa and small crinoid stem ossicles);

70 feet of thin-bedded friable light-grey sandy bryozoal calcarenite with few thin beds of ferruginous limestone; fossils include dendritic and fenestellid bryozoa, solitary corals, Cleiothyridina, Spiriferella, chonetid, small crinoid stem ossicles;

84 feet of thin-bedded friable grey fine-grained calcarenaceous quartz greywacke with few thin hard calcareous quartz greywacke beds; fossils include dendritic and fenestellid bryozoa, small crinoid stem ossicles, and solitary corals;

99 feet of thin-bedded friable to medium-hard light-grey silty calcarenite and hard grey limestone, coquinoid in places; fossils include large crinoid stem ossicles, fenestellid and dendritic bryozoa, spiriferids, productids, solitary corals;

48 feet of thin-bedded friable light-grey calcarenaceous fine-grained quartz greywacke and hard grey medium-grained crystalline limestone;

125 feet of thin-bedded friable to medium-hard light grey fine-grained to coarse-grained sandy calcarenite and few thin beds of hard grey medium-grained crystalline limestone, some coquinoid (10%); fossils include fenestellid and dendritic bryozoa, crinoid stem ossicles, small productids, Syringothyris, spiriferids, Calceolispongia plates, chonetids, corals;

248 feet of friable light grey fine-grained sandy bryozoal calcarenite with few thin beds of hard grey fine-grained crystalline limestone, some coquinoid, some sandy (5%); fossils include crinoid stem ossicles, solitary corals, dendritic bryozoa, Spiriferella, chonetids, productids, Calceolispongia plates;

41 feet of friable light grey fine-grained calcarenaceous quartz greywacke and hard grey coquinoid limestone (30%); fossils include small crinoid stem ossicles, small productids, bryozoa, solitary coral;
20 feet of friable light grey calcarenaceous fine quartz greywacke with few fossils;
Conformably overlying friable grey fine-grained quartz greywacke with pebbles, of the LYONS GROUP.

765 feet - amended type thickness of Callytharra Formation.

As this section is from the only locality where a complete section of the Callytharra Formation is exposed, it is proposed to define this as the amended type section of the Callytharra Formation. The disconformity between the Callytharra and the overlying Cordalia Greywacke in this section is probably very small: there is no sign of the ferruginous surface on the Callytharra although the base of the Cordalia is coarse-grained and calcareous. There probably is a disconformity but it indicates non-deposition rather than erosion.

The base of the formation is placed at the base of the calcarenaceous quartz greywacke which is between the uppermost boulder bed of the Lyons Group and the lowermost hard limestone beds of the Callytharra Formation. This change of lithology can only be seen in good exposures, but the boundary may be mapped by reference to the Lyons boulder bed and the hard limestone of the Callytharra. The top of the Callytharra Formation is very variable, as it is a surface of disconformity. It can be recognised by the change from fossiliferous, calcarenaceous sediments to non-fossiliferous quartz greywacke or quartz sandstone. The Callytharra below the disconformity is generally ferruginised, and the basal beds of the overlying formation are generally coarse-grained and calcareous.

The dominant rock type in the Callytharra Formation is calcarenaceous quartz greywacke. The fragmental calcite, probably mainly comminuted shells, bryozoa and crinoids, is generally somewhat coarser in grain-size than the accompanying detrital silicates (quartz, mica, felspar, chert). The proportion of fragmental calcite varies between wide limits within the formation - from less than 20% in the lowermost beds to about 80% in some of the calcarenite beds in the most northerly outcrops. The hard limestone beds are fairly uniform although there are minor variations particularly in the proportions of fossils and of sand. In general crystalline calcite (grain-size 0.1 to 0.5 mm.) constitutes from about 60 to 90% of the rock. Sand and silt (of quartz, felspar, chert, and mica) forms up to about 20% of the rock and fossils and fossil fragments about 10% to about 40%. The rock has the appearance in the field of being a recrystallised calcarenite and the few thin sections seen confirm this. Some of the finer-grained non-fossiliferous limestone beds may be 'chemical limestone' formed by the precipitation of calcium carbonate from sea water. In the Lyndon area, the formation consists of four easily separated members - the lowermost consisting of friable and hard beds (61 feet), the next highest mainly of fine-grained friable calcarenite (248 feet) which weathers down to form valleys with little outcrop, friable and hard beds (272 feet) forming scarps or cuestas and the uppermost, friable fine-grained rock with few thin hard beds (184 feet) forming reduced topography. Much of the variation in thickness of the formation is due to the erosion of the upper members.

The thickest outcropping section of the Callytharra Formation is exposed on the Lyndon River, 13 miles east of Mia Mia Homestead, where four members are present. At K-55, the thickness is 540 feet and the uppermost member is not present. Four miles south-west of Moogooree Homestead, the thickness is 423 feet; the uppermost and about half of the next member are absent. Ten miles east of Lyons River Homestead, the thickness is 235 feet, the uppermost and most of the next member are absent, and the third member from the top is much reduced in thickness although the lowermost member is about the same thickness as on the Lyndon. The westward divergence is well illustrated by the thicknesses at K-35 (400 feet) and the ridge 6 miles to the east (250 feet). This is an apparent divergence of 25 feet per mile westward. Part of this is due to greater erosion of the top of the formation in the eastern area, but the original divergence is about 24 feet per mile westward.

Most of the published lists of fossils contained in the Callytharra Formation are in need of revision. This is being done at present by G.A. Thomas, J.M. Dickins, B.F. Glenister, C. Teichert and P.J. Coleman. Until their results are available, any fossil list which might be compiled would be misleading. The best statement of the present position is by Teichert (1951). The Callytharra fauna includes foraminifera (both arenaceous and calcareous genera), corals (small single forms), Rhopaloblastus, crinoids (Calceolispongia and other genera), bryozoa (many species and very many individuals), brachiopods (Chonetes, Neospirifer, Spiriferella, Syringothyris, Cleiothyridina, Phricidothyris, Dictyoclostus, Linoproductus, Streptorhynchus,) pelecypods (Aviculopecten), gastropods (Warthia, Ptychomphalina), nautiloids (Pseudorthoceras, Mooreoceras, Brachycycloceras, Domatoceras, Stearoceras), and a single goniatite (cf. Metalegoceras). The only plant found in this formation is a single specimen of Gangamopteris (Teichert, 1942b).

The Callytharra Formation is correlated with the Fossil Cliff Formation of the Irwin Basin (Clarke, Prendergast, Teichert and Fairbridge, 1951), which has a similar lithology and fauna, and with the Nura Nura limestone member of the Poole Sandstone of the Fitzroy Basin (Guppy, Lindner, Rattigan and Casey, 1952). Of these three formations the Nura Nura member is the only one in which fossils diagnostic of age have been found. There Metalegoceras clarkei, M. striatum and Thalassoceras wadei indicate an Artinskian age (Teichert, 1942). However, there is little difference between the fauna of the bottom part of the Callytharra Formation and the upper part of the Lyons Group, so that it is likely that as the faunas are studied more closely the Sakmarian-Artinskian boundary will be placed elsewhere than at the base of the Callytharra and the presence of ammonoids of Sakmarian affinities higher in the section (Teichert, 1944a) may be an indication that the boundary may even be above the Callytharra. For the present the Callytharra Formation may be referred to the base of the Artinskian.

Near the Arthur River, there are several beds containing coarse well-rounded quartz sand in the third member from the base. This, and the rapid eastward convergence in this area, may indicate that the shoreline during the deposition of the Callytharra Formation was not very far to the east of the present outcrop on the Arthur River. Farther north along the outcrop less coarse sand is evident and the proportion of calcium carbonate increases. This probably indicates that the shoreline was farther to the east of the outcrop in the Moogooree Area than in the Arthur River area and that the trend of the shoreline was north-easterly; the fine-grained clastics of the Lyndon area confirm this. There is a marked increase in the proportion of fossil remains from south to north, which may be related to the decrease in the amount of clastic silicates in this direction. If this tendency continues into the basin the basinward equivalent of the Callytharra Formation may be expected to be much more calcareous than the outcropping formation. In outcrop, the Callytharra Formation cannot be regarded as a source formation for petroleum, but in its basinward extension the alternation of fine clastic and organic sediments may have resulted in a source formation for oil.

Cordalia Greywacke

The Cordalia Greywacke is defined as the formation of laminated fine-grained quartz greywacke with calcareous lenses which lies conformably beneath the Wooramel Sandstone and, in outcrop, above the disconformity at the top of the Callytharra Formation.

The name (pronounced cor-dā'-lē-a) is taken from Cordalia Well on Mia Mia Station, 15 miles east-south-east of Mia Mia Homestead.

The Cordalia Greywacke outcrops only between the Minilya and Lyndon Rivers, in the scarp formed by the Callytharra Formation and the Wooramel Sandstone.

The type section is $\frac{3}{4}$ mile north-east of Round Hill, Winning Station, $14\frac{1}{2}$ miles east of Mia Mia Homestead, at Lat. $23^{\circ}20\frac{3}{4}'$S., Long. $114^{\circ}40'$E. There the sequence in descending order is as follows:

	Thin-bedded hard calcareous fine-grained quartz sandstone of the Wooramel Sandstone conformably overlying
60 feet of	thin-bedded friable grey fine-grained quartz greywacke and dark-grey coarse-grained siltstone (Sample MG/164);
0 to 7 feet of	hard, grey to brown, laminated calcareous fine-grained quartz greywacke (lenticular);
19 to 42 feet of	friable grey laminated micaceous fine-grained quartz greywacke;
0 to 16 feet of	hard, grey to brown, laminated calcareous fine-grained quartz greywacke (lenticular), (Sample MG/163);
80 feet of	laminated friable light-grey fine-grained micaceous quartz greywacke (Sample MG/162);
3 feet of	friable light-grey calcarenite with very coarse quartz sand and bryozoa and small brachiopods;
15 feet of	hard cream medium-grained to coarse-grained calcareous sandstone with lenses of very coarse-grained sand;
	disconformably overlying friable light-grey calcarenaceous fine-grained quartz greywacke of the Callytharra Formation.
200 feet - type thickness of the CORDALIA GREYWACKE.	

The base of the formation, in outcrop, rests on the top, generally ferruginous, of the calcarenaceous Callytharra Formation. The details of the lithology of the base of the Cordalia Greywacke vary from place to place, but in most places there is a coarse sandstone, generally calcareous, at the base. This is interpreted as being a transgressional basal 'conglomerate'. The top of the Cordalia Greywacke grades into the base of the Wooramel Sandstone. Generally the lowermost beds of the Wooramel Sandstone, where they overlie the Cordalia Greywacke, are more resistant to erosion, because of a calcareous cement. The change in lithology from quartz greywacke below to quartz sandstone above is marked but not sharp. The gradational change from quartz greywacke to quartz sandstone is accompanied by an increase in grain-size from fine-grained to medium-grained and by an increase in the thickness of beds from laminae ($\frac{1}{2}$ inch or less) to thin beds (up to 6 inches).

The dominant lithology of the Formation is quartz greywacke consisting of angular to subangular quartz grains (about 70%), mica (up to about 5% but generally less), minor felspar (up to about 5%), garnet and tourmaline (1%), and a fine-grained matrix (20 to 30%) consisting of quartz, felspar, mica, and clay minerals. In the calcareous lenses in the middle part of the formation, the composition of the clastic fraction is the same but it constitutes only about 60% of the rock, the other 40% being interstitial calcite, very fine-grained and crystalline. The Formation typically is laminated and ripple-marked so that the laminae are undulating rather than parallel. Towards the top the thin beds are finely cross-bedded.

The type section is the thickest exposed section of the formation. From there the thickness decreases fairly evenly to K-52, where the thickness is 35 feet. This is an apparent (minimum) convergence of 4 feet per mile southward. Seven miles east-south-east of K-52 the Cordalia Greywacke is absent. This indicates a minimum convergence of 5 feet per mile eastward. At K-55, 8 miles west of K-52, the thickness is 107 feet. Taken together, these indicate that the regional divergence of the Cordalia Greywacke may be 9 feet per mile westward.

The only fossils found in this formation are bryozoa and small brachiopods near the base of the type section. The age of the Cordalia Greywacke must be determined by reference to the adjoining formations. The Callytharra Formation is referred to the basal Artinskian. As the Cordalia Greywacke is separated from the Callytharra Formation by a disconformity and is overlain by formations referred to the Artinskian it may also be placed in the Artinskian. A disconformity underlies the Nura Nura limestone member at the base of the Poole Sandstone. It is possible that the disconformity separating the Callytharra and the Cordalia may be the equivalent of the pre-Nura Nura disconformity, in which case the Cordalia Greywacke would be equivalent to the Nura Nura member and therefore basal

Artinskian. This is a problem which current palaeontological work may help to solve.

The Cordalia Greywacke is a transgressive formation overlapping the eroded surface of the Callytharra Formation. The shoreline of the sea in which this formation was deposited ran north-easterly through Williambury. The lithology indicates moderately rapid sedimentation with the shallow-water zone. No similar formation is reported from the Irwin Basin (Clarke et al, 1951). However, there is a thick ironstone developed at the stratigraphical top of the Fossil Cliff section which may well be the equivalent of the disconformity at the top of the Callytharra Formation, in which case the overlying dark grey pyritic sandy carbonaceous siltstone (at the base of the High Cliff section) may be the stratigraphical equivalent of the Cordalia Greywacke.

Wooramel Sandstone

The Wooramel Sandstone was named by Rudd but not clearly defined (Condit et al, 1936, p. 1042). Raggatt (1936) restricted it to the sandstone overlying the Callytharra and overlain by sandy carbonaceous shale. In the area of its outcrop, he included the Cordalia Greywacke with the Wooramel Sandstone. The Wooramel Sandstone is re-defined as the quartz sandstone overlying the Cordalia Greywacke conformably or the Callytharra Formation disconformably and overlain conformably by the Coyrie Formation.

The name (pronounced woo-ra-mel) is taken from the Wooramel River which cuts through the formation at Lat. $25^{\circ}50\frac{1}{2}$'S., Long. $115^{\circ}34$'E.

In the area covered by this report, the Wooramel Sandstone outcrops in a strike ridge running from north of the Lyndon River (13 miles east-north-east of Mia Mia Homestead) to K-55, in a parallel strike ridge from six miles north-east of Moogooloo to 12 miles west of Moogooree Homestead, in another strike ridge from 15 miles north-west of Moogooree Homestead past Lyons River Homestead and K-35 and in a line of discontinuous outcrops from 8 miles east of Lyons River Homestead to 7 miles east of K-35. There is also a small outcrop south of Mooka Homestead.

The type section has not been examined. The thickest section measured is four miles south-west of Moogooree Homestead at Lat. 24°6½'S., Long. 115°9¾'E. There the sequence in descending order is as follows:

	Soft dark grey laminated siltstone with few thin calcareous beds of the COYRIE FORMATION, conformably overlying
10 feet of	hard dark-brown ferruginous pebbly coarse quartz sandstone;
33 feet of	firm to medium-hard pale cream medium-grained, coarse-grained and very-coarse-grained quartz sandstone with scattered pebbles to 2";
42 feet of	firm to medium-hard white fine-grained silty quartz sandstone (sample G/233);
50 feet of	medium-hard white medium-grained quartz sandstone with few coarse-grained and very-coarse-grained beds;
20 feet of	bedded friable white medium-grained quartz sandstone (beds to 6");
20 feet of	bedded white friable coarse-grained to very-coarse-grained quartz sandstone, some silty (Sample G/232);
75 feet of	bedded white friable medium-grained to coarse-grained quartz sandstone with a ferruginous skin on the surface (Sample G/231);
	Disconformably overlying hard ferruginous top of CALLYTHARRA FORMATION.
250 feet -	thickness of WOORAMEL SANDSTONE

A section one mile south of K-35, measured by C.E. Prichard, shows the variation in thickness and lithology in the southeastern part of the area. There, the sequence from the top downwards is:

	Top of outcrop - probably top of Wooramel Sandstone
1 foot of	hard dark-brown ferruginous medium-grained quartz sandstone with coarse grains and ½" quartz pebbles;
19 feet of	cross-bedded medium-grained quartz sandstone with coarse grains; thin pebble bed with ½" quartz pebbles at base;
25 feet of	medium-grained quartz sandstone with many coarse grains;
14 feet of	coarse-grained quartz sandstone and laminated micaceous siltstone;
22 feet of	fine-grained and medium-grained quartz sandstone;
8 feet of	medium-grained micaceous quartz sandstone with silt 'biscuits'; pebble bed at base with ½" pebbles;
43 feet of	thin-bedded medium-hard to friable fine-grained silty quartz sandstone;
	Disconformably overlying the ferruginous top of the CALLYTHARRA FORMATION.
122 feet -	thickness of WOORAMEL SANDSTONE.

A section immediately east of K-55 shows the conformable relationship with the Cordalia Greywacke; the sequence in descending order is:

	Soft black to light grey laminated carbonaceous siltstone and shale of the COYRIE FORMATION conformably overlying
5 feet of	friable pale red-brown coarse to very coarse quartz sandstone;
55 feet of	medium-hard to friable white to red-brown medium-grained quartz sandstone, coarse-grained beds and few thin beds of fine sandstone and of siltstone;
25 feet of	medium-hard and friable white medium-grained quartz sandstone;
5 feet of	medium-hard light-brown coarse and very coarse quartz sandstone with small pebbles of quartz;
80 feet of	thin-bedded medium-hard white medium-grained quartz sandstone with little white silt matrix; cross-bedded, ripple-marked with worm burrows and mollusc trails and fragments of fossil wood near the base; conformably overlying friable thin-bedded to laminated fine-grained quartz greywacke of the CORDALIA GREYWACKE.
170 feet -	thickness of the WOORAMEL SANDSTONE.

The base of the formation, where it overlies the disconformity at the top of the Callytharra Formation, is at the very marked change of lithology from calcarenaceous quartz greywacke and thin hard limestone to quartz sandstone. This change is very sharp and moreover is usually marked by the ferruginisation of the top of the Callytharra. Where the Wooramel is conformable above the Cordalia, the change is gradational but is marked by the increase in cleanness, hardness, and thickness of bedding. In some places there is a thin calcareous bed, ferruginous in outcrop, at the top of the Cordalia Greywacke.

The formation consists predominantly of quartz sandstone with very few thin beds of quartz siltstone. The quartz sandstone consists predominantly of quartz grains, well sorted and generally well rounded or showing crystalline quartz overgrowths. The grain-size is very variable within the formation (from 0.02 to 30.0 mm.), but within individual beds the grain-size is very uniform except that some beds contain a few small pebbles. The only other constituents of the quartz sandstone are felspar (about 3%), little muscovite and bleached biotite (about 1%) and tourmaline and zircon (less than 1%). White silt is a common constituent (up to about 10%) and in a few thin beds forms the whole of the rock. The sandstone is cross-bedded throughout, but the cross-bedding is rarely a very prominent feature. Bedding is generally thin (1 inch to 1 foot). Medium-sized wave ripple-marks are common. In the lower part of the formation, invertebrate trails and burrows are quite common.

The Wooramel Sandstone varies in thickness from 122 feet, one mile south of K-35, to 250 feet, 4 miles south-west of Moogooree. In the area between the Minilya and Lyndon Rivers the thickness is mainly about 140 feet except at K-55 where it is 170 feet. No regional convergence is obvious.

Very few fossils are known from the Wooramel Sandstone as here defined; fossils previously reported as from the Wooramel Sandstone have mainly come from the overlying greywacke of the Coyrie Formation. Fragmentary fossil wood is found in the lower part of the formation and in one place 9 miles west-south-west of Williambury there are spiriferids and bryozoa within the topmost ferruginous sandstone.

Its stratigraphical position disconformably above the probably Artinskian Callytharra Formation and below the Artinskian Wandagee Formation fixes its age as Artinskian.

The Wooramel Sandstone is a typical 'stable shelf sandstone' (Dapples, Krumbein, and Sloss, 1948). Its outcrop area and thickness indicate a considerable transgression beyond the Cordalia shoreline. Its lithology indicates slow deposition within the zone of strong wave action - with sufficient re-working to destroy most of the unstable minerals and to remove the silt and clay. Most of the silt present is quartz silt produced by the abrasion of the quartz grains. This formation may be expected to continue out into the basin with very little change in thickness or lithology to the area where the wave action was negligible. It is likely, from the evidence of the outcrop at Mooka, that this formation continues from its outcrop westward at least as far as the present coastline.

The Wooramel Sandstone is correlated with the High Cliff Sandstone of the Irwin Basin (Clarke et al, 1951, p.56) although there is much more carbonaceous shale there (12%) than in the Wooramel (personal observation). The Wooramel may also be correlated with part of the Poole Sandstone of the Fitzroy Basin (Guppy et al, 1952).

Byro Group

Raggatt (1936) defined the Byro 'Stage' as extending from the top of the Wooramel Sandstone to the base of the 'Kennedy Range sandstones'. This large lithological unit, characterised by quartz greywacke, siltstone and shale, is re-named the Byro Group to conform with Australian stratigraphical nomenclature. It comprises the following formations in ascending order - Coyrie Formation, Mallens Greywacke, Bulgadoo Shale, Cundlego Formation, Quinnanie Shale, Wandagee Formation, Norton Greywacke and Baker Formation. The whole of the group is Artinskian in age as it contains the diagnostic fossils _Propinacoceras_ (Teichert, 1942a) and _Helicoprion_ (Teichert, 1943) and underlies the Coolkilya Greywacke containing Artinskian _Paragastrioceras_, _Pseudogastrioceras_ and _Helicoprion_. The group as a whole, or part of it, correlates with the Irwin River Coal Measures (Clarke et al., 1951) and with the Noonkanbah Formation of the Fitzroy Basin (Guppy et al., 1952).

Coyrie Formation

This formation was informally named 'Coyrie Shale' by Teichert (1950, p.1791), but wrongly correlated with the Bulgadoo Shale. The Coyrie Formation is defined as the sequence of siltstone, shale, and quartz greywacke which overlies the Wooramel Sandstone conformably and is overlain conformably by the Mallens Greywacke.

The name is taken from Coyrie Paddock (Williambury Station) the north-eastern corner of which is 14 miles south of Williambury Homestead. The formation outcrops poorly across Coyrie Paddock and the type section is just outside the eastern boundary fence of the paddock at its south end.

The formation crops out from 8 miles west-north-west of Moogooree Homestead to 2 miles west of K-35 in an area of reduced topography on the west side of the Callytharra-Wooramel strike ridge. There are also small outcrops on the road from Mia Mia to Cordalia Well, south of the Lyndon River. The formation is generally poorly exposed except in the type locality, where it is exposed in a scarp at the head of a small stream.

At the type locality - 5 miles south-west of Moogooree Homestead at Lat. $24^{o}06\frac{1}{2}$'S., Long. $115^{o}09$'E. - the sequence in descending order is as follows:

	Firm pale-brown medium-grained coprolitic quartz greywacke of the MALLENS GREYWACKE conformably overlying
33 feet of	friable laminated and cross-laminated light-grey very micaceous fine-grained quartz greywacke;
5 feet of	firm dark purplish-red fine-grained quartz greywacke with three thin beds of Chonetes coquinite (sample G/303);
47 feet of	friable light-grey laminated fine-grained quartz greywacke with thin hard calcareous beds, some containing foraminifera and gastropods;
1 foot of	hard light greenish-grey calcareous fine-grained coquinoid quartz greywacke; fossils include brachiopods (spiriferid, productid), pectenid, crinoid stem ossicles (Sample G/302);
32 feet of	friable light-grey laminated fine-grained quartz greywacke with thin hard calcareous beds;
40 feet of	friable to firm, roughly thin-bedded, light-grey medium-grained quartz greywacke with many worm burrows and trails on some bedding planes and some large ferruginous concretions (up to 2' x 1' x 1');
17 feet of	firm rough-bedded fine-grained quartz greywacke with few thin lenticular hard calcareous beds;
	- - - - - - - - - - - -
10 feet of	soft dark-grey coarse-grained siltstone with fine quartz sand;
52 feet of	friable greenish-grey laminated micaceous fine-grained quartz greywacke with lenses and beds of hard grey calcareous micaceous fine-grained quartz greywacke and few thin soft dark-grey coarse-grained siltstone beds; few fossils - Hyperammonoides;
98 feet of	soft black carbonaceous fine-grained to coarse-grained siltstone with thin friable laminated fine-grained quartz greywacke, some calcareous (Sample G/301);
145 feet of	thin soft dark-grey coarse-grained siltstone, friable grey fine-grained quartz greywacke, some calcareous and few thin red calcareous siltstone beds; many fossiliferous beds; fossils include foraminifera, crinoid stem ossicles, brachiopods, Calceolispongia plates, pelecypods, gastropods, Propinacoceras, straight nautiloid, bryozoa, and Gangamopteris (Samples G/240, 264,265,267,268,271,272,273,274);
30 feet of	firm dark-grey laminated coarse-grained siltstone with few thin beds of hard calcareous quartz greywacke (Sample G/269, 270);

103 feet of firm to soft dark-grey laminated carbonaceous siltstone and shale with thin laminae of fine white sand and thin beds of fine-grained quartz greywacke and medium-hard nodules of red, possibly phosphatic, siltstone; several fossil beds including foraminifera, pelecypods, gastropods, straight nautiloid, Chonetes, Conularia, trilobite (Samples G/239, 263);

- - - - - - - - - - - -

75 feet of soft dark-grey laminated coarse-grained siltstone, and friable grey medium-grained micaceous quartz greywacke in beds about 10 feet thick, and thin hard calcareous coarse-grained quartz greywacke; few fossils, brachiopods, nautiloids, Propinacoceras and gastropods (Samples G/238, 284);

42 feet of friable to medium-hard thin-bedded fine-grained to medium-grained quartz greywacke with few thin calcareous beds; poorly preserved fossil wood at base (Sample G/237);

15 feet of soft dark-grey siltstone with laminae of fine-grained quartz greywacke (Sample G/236);

68 feet of medium-hard medium-grained and friable fine-grained pale brown quartz greywacke with calcareous ripple-marked bedding planes, invertebrate trails and burrows, fossil wood (Sample G/312, 235);

- - - - - - - - - - - -

42 feet of soft dark-grey laminated siltstone with few thin calcareous beds and few thin fine-grained quartz greywacke beds and a 3" bed of hard grey limestone 3' from the base (Sample G/234, 311); conformably overlying hard dark-brown ferruginous pebbly quartz sandstone of the WOORAMEL SANDSTONE.

855 feet - type thickness of the COYRIE FORMATION.

The base of the Coyrie Formation (and of the Byro Group) is placed at the base of the first thick siltstone overlying the quartz sandstone of the Wooramel Sandstone. The top of the Coyrie Formation is placed at the change in lithology from the friable laminated micaceous quartz greywacke below to the resistant, medium-grained thin-bedded coprolitic quartz greywacke above. This does not appear to be a very marked change but it does coincide with the edge of the outcrop of the Mallens in the areas of poor outcrop, where the Coyrie is marked by the low ridges of the hard calcareous beds which occur to within 35 feet of the top of the formation as here defined. There are four easily separated members in the formation : the bottom siltstone member, the quartz greywacke and siltstone member with many hard calcareous beds, the siltstone member, and the uppermost member of quartz greywacke with hard calcareous beds.

Little petrological work has been done on the rocks of the Coyrie Formation. The quartz greywacke of the second member from the base consists of about 60% quartz grains, generally round to sub-round but with crystal overgrowths, 10% to 15% felspar (mainly angular orthoclase, perthite, and oligoclase), about 1% mica (muscovite and biotite), about 0.5% heavy minerals (leucoxene, zircon, tourmaline), and about 20% to 25% of kaolinitic silty matrix. (Edwards, 1952, p.34). Some of the hard beds of the top member were found to be sandy limestones with about 60% crystalline calcite. The clastic fraction comprises quartz, biotite, and felspar (orthoclase).

The thickness of the Coyrie Formation ranges from about 500 feet at Arthur River (west of K-35) to about 1000 feet at the Lyndon River, a divergence of about 4 feet per mile north-north-westward.

There is a varied but rather dwarfed fauna in the Coyrie Formation. Fossils recognized in the field but not yet further identified include : fossil wood and _Gangamopteris_ leaves, foraminifera (_Hyperammonoides_ and _Ammodiscus_), bryozoa, crinoid stem ossicles, _Calceolispongia_ plates, brachiopods (_Dielasma_, spiriferids, ?_Aulosteges_, _Chonetes_, productids), pelecypods (_Atomodesma_, _Nucula_, _Nuculana_, _Undulomya_), small gastropods, small straight and large coiled nautiloids, _Propinacoceras_, trilobite (?_Ditimopyge_).

None of these forms are known to be very good guide fossils except for a general Permian age. It is noticeable that the fauna is very different from that of the Callytharra Formation, although this may be in part a facies variation. The fauna comprises species almost all of which are known from the Wandagee Formation, although the individuals in the Coyrie are mainly dwarfed forms.

The Coyrie Formation is most probably the equivalent of the Irwin River Coal Measures or part of them.

Mallens Greywacke

The 'Mallens Sandstone' was named informally by Teichert

(1950, table on p.1791) who correlated it, incorrectly, with the Cundlego Formation. The Mallens Greywacke is defined as the formation of quartz greywacke lying conformably between the Coyrie Formation below and the Bulgadoo Shale above.

The name is taken from Mallens Paddock (Williambury Station), the north-eastern corner of which is 7 miles south of Williambury Homestead. The type section of the Formation is in the paddock to the south of Mallens Paddock (Coyrie Paddock) but the formation does extend into Mallens Paddock although the exposures are poor.

The Mallens Greywacke crops out on the north bank of the Lyndon River 10 miles east of Mia Mia Homestead, at Burna Burna (7½ miles north of Wandagee); in several small fault blocks in the area west of Donnelly's Well, Williambury, 16 to 20 miles south-south-west of Williambury Homestead; at the type locality 6 miles west of Moogooree Homestead; and in a belt from 5 miles north-east of Merlinleigh to the Gascoyne River six miles south of K-35. The outcrop area generally is a sandy rounded low strike ridge except in the type locality where the topography is controlled by the northern scarp of the Kennedy Range. There is generally a fairly dense cover of acacia scrub and spinifex on its outcrop.

The type section - in Coyrie Paddock (Williambury) at Lat. 24°05'S., Long. 115°07'E., 16 miles south of Williambury Homestead and 6 miles west of Moogooree Homestead - in descending order consists of:

soft dark-grey siltstone with brachiopods and Calceolispongia, of the BULGADOO SHALE conformably overlying

50 feet of friable and medium-hard, roughly bedded and laminated, grey fine-grained quartz greywacke with pelecypods and Calceolispongia plates and thin hard calcareous fine quartz greywacke beds (Sample G/307);

19 feet of friable grey laminated fine-grained quartz greywacke and soft dark-grey coarse siltstone (Sample G/308);

46 feet of friable light-grey laminated micaceous fine-grained quartz greywacke with thin beds of hard grey calcareous quartz greywacke;

17 feet of soft dark-grey laminated coarse-grained siltstone and friable grey laminated fine-grained quartz greywacke;

63 feet of friable light-grey laminated and thin-bedded fine-grained quartz greywacke with few pelecypods (Sample G/277);

90 feet of friable to medium-hard fine-grained to medium-grained quartz greywacke with thin beds of laminated quartz greywacke, large calcareous concretions weathering to ferruginous concretions, invertebrate trails and burrows (Sample G/306);

35 feet of medium-hard grey medium-grained quartz greywacke with many large calcareous concretions (weathering ferruginous) and several pelecypod coquinites (Sample G/305);

160 feet of medium-hard thin-bedded light-grey medium-grained quartz greywacke with few thick beds of slightly calcareous coprolitic quartz greywacke and few calcareous (ferruginous) concretions (Sample G/304);

37 feet of firm light-brown medium-grained quartz greywacke, roughly thin-bedded, with a few beds of calcareous (ferruginous at surface) concretions, undulate bedding planes covered with branching "burrows" $\frac{1}{4}$" to $\frac{1}{2}$" in diameter;

conformably overlying friable laminated and cross-laminated light grey fine-grained quartz greywacke of the COYRIE FORMATION.

517 feet - type thickness of the MALLENS GREYWACKE.

The base of the formation is placed at the change in lithology from the laminated fine-grained quartz greywacke which is characteristic of the upper member of the Coyrie Formation to the medium-grained thin-bedded quartz greywacke typical of the Mallens Greywacke. This is only determinate where the outcrop of the junction of the two formations is well exposed but in poorly exposed outcrop the junction is indicated by the hard calcareous beds of the upper member of the Coyrie and by the relative hardness and resistance to erosion of the Mallens. The top of the formation is placed at the top of the uppermost bed of typical Mallens lithology (coprolitic quartz greywacke) overlain by mainly siltstone and shale of the Bulgadoo Shale. Several beds of hard calcareous quartz greywacke near the top of the Mallens Greywacke help to indicate the junction with the Bulgadoo Shale in poorly exposed outcrops. There are several beds of siltstone up to about 5 feet thick in the top part of the formation and several beds of quartz greywacke up to 12 feet thick in the bottom part of the Bulgadoo Shale; the junction is placed at the top of the dominantly greywacke lithology and at the base of the dominantly lutaceous lithology.

Very little petrological work has been done on rocks of the Mallens Greywacke, most of those referred to the Mallens in Edwards' report (1952, p. 40) having been incorrectly placed in that formation. The specimens of Mallens are not described in detail.

Two specimens T/34 and T/36, from Burna Burna, are probably referrable to the Mallens. Specimen T/36 is a quartz sandstone consisting of rounded quartz grains with crystal overgrowths, very few hornfels and quartzite grains and practically no felspar. This lithology is absent in the type locality. Specimen T/34 contains 30% to 40% calcite cement. The clastic fraction consists of angular to rounded grains of quartz (about 75%) fresh felspar (about 20%) - microcline, orthoclase, and acid andesine - muscovite and bleached biotite (about 2%), a few fragments of chert and quartzite and shell fragments. Heavy minerals are practically absent. This rock is more like some of the rocks in the type section but is not the typical lithology. In hand specimen the typical rock type of the Mallens Greywacke in the main outcrop areas consists of quartz (about 40% to 65%), felspar (about 10% to 20%), red garnet (up to about 10%), black chert (up to about 5%), and mica (up to about 2%), with a variable amount of micaceous silt matrix (10% to about 25%).

Thickness measurements of the Mallens are generally not very reliable because of the poor outcrop and the consequent difficulty of determining dips accurately and of locating boundaries accurately. The thickness ranges from about 300 feet ten miles north-east of Gascoyne Junction to about 700 feet on the Lyndon River, 11 miles east of Mia Mia Homestead - a divergence of about 3 feet per mile. The type thickness of 517 feet about half-way between the above two localities indicates that the divergence is probably close to linear, at least in this north-north-west direction.

The Mallens Greywacke contains two faunas, one found in the uppermost and the other in the middle part of the formation. The upper fauna, found in association with the siltstone beds of this part of the sequence, includes spiriferids (medium and small *Neospirifer*), streptorhynchid, *Chonetes*, pelecypods and gastropods. The lower fauna consists mainly of pelecypods, with few spirifers and small gastropods. No fossils indicative of precise age have been found in this Formation, which is referred to the Artinskian because of its position between the Callytharra and the Coolkilya Greywacke.

The lithology and internal structures of the Mallens Greywacke indicate that the Formation was deposited moderately quickly in the shallow marine environment on a steadily sinking shelf. The rate of deposition was slow enough to allow some re-working, resulting in low proportions of silty matrix and of unstable minerals, but not slow enough to allow complete cleaning of the sand except perhaps farther out in the basin: the rock at Burna Burna is much cleaner than elsewhere along the main belt of outcrop amd may indicate more stable conditions in this area. The increase in thickness along the main outcrop belt, in a north-north-west direction, probably indicates a shoreline running north-eastward through or near Byro Homestead.

The Mallens Greywacke cannot be correlated directly with any formation in either the Irwin Basin or the Fitzroy Basin, but is probably the equivalent of a part of the Irwin River Coal Measures.

Bulgadoo Shale

The Bulgadoo Shale was named by Teichert (1941, p.381) who thought that it rested on the Wooramel Sandstone. He described the Bulgadoo "Series" as consisting of possibly '1000 feet of carbonaceous shales with sandstone here and there ... corresponding with the basal beds of the Byro "Series" ' of Raggatt (1936). In 1946, he stated the thickness to be 2200 feet (p.99). Because of these errors in the relationships of the Bulgadoo Shale it is necessary to define it. The Bulgadoo Shale is defined as the formation, consisting dominantly of carbonaceous shale and siltstone with minor quartz greywacke and limestone beds and containing a meagre fauna of dwarfed brachiopods, crinoids, including Calceolispongia, Thamnopora, small gastropods, nautiloids, ammonoids, and Helicoprion, which rests conformably between the Mallens Greywacke below and the Cundlego Formation above.

The name (pronounced boo'l-ga-dōō') is taken from Bulgadoo Pool on the Minilya River (at Lat. 23°44½'S., Long. 114°30'E.) which is Teichert's type locality although only the upper part of the formation is exposed there.

The Bulgadoo Shale outcrops on either side of the Minilya River between Cundlego Crossing and Middalya Homestead, in small fault blocks between Wandagee Homestead and Wandagee Hill, along the Barrabiddy Creek north and northeast of K-56, at the head of Norton Creek, in a small area 7 miles west of Moogooree, and in a belt from Merlinleigh Homestead to Bidgemia Homestead and beyond. The area of outcrop of the Bulgadoo Shale is generally very reduced topographically and very sparsely covered by stunted vegetation. Exposures of the formation are generally poor except where there has been recent dissection.

Teichert's type locality is unsuitable as it is broken up by very many small strike faults which make it almost impossible to reconstruct a reliable stratigraphical section of the formation in this area, although the exposure of small parts of the section is better than anywhere else in the district. Several part sections have been measured in this locality but an amended type section, in which the top and base are well exposed and in which there is no faulting, is preferred for establishing the type thickness and lithology of this formation. The locality nearest to Teichert's type locality which fulfils the above requirements is 7½ miles south of west of Moogooree Homestead at Lat. 24°05½'S., Long. 115°06'E. This is proposed as the amended type locality. The sequence in this locality in descending order is as follows:

Friable pale brown thinly-laminated fine-grained micaceous quartz greywacke of the CUNDLEGO FORMATION conformably overlying

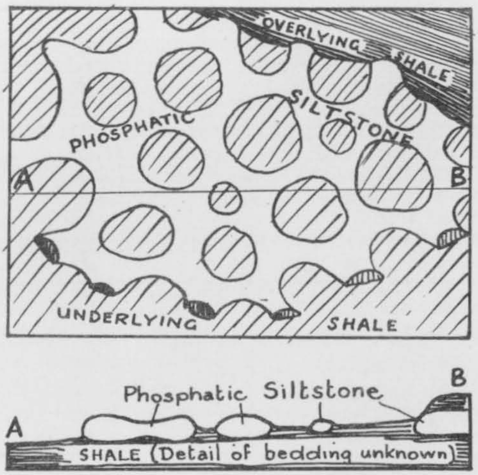
43 feet of soft dark-grey laminated siltstone with thin beds of laminated fine-grained quartz greywacke;
13 feet of soft dark-grey laminated siltstone;
30 feet of soft black carbonaceous shale;
1 foot of hard grey calcareous fine-grained quartz greywacke;
49 feet of soft dark-grey laminated fine-grained to coarse-grained siltstone;

2 feet of medium-hard greenish-grey calcareous quartz greywacke with crinoids, Thamnopora, Chonetes, (Samples MG/235, G/281, 282); thin cone-in-cone limestone;
38 feet of soft dark-grey fine-grained to medium-grained siltstone with few 'network beds' to 6" thick of medium-hard phosphatic siltstone containing small Chonetes, small gastropods, nautiloid, pelecypods; (Sample G/283);
50 feet of soft dark-grey laminated fine-grained to medium-grained siltstone with few 'network beds' of medium-hard red phosphatic siltstone; few pelecypods and Chonetes;
25 feet of soft grey thin-bedded shale and evaporite gypsum;
25 feet of friable light-grey laminated fine-grained quartz greywacke;
50 feet of soft black finely-laminated carbonaceous shale;
40 feet of soft dark-grey finely-laminated fine-grained siltstone;
20 feet of soft dark-grey thin-bedded fine-grained siltstone and evaporite gypsum;
140 feet of soft dark-grey medium-grained to fine-grained micaceous carbonaceous siltstone with many medium-hard red phosphatic siltstone 'network beds' up to 9" thick; Chonetes, small crinoid stem ossicles, bryozoa;
30 feet of soft black carbonaceous shale (Sample G/310);
70 feet of soft dark-grey laminated fine-grained to medium-grained carbonaceous siltstone with medium-grained red phosphatic siltstone 'network beds', and friable grey fine-grained laminated quartz greywacke with thin hard calcareous beds (Sample G/309); fossils include Chonetes, productids, spiriferids, Calceolispongia; overlying friable light greenish-grey laminated fine-grained quartz greywacke with thin hard calcareous beds, of the Mallens Greywacke.

626 feet - type thickness of the BULGADOO SHALE.

The base of the Bulgadoo Shale is placed at the change in lithology from dominantly quartz greywacke below to dominantly lutaceous sediments above and by the presence in the Bulgadoo of the beds of red phosphatic siltstone. The top of the formation is marked by the change from dominantly lutaceous sediments (siltstone and shale) to dominant quartz greywacke. The junction is marked by a thin hard calcareous quartz greywacke bed containing an interformational conglomerate of 'pebbles' of red and yellow phosphatic siltstone, and fossils. This bed is particularly well marked in the poorly exposed outcrop and forms a good mapping marker.

Very little has been done on the petrology of the Bulgadoo Shale. The dominant lithology is fine-grained and medium-grained micaceous, carbonaceous siltstone. One specimen of this rock-type yielded 3½% volatiles and 6½% fixed carbon; some of the shales probably have more hydrocarbons than this. Two evaporite units have been observed in this formation: they consist of soft lutite beds up to 6 inches thick with undulate beds of evaporite gypsum up to about 4" thick. A characteristic feature of the Bulgadoo Shale and of shales in other parts of the Byro Group is the type of bed for which the name "network bed" is proposed. A "network bed" consists of a reticulation of one lithology in another dominant lithology. In the Byro Group, the reticulation is composed of moderately hard calcareous and possibly phosphatic coarse-grained siltstone in a dominant lithology of laminated siltstone or shale.



Text Figure 1. - "Network structure" - reticulate bed of phosphatic siltstone in shale. Above - bedding plane view; below - section : A-B is about 6 feet long.

In bedding plane plan, a 'network bed' appears reticulate, with sub-circular holes filled with the dominant rock type. In vertical section, the bed appears as a series of disconnected ovate areas of rock of different lithology from the surrounding rock (See Text Figure 1). These could be mistaken for concretions except for the difference between the grain-size of the clastics composing them and the surrounding rocks. In some beds the holes are very large compared with the thickness of the reticulating material but in the more typical occurrence the diameter of the holes is about 2 to

4 times the thickness of the bed. A vertical section fresh enough to show the details of the lamination of the surrounding rock in the vicinity of the rock of the "network bed" has not been seen. It is thought that the form of the reticulation is probably related to polygonal shrinkage cracks in marine-deposited clay. The rounded form of the reticulating siltstone, the relative coarseness of that siltstone and its absence from other normal beds have not been explained. One of these beds would have to be excavated into fresh, unweathered material where the relationships of the bedding planes could be observed before an adequate background of observed relationships would be available on which to base an explanation. The rock of these 'network beds' is probably that in which Simpson (1926, p.93) found 7.35% of P_2O_5.

Very few reliable thicknesses of the Bulgadoo Shale are obtainable. In most areas one or other of the boundaries is covered by sand or is faulted out; in other areas where the boundaries can be located accurately, dip readings are not reliable. About eight miles north-east of Gascoyne Junction, the thickness is about 450 feet, at Merlinleigh it is 500 feet, and at the amended type section 626 feet. No thickness is available north of this area. A divergence northward is indicated.

Fossils in the Bulgadoo Shale are relatively few in number of species and individuals, and most forms are dwarfed. Fossils include foraminifera, bryozoa, corals (Thamnopora), crinoids, including Calceolispongia barrabiddiensis and C.acuminata (Teichert, 1949), Chonetes, spiriferids and productids, pelecypods, gastropods, nautiloid, ammonoid (Pseudoschistoceras simile (Teichert, 1944), and the shark Helicoprion.

Because of its stratigraphical position, between the Sakmarian Lyons Group and the Artinskian Coolkilya Greywacke, the Bulgadoo is referred to the Artinskian although, as Teichert has pointed out (1944, p.84), the ammonoid Pseudoschistoceras may indicate a Sakmarian or Sakmarian/Artinskian age.

The lithology and fauna of the Bulgadoo Shale indicate 'barred-basin' environment of deposition with the restriction of circulation becoming complete on two occasions when evaporites were deposited.

The Bulgadoo Shale can probably be correlated with part of the Irwin River Coal Measures, although it may be higher in the succession than that formation.

Cundlego Formation

The formation overlying the Bulgadoo Shale was named 'Cundlego Series' by Teichert (1941, p.381) and described as consisting of "fine-grained shaly to coarse-grained massive sandstones, commonly cross-bedded, with many intercalations of shale" with a thickness of 1500 feet. Teichert (1950, p.1791) renamed the formation 'Cundlego Sandstone' but as over 30% of the formation consists of siltstone as intercalations and members it is proposed to amend the name to 'Cundlego Formation', which is defined as the formation, consisting of fine-grained laminated quartz greywacke, hard calcareous quartz greywacke, and laminated carbonaceous siltstone, conformably overlying the Bulgadoo Shale and conformably underlying the Quinnanie Shale. In the Gascoyne area the coarser equivalent of the Quinnanie Shale is included with the Cundlego Formation (as it is of the same lithology) and the Cundlego Formation there is conformable under the Wandagee Formation.

The name (pronounced cu'n-del-gō) is taken from Cundlego Well and Cundlego Crossing on the Minilya River, at Lat. $23^{\circ}44\frac{1}{2}$'S., Long. $114^{\circ}27\frac{1}{4}$'E., about 5 miles west-north-west of Wandagee Homestead.

The type section (at Lat. $23^{\circ}45\frac{1}{4}$'S., Long. $114^{\circ}28\frac{1}{4}$'E.) is from $1\frac{1}{2}$ miles east-south-east to 1 mile south-east of Cundlego Well. It is one of the very few complete sections of this formation in this vicinity. The closely-spaced strike faults in the Wandagee area generally cut off parts of this formation. The sequence in the type section, from top to bottom, is as follows:

Soft white gypsite with fragments of red phosphatic siltstone of the QUINNANIE SHALE conformably overlying

2 feet of hard light-grey calcareous fine-grained quartz greywacke;

80 feet of friable light-grey laminated fine-grained quartz greywacke with few thin lenticular beds of hard calcareous quartz greywacke;

3 feet of hard grey laminated calcareous fine-grained quartz greywacke;

130 feet of friable laminated fine-grained quartz greywacke with thin hard calcareous lenses, and thin beds of soft dark-grey coarse-grained siltstone.

40 feet of medium-hard light-grey fine-grained quartz greywacke with thick, short lenses of hard calcareous quartz greywacke;

25 feet of firm light greenish-grey laminated fine-grained quartz greywacke;

30 feet of roughly bedded (? slumped) soft dark-grey siltstone (Sample G/218);

5 feet of lenticular hard cross-laminated calcareous fine-grained quartz greywacke;

25 feet of friable light greenish-grey laminated fine-grained quartz greywacke with Calceolispongia (Sample G/217);

20 feet of medium-hard grey laminated fine-grained quartz greywacke with beds of spiriferids (Samples G/215, 216) and beds to 2' thick of hard grey laminated calcareous quartz greywacke;

167 feet of friable light greenish-grey laminated fine-grained quartz greywacke with beds and lenses of hard grey laminated calcareous fine-grained quartz greywacke and few fossiliferous beds (Sample G/214); fossils include Chonetes, gastropods, Calceolispongia; few thin hard yellowish limestone beds; few thin soft dark-grey siltstone beds;

53 feet of soft dark-grey carbonaceous shale and siltstone with selenite at surface and few thin 'network beds' of medium-hard red phosphatic siltstone;

50 feet of friable light greenish-grey laminated fine-grained quartz greywacke with thin hard calcareous beds;

10 feet of hard grey laminated (cross-laminated) fine-grained calcareous quartz greywacke with fontainebleu structure (Sample G/213);

80 feet of friable light-grey laminated fine-grained quartz greywacke with few thin hard calcareous beds and much crumpling;

45 feet of medium-hard light-grey laminated quartz greywacke and thin soft dark grey siltstone;

215 feet of interlaminated soft dark-grey siltstone, some carbonaceous, and friable light-grey fine-grained quartz greywacke minutely current-bedded in places;

30 feet of soft dark-grey laminated siltstone with thin beds of friable light-grey fine quartz greywacke;

30 feet of friable light greenish-grey laminated fine-grained quartz greywacke, thin beds of soft dark-grey siltstone and of red phosphatic siltstone;

50 feet of friable light greenish-grey fine-grained quartz greywacke with few thin beds of red phosphatic siltstone thin beds of hard grey calcareous fine-grained quartz greywacke at the top and base; the basal hard bed has "pebbles" of red siltstone and fossils (Chonetes, gastropods) (Sample G/212);

conformably overlying soft dark-grey laminated siltstone with few thin network beds of red phosphatic siltstone and very few beds of quartz greywacke - the Bulgadoo Shale.

1090 feet - type thickness of the CUNDLEGO FORMATION.

The base of the Cundlego Formation is the thin bed of hard calcareous quartz greywacke containing small fragments of red phosphatic siltstone and fossils separating the dominantly lutaceous sediments of the Bulgadoo Shale below from the dominantly sandy sediments of the Cundlego above. The top of the Cundlego Formation in the type section is placed at the hard calcareous bed separating the greywacke and siltstone lithology of the Cundlego below from the carbonaceous shale of the Quinnanie Shale above. In the Lyons River - Gascoyne area, the lithology of the Quinnanie Shale has changed to siltstone and laminated quartz greywacke which is included in the Cundlego Formation. There the top of the Cundlego Formation is placed at the base of the richly fossiliferous interbedded medium-hard quartz greywacke and siltstone of the Wandagee Formation.

The friable quartz greywacke of the Cundlego Formation consists of 60% fine-sand-size minerals and 40% lutaceous matrix (Edwards, 1952, p.40 and Table 6). The minerals present comprise subangular to sub-round grains of quartz (about 60% - 40% in the sand and 20% in the matrix), angular grains of felspar (10% to about 20% - 5% to 10% in the sand, 5% to 10% in the matrix), biotite and muscovite (about 10% in the sand and perhaps 5% in the matrix), a little glauconite (about 1%), and abundant heavy minerals (about 4%) including colourless to pale pink garnet, zircon, and tourmaline. There is very little clay in the matrix. Sorting is poor - the grainsize ranges from 0.15 to 0.01 mm. Porosity is low (less than 10%) and permeability is low. The hard calcareous quartz greywacke consists of from 60% to 70% clastic grains and from 30 to 40% calcite which generally forms ophitic (fontainebleu) structure with calcite crystals from 1 to 10 mm. in diameter enclosing many fragmental grains. The composition of the clastic fraction is similar to that of the friable non-calcareous quartz greywackes but there is less fine-grained matrix and less heavy minerals. The siltstone of the Cundlego Formation has not been examined petrologically but in the field was seen to consist of relatively coarse quartz silt with much mica and black carbonaceous material.

As the Quinnanie Shale merges into the top part of the Cundlego Formation in the southern part of the area the thickness variations of these two formations will be considered together under 'Quinnanie Shale'. Between the Minilya and the Lyndon Rivers, the Cundlego Formation increases in thickness from 1090 to at least 1250 feet - a divergence of almost 7 feet per mile northward.

Fossils are very sparsely scattered through the Cundlego Formation; they are generally present in the basal beds but elsewhere in the formation fossiliferous beds are noticeably impersistent. The basal bed contains bryozoa (small and large branching forms and large fenestellid types), crinoid stem ossicles, brachiopods (mainly Chonetes, small spiriferid), gastropods, pelecypod, Laevidentalium. Within the formation Calceolispongia truncata (Teichert, 1949a), Neospirifer, Streptorhynchus, and Chonetes are common. Less abundant forms include bryozoa, corals, Plerophyllum and Verbeekiella (Hill, 1942), and pectinids and other pelecypods.

The Cundlego Formation is referred to the Artinskian Stage of the Permian because of its position, between the Sakmarian Lyons Group and the Artinskian Coolkilya Greywacke.

The Cundlego Formation may be correlated with part of the Irwin River Coal Measures and with part of the Noonkanbah Formation of the Fitzroy Basin.

The facies variation towards finer-grained sediments in the southern outcrop area combined with the thickness decrease in that direction may indicate that the main source of supply of sediment was into the northern end of the basin. There is not sufficient information available on the east-west variation in thickness and facies to indicate the location of the shoreline.

Quinnanie Shale

The name 'Quinnanie Shale' was introduced by Teichert

(1950, p.1791) as a formation name for the unit to which he had given the invalid name of 'Lingula stage' which was the lowermost unit of his 'Wandagee Series' (Teichert, 1946, p.99). In that paper, Teichert defined this unit as consisting of 560 feet of "carbonaceous and gypseous shales, with some sandstone and limestone horizons (the latter fossiliferous)". To this definition should be added "resting conformably between the Cundlego Formation below and the Wandagee Formation above". This relationship is implied in the table which includes the above definition, but not stated.

The name (pronounced kwin-a'n-nē) is taken from Quinnanie Corner, the south-eastern corner of Coolkilya Paddock, Wandagee Station, at Lat. 23°48'S., Long. 114°28'E.

The Quinnanie Shale outcrops in a narrow discontinuous belt of reduced topography and poor exposure from the type locality to Barrabiddy Creek. There is another small outcrop near the head of Nortons Creek. East and south-east of Merlinleigh the formation is reduced in thickness and changing into the coarser sediments typical of the Cundlego Formation. In the area between Lyons River Homestead and Gascoyne, the stratigraphical equivalent of the Quinnanie is included in the Cundlego Formation. The surface of the outcrop area of the formation is flat and generally contains swampy areas. The vegetation is very sparse.

The type section, on the northern bank of the Minilya River, at Lat. 23°44'S., Long. 114°25'E., is not a complete section of the formation as the junction between the Quinnanie and the Cundlego is a fault cutting out the uppermost part of the Cundlego and possibly the lowermost part of the Quinnanie. The sequence in the type section, in descending order, is as follows:

Thin-bedded friable light-grey medium-grained to fine-grained fossiliferous quartz greywacke of the WANDAGEE FORMATION, conformably overlying

38 feet of soft dark-grey micaceous carbonaceous siltstone with selenite in weathered rock;

2 feet of lenticular medium-hard grey calcareous fine-grained quartz greywacke;

60 feet of soft dark-grey micaceous siltstone (with selenite in weathered rock) with few small productids;

125 feet of soft dark-grey laminated micaceous, carbonaceous siltstone and soft black carbonaceous, pyritic shale and few thin 'network beds' of medium-hard red phosphatic siltstone;

10 feet of medium-hard to friable grey fine-grained quartz greywacke with medium-hard red 'mud-balls' of phosphatic siltstone containing Lingula, spiriferids, crinoid stem ossicles, productids, gastropods, pectenids (Sample MG/252);

110 feet of soft dark grey micaceous carbonaceous siltstone and shale (Sample MG/251) with few 'network beds' of medium-hard red phosphatic siltstone;

Faulted against Cundlego Formation.

By correlation of the above part-section with a complete but poorly exposed section 4000 feet north-east of Quinnanie Corner, the section of the formation may be completed thus:

10 feet of friable grey fine-grained quartz greywacke with 'mud-balls' of medium-hard red phosphatic siltstone containing fossils including foraminifera, crinoid stem ossicles, Calceolispongia, Lingula, Chonetes, Neospirifer, Linoproductus, gastropods (Samples MG/242, 243);

160 feet of soft dark-grey carbonaceous siltstone and shale weathering to gypsite at the surface; conformably overlying a bed of hard grey calcareous fine-grained quartz greywacke 2 feet thick at the top of the CUNDLEGO FORMATION.

515 feet - type thickness of the QUINNANIE SHALE

The base of the Quinnanie shale is placed at the lithological change from quartz greywacke below to dominantly siltstone and shale above. In the type area this is marked by a hard calcareous bed at the top of the Cundlego Formation. The top of the Quinnanie Shale is placed at the base of the lowermost fossiliferous calcareous quartz greywacke of the Wandagee Formation. Above this bed the siltstone beds are relatively thin (generally less than 10 feet thick); below it the lutaceous sediments are pre-dominant.

The only petrological work done on the rocks of the Quinnanie Shale is that by Higgins and Carroll (1940) on the heavy minerals. They do not state the lithology of the sample analysed but the very low percentage of heavy minerals ("trace") suggests that the specimen may have been a siltstone. Garnet, leucoxene and zircon are the main heavy minerals.

At the head of Norton Creek the Quinnanie Shale is about 400 feet thick although only the uppermost 85 feet is shale. The lower part is siltstone and laminated fine-grained quartz greywacke, but as the siltstone is dominant it is referred to the Quinnanie. This section shows the change of facies in this formation towards the Cundlego type. One mile south of Merlinleigh Homestead, the thickness of the formation which can be referred to the Quinnanie is only 135 feet, and east of K-38 there is nothing between the Cundlego and Wandagee Formations that can be placed in the Quinnanie Shale . Taking the Cundlego Formation and Quinnanie Shale together, the thickness on the Minilya River at Wandagee is 1605 feet. At the head of Nortons Creek, 53 miles to the south east, the thickness is about 1000 feet - a convergence of 11 feet per mile. Fifty-six miles south of the previous locality, 8 miles north-east of Gascoyne Junction, the thickness is about 700 feet - a convergence of 5½ feet per mile. If convergence is uniform between Wandagee and Gascoyne Junction, these figures would indicate a westward divergence of 20 feet per mile.

Fossils in the Quinnanie Shale are most numerous in the quartz greywacke beds. In the lutites only arenaceous foraminifera and few megafossils are found. In the sandy beds there is a fairly rich fauna including arenaceous foraminifera, crinoid stem ossicles, *Calceolispongia*, *Lingula*, *Neospirifer*, *Linoproductus*, *Chonetes*, *Streptorhynchus*, Bellerophontidae, Aviculopectinidae, *Permonautilus*.

The age of the Quinnanie Shale is Artinskian as it lies between the Artinskian Callytharra Formation and the Artinskian Coolkilya Greywacke.

The Quinnanie Shale is of typical euxinic facies (pyritic black shale) deposited in a 'barred basin' with restricted circulation. The fossiliferous quartz greywacke beds indicate the incoming of more normal marine conditions for short periods. No evaporites are known from the Quinnanie.

Wandagee Formation

The name 'Wandagee Formation' was first used by Condit (1935, p.870) for the "carbonaceous sandy and calcareous shale, and sandstones with erratic boulders and marine fossils" outcropping on the Minilya River downstream of Wandagee Homestead. It was thought to be the uppermost formation of the Permian of the basin, because of the correlation of the Cundlego with the Kennedy Group. Raggatt (1936, p.145) called this sequence the 'Wandagee Stage'. His type section (p.146) shows that this comprised the Quinnanie Shale and the Wandagee Formation as now restricted. Teichert in 1941 re-named Raggatt's section the 'Wandagee Series' which is informal as it was not intended as a time-rock term. He separated the sequence into four 'stages', also informal. In 1950 (p.1791) he gave these 'stages' formation names without formal definition of lithological boundaries. The Quinnanie Shale was separated from the base of Raggatt's 'Wandagee Stage' and the remainder of Raggatt's 'Wandagee Stage' was given the old name of Wandagee Formation.

The Wandagee Formation is re-defined as the formation conformable between the Quinnanie Shale (or the equivalent part of the Cundlego Formation) and the Norton Greywacke. It consists of siltstone and quartz greywacke, some calcareous, with thin beds of limestone. The lower part is very fossiliferous, the upper part contains fossiliferous beds.

The name (pronounced wo'n-d<u>a</u>-jē) is taken from Wandagee Station, where the type section outcrops on the Minilya River.

The type section of the Wandagee Formation is along the right (north) bank of the Minilya River $8\frac{1}{2}$ miles west of Wandagee Homestead, at Lat. $23^{\circ}44'$S., Long. $114^{\circ}24\frac{3}{4}'$E. In descending order, the sequence there is as follows:

Thin-bedded friable and medium-hard light-grey medium-grained to fine-grained quartz greywacke of the NORTON GREYWACKE, conformably overlying

70 feet of friable light-grey laminated fine-grained quartz greywacke and soft dark-grey siltstone;

35 feet of laminated and thin-bedded medium-hard to friable light-grey medium-grained to fine-grained quartz greywacke (Sample MG/284);

10 feet of cyclic friable light-grey fine-grained quartz greywacke and soft dark-grey micaceous carbonaceous siltstone; cycles 3" to 6" thick (Sample MG/283);

30 feet of soft dark-grey micaceous siltstone with few thin beds of friable fine-grained quartz greywacke (Sample MG/260);

58 feet of soft dark-grey siltstone with thin beds and lenses of medium-hard grey calcareous medium-grained quartz greywacke and red phosphatic 'mud-balls' containing small and large productids and large spiriferids (Sample MG/259):
10 feet of thin-bedded medium-hard grey fine-grained greywacke with invertebrate trails, and soft dark-grey siltstone; beds 3 to 6 inches thick;
21 feet of soft dark grey micaceous carbonaceous siltstone with beds from 1" to 6" thick of medium-hard to friable fine-grained quartz greywacke containing _Strophalosia_, _Neospirifer_, and _Chonetes_ (Sample MG/258);
16 feet of soft friable dark-grey micaceous, carbonaceous shale;
7 feet of soft dark-grey micaceous siltstone and medium-hard grey quartz greywacke;
66 feet of medium-hard grey quartz greywacke in beds to 2' thick with ferruginous 'mud-balls' and large _Neospirifer_, _Calceolispongia elegantula_, _C. multiformis_, corals, small productids, fenestellid bryozoa, _Astartila_ (Sample MG/257);
3 feet of medium-hard grey micaceous fine-grained quartz greywacke;
18 feet of thin-bedded friable dark-grey fine-grained quartz greywacke and micaceous siltstone with bryozoa, _Calceolispongia_, crinoid stem ossicles, _Neospirifer_, _Taeniothaerus_, _Conularia_, Bellerophontidae (Sample MG/256);
6 feet of massive medium-hard grey calcareous quartz greywacke;
4 feet of thin-bedded soft dark-grey micaceous coarse siltstone;
4 feet of medium-hard grey medium-grained quartz greywacke containing large _Aulosteges_, small productids, large spiriferids, and crinoid stem ossicles in red phosphatic 'mud-balls';
12 feet of thin-bedded friable dark-grey very fine-grained quartz greywacke with large _Aulosteges_, large _Neospirifer_, small productids, crinoid stem ossicles and _Calceolispongia_ (Sample MG/255);
6 feet of bedded medium-hard grey quartz greywacke with _Calceolispongia_ and small productids, _Taeniothaerus_, _Neospirifer_, Orthotetinae, _Atomodesma_, pectinids, and bryozoa (Sample MG/253, 254);
45 feet of thin-bedded friable grey medium-grained to fine-grained quartz greywacke with large and small productids, spiriferids, and _Calceolispongia_;
4 feet of hard grey calcareous quartz greywacke; conformably overlying 38 feet of soft dark-grey micaceous carbonaceous siltstone of the Quinnanie Shale.

425 feet - type thickness of WANDAGEE FORMATION.

The base of the Wandagee Formation is marked by the hard calcareous bed about 4 feet thick which separates the fossiliferous fine greywacke of the Wandagee above from the sparsely fossiliferous carbonaceous siltstone of the Quinnanie below. The above type section is continuous with the type section of the Quinnanie Shale.

The bottom 100 feet generally crops out as a low strike ridge with abundant fossils scattered over the surface. In aerial photographs this member has a dark tone with about seven beds showing up clearly. The upper 325 feet form a reduced flat surface with very sparse vegetation; one fossiliferous quartz greywacke bed about 230 feet above the base forms a prominent strike ridge in some places. This upper silty part generally has a very light tone in aerial photographs.

The only petrological work done on the Wandagee Formation is that of Higgins and Carroll (1940) on the heavy minerals. Their samples numbered 9 to 15 comc from the Wandagee Formation. They show only trace amounts of heavy minerals, consisting mainly of leucoxene, zircon, and garnet, with minor ilmenite, tourmaline, and rutile. These samples were probably all siltstones. In hand specimen, the quartz greywacke of the Wandagee Formation is seen to consist of subangular to subround quartz (about 60%), felspar (about 10%), white mica (1% to 3%), and silt matrix (about 30%). There are some dark grains which may be black chert (about 5%). The arenites, like most of the arenites of the Byro Group, have insufficient silty matrix and/or rock fragments to be called a greywacke (Condon, 1952) but the presence of appreciable amounts of felspar and silty matrix precludes the use of 'sandstone'. For this marginal but important rock type the term Quartz greywacke is used, very much in the sense of Fischer's '<u>qartz-wacke</u>' (1933).

The Wandagee Formation is one of the most uniform formations in thickness. The thickness is 425 feet in the type section on the Minilya River, 650 feet at the head of Norton Creek, 800 feet 4½ miles north of Paddys Outcamp, 545 feet one mile south of Merlinleigh Homestead, and 395 feet 12 miles north of Gascoyne Junction. Convergence appears to be south-westward at about 10 feet per mile.

The Wandagee Formation is one of the more richly fossiliferous formations of the Upper Palaeozoic sequence of the Carnarvon Basin. There is a large number of species, a large number of individuals, and the individuals include large to very large forms. They include foraminifera: <u>Ammodiscus</u>, <u>Hyperammonoides</u>, (Crespin, 1947, p.17); corals - <u>Allotriophyllum</u>, <u>Euryphyllum</u>, Verbeekiella, Thamnopora (Hill, 1942); crinoids - Calceolispongia (Teichert, 1949); bryozoa - Fenestrellina, Minilya, Polypora (Crockford, 1944a and b); brachiopods - Aulosteges, Dictyoclostus, Krotovia, Linoproductus, Strophalosia, Taeniothaerus (Prendergast, 1944), Chonetes, Phricidothyris, Neospirifer, Spiriferella, Streptorhynchus (J.M. Dickins and G.A. Thomas, personal communication); pelecypods - Atomodesma, Astartila, Streblopteria (J.M. Dickins, personal communication), Deltopecten; gastropods - bellerophontids, ?Omphalotrochus, Conularia; ammonoids - Propinacoceras (Teichert, 1942, p.226); nautiloids - Titanoceras (Teichert, 1951).

No species of the Wandagee Formation fauna is diagnostic of precise age, but the assemblage of foraminifera is related to the Eastern Australian Maitland Group (former 'Upper Marine') and the assemblage of brachiopods is closely related to that of the Lower Productus Limestone of the Salt Range. The diagnostic ammonoid Paragastrioceras is found in the Coolkilya Greywacke. By reason of its position relative to the stratigraphical position of Paragastrioceras, and of its correlation with the Lower Productus Limestone, the Wandagee Formation may be referred to the Artinskian Stage of the Permian with reasonable certainty.

There is no formation in the Irwin Basin which can be definitely correlated with the Wandagee Formation although it is possible that the Irwin River Coal Measures are the equivalent of the Byro Group as a whole. The Wandagee Formation may be correlated with the Noonkanbah Formation of the Fitzroy Basin.

The variation in thickness and lithology from north-west to south-east suggests that the main source of the sediments was to the north of the outcrop area and that the shore-line ran in a north-westerly direction through the vicinity of Mangaroon, or even farther east.

Norton Greywacke

The Norton Greywacke is defined as the formation, consisting of thin-bedded greywacke and quartz greywacke containing lamellibranchs, resting conformably between the Wandagee Formation below and the Baker Formation above.

The name is taken from Norton Creek, which flows into the Minilya River from the south-east at Lat. $24^{\circ}00\frac{1}{2}$'S., Long. $114^{\circ}56\frac{1}{4}$'E. The type locality of the formation is in the south-eastern drainage area of this creek.

The Norton Greywacke generally outcrops as a prominent rounded strike ridge which has a very dark tone on aerial photographs. It supports a relatively dense growth of acacia scrub and spinifex. There is a small area of outcrop in the syncline north of the Minilya River nine miles westward from Wandagee Homestead and there are poor outcrops on the Wandagee to Manberry road north of Wandagee Hill, $6\frac{3}{4}$ and $7\frac{1}{2}$ miles from Wandagee. The formation crops out around the north-western end of the Kennedy Range, mainly on the flat below the scarp, from near Paddys Outcamp on the Middalya to Hill Springs road to the head of the western branch of Norton Creek. To the east of the Kennedy Range the formation is well exposed in a prominent strike ridge from five miles south-south-west of Merlinleigh Homestead to 8 miles north of Gascoyne Junction.

The type section of the Norton Greywacke is in the ridge between the head of 'Blackheart Creek' and Norton Creek, at the south-western end of Williambury Station, south of the southern fence of Kimbers Paddock. This locality is 25 miles south-south-west of Williambury Homestead and 26 miles south-east of Middalya Homestead, at Lat. $24^{\circ}12\frac{1}{4}$S., Long $115^{\circ}02$'E. The sequence from top to bottom is as follows:

	Soft dark-grey laminated micaceous, carbonaceous siltstone of the Baker Formation, conformably overlying
5 feet of	medium-hard grey calcareous medium-grained quartz greywacke;
80 feet of	friable grey laminated medium-grained micaceous quartz greywacke with ferruginous concretions to 2' x 1' x 1';
75 feet of	friable to medium-hard grey roughly-bedded medium-grained quartz greywacke with a ferruginous skin at the surface; many conical 'worm mounds' to 6" high and 18" diameter on bedding planes; scattered large ferruginous concentric-laminated concretions to 3' x 2' x1';
1 foot of	pelecypod coquinite (at the surface, the shells are missing - ferruginous casts preserve the fossils) (Sample MG/264);

24 feet of medium-hard light yellow-brown roughly-bedded medium-grained quartz greywacke; some beds ferruginous at the surface;

25 feet of medium-hard, light yellow-brown roughly bedded medium-grained quartz greywacke with conical 'worm mounds' and pelecypods;

25 feet of friable thin-bedded to laminated medium-grained quartz greywacke;
conformably overlying 50 feet of soft dark-grey siltstone with few thin beds of laminated fine-grained quartz greywacke, of the Wandagee Formation.

235 feet - type thickness of the NORTON GREYWACKE.

The base of the Norton Greywacke is marked by the change in lithology from the lutaceous type of the uppermost part of the Wandagee Formation below to the roughly-bedded medium-grained quartz greywacke of the Norton above.

The only work done on the petrology of the Norton Greywacke is the heavy mineral analyses of Higgins and Carroll (1940). Their samples numbered 1, 3 and 5, from their positions on the accompanying plan, are almost certainly Norton Greywacke and have similar heavy mineral indices and content. The dominant heavy minerals in these samples are zircon, leucoxene, and garnet, with minor ilmenite, rutile, and tourmaline. In hand specimen, the rock of the lower part of the Norton Greywacke is seen to consist of subangular to subrounded quartz (50% to about 70%), felspar (about 10%), mica (about 3%) and black mineral (? chert) - about 10% with a dark silty matrix (about 30% to 40%).

The thickness of the Norton Greywacke varies from 177 feet in the Minilya Syncline to about 250 feet at Paddys Outcamp on the Middalya to Hill Springs road, 160 feet 9½ miles south-south-west of Merlinleigh Homestead, and 215 feet 12 miles north of Gascoyne Junction. This indicates that divergence is westward in the Kennedy Range area and south-westward between Norton Creek and Wandagee Hill.

Fossils are not very plentiful in the Norton Greywacke. In the type locality, two pelecypod coquinites and one Chonetes coquinite bed constitute the only fossiliferous beds seen. On the east side of the Kennedy Range, brachiopod coquinite beds occur in the uppermost part of the Norton Greywacke. Fossils so far identified by J.M. Dickins from the Norton include : Oriocrassatella, Streblopteria, Schizodus, Atomodesma, pectenid, Chonetes, Strophalosia, Neospirifer, ?Aulosteges, gastropods, Calceolispongia. None of these is diagnostic of precise age. The stratigraphical position of the Norton Greywacke, beneath the Artinskian Coolkilya Greywacke, places it in the Artinskian.

The Norton Greywacke may be correlated with the upper part of the Noonkanbah Formation of the Fitzroy Basin, but it is doubtful if there is any equivalent formation in the Irwin Basin.

The Norton Greywacke is marked by the absence of siltstone and in that respect is different from the bulk of the Byro Group. It indicates the incoming of the environment of deposition in which the whole Kennedy Group was deposited. This environment is probably related to the closing stages of the Permian sedimentation in this basin, when the source area must have been reduced and the rate of sedimentation reduced. The environment of deposition was a shallow sea over a slowly subsiding shelf. The unsorted nature of the sediments probably implies humid conditions in the source area while the comparative absence of felspar and rock fragments indicates that the source area was subject to chemical weathering and therefore was probably of low relief.

Nalbia Greywacke

The "Nalbia Sandstone" was named by Teichert (1950) to replace the informal 'Schizodus beds' which he had described (Teichert, 1946) as consisting of "190 feet of well-bedded, shaly and friable sandstones, greenish grey to brown. Rich in fossils (pelecypods) in some places, almost unfossiliferous in others". In a recent paper (Teichert, 1952) he stated "the Nalbia Sandstone is a grey calcareous sandstone, hard when fresh ... weathers into crumbly friable sandy rock ... generally of dark olive brown colour". From the discussion of the outcrop area and fossils of the "Nalbia Sandstone" and "Coolkilya Sandstone" in that paper, it appears that in some places Teichert has correlated his "Nalbia Sandstone" with the unit which is here named Norton Greywacke whereas in other places he has included a unit of similar thickness, lithology and fauna in his "Coolkilya Sandstone". As it is only in the well-exposed unbroken sections in the Kennedy Range area that the sequence between the upper part of the Byro Group and the lower part of the Kennedy Group can be established with certainty, it is proposed to retain the name "Nalbia Greywacke" only for those isolated outcrops in the Wandagee Hill area containing the characteristic Schizodus coquinites. This includes the type locality (personal communication, Dr. C. Teichert) 0.9 mile west of Quinnanie Corner, Wandagee Station, and the central part of the north-plunging syncline in the middle part of Coolkilya Paddock, Wandagee Station. The only other area where the characteristic Schizodus coquinites are exposed is immediately north-east of Paddys Outcamp, Middalya Station and 3 miles to the north of that outcamp. This is the only place where there is reasonable certainty that the "Nalbia Greywacke" may be correlated with the "Norton Greywacke". As there are Schizodus coquinites also in the Coolkilya Greywacke, and as the heavy mineral analysis of the "Nalbia Greywacke" is closer to that typical of the Coolkilya Greywacke than to that of the Norton Greywacke (Higgins and Carroll, 1940) there is some residual doubt about the stratigraphical position of the "Nalbia Greywacke".

The sequence in the type locality, 0.9 mile west of Quinnanie Corner, Wandagee Station, is as follows (in descending order):

Top of outcrop

15 feet of friable thin-bedded dark greenish brown silty greywacke;
1 foot of hard grey calcareous quartz greywacke with Schizodus coquinite up to 6 inches thick containing Schizodus (abundant), Oriocrassatella, Pachydomus, Aviculopecten, Chonetes, Neospirifer, Strophalosia kimberleyensis, Bellerophon, Warthia spp., Mourlonia, Marocheilus (Sample ML/65);
54 feet of friable thin-bedded dark greenish grey medium-grained silty quartz greywacke;
1 foot of hard grey calcareous quartz greywacke with thin Schizodus coquinite containing abundant Schizodus and Oriocrassatella, Stutchburia, Mourlonia, Warthia, and Neospirifer (Sample ML/64);

47 feet of	friable thin-bedded dark greenish grey medium-grained silty quartz greywacke;
2 feet of	hard brownish green calcareous greywacke with Schizodus coquinite up to 6 inches thick containing abundant Schizodus, and Oriocrassatella, Stutchburia, Streblopteria, Warthia, Bellerophon, Mourlonia, Strophalosia kimberleyensis, Chonetes; (Sample ML/63);
10 feet of	friable dark greenish brown medium-grained silty quartz greywacke;
	Bottom of outcrop
130 feet -	thickness of "Nalbia Greywacke" in Teichert's type locality.

As the sequence above and below the "Nalbia Greywacke" is not exposed the top and base of the "Nalbia Greywacke" cannot be defined.

Because of the doubts as to the stratigraphical position of the Nalbia the faunas from different localities which have been referred to the Nalbia need to be kept separate so that there will be less possibility of mixing faunas from different stratigraphical levels. At the type locality the fauna is dominated by pelecypods, of which the main genera are: Schizodus, Oriocrassatella, Stutchburia, Pachydomus, Streblopteria and Aviculopecten; gastropods are mainly small Warthia, Mourlonia, Bellerophon and Marocheilus; the few brachiopods include Neospirifer byroensis, Chonetes, and Strophalosia kimberleyensis; Calceolispongia (few basal plates) is the only other form recognized. In the syncline in the central part of Coolkilya Paddock, Wandagee Station, there are two Schizodus coquinites about 40 feet apart stratigraphically and a Cleiothyridina coquinite about 50 feet above the upper Schizodus coquinite. It is from this locality that Teichert reported Paragastrioceras Pseudogastrioceras and Propinococeras and the shark Helicoprion but referred it to the Coolkilya Greywacke.

It is probable that this sequence in the Coolkilya Syncline belongs to the "Nalbia Greywacke" in which case the "Nalbia Greywacke" is of definite Artinskian age.

For the present the "Nalbia Greywacke" is correlated tentatively with the sequence containing diagnostic Artinskian species in the Coolkilya Syncline and, because of the appearance of "Nalbia"-

type beds in the area north of Paddys Outcamp, Middalya Station, with the Norton Greywacke. If this correlation is correct it is possible that the top of the Byro Group is approximately equivalent to the top of the Artinskian and that the Kennedy Group could be correlated with the Kungurian Stage.

Baker Formation

The Baker Formation is defined as the formation of siltstone and laminated quartz greywacke conformable between the Norton Greywacke below and the Coolkilya Greywacke above.

The name is taken from Baker's Bore on Middalya Station at Lat. $24^{o}07\frac{3}{4}$'S., Long. $114^{o}55$'E.

This Formation outcrops in the 'Minilya Syncline' north of the Minilya River nine miles westward of Wandagee Homestead, in poorly exposed narrow belts north of Wandagee Hill (crossing the Wandagee to Manberry road $6\frac{3}{4}$ and $7\frac{1}{2}$ miles westward of Wandagee Homestead), in a very poorly exposed belt around the north-western end of Kennedy Range from 6 miles north-east of Paddys Outcamp to 2 miles south-west of K-54, in a belt from 1 mile south of K-54 to the type locality 15 miles south-east of K-54, and in a belt on the east side of the Kennedy Range from 9 miles west of south of Merlinleigh Homestead to 9 miles north of Gascoyne Junction and thence to the vicinity of K-37. The Formation forms a strike valley of reduced topography with very sparse vegetation including halophytic types. On aerial photographs the outcrop of the Formation has a very light tone although this is masked in many areas by the dark tone of the ferruginous scree from the adjoining Kennedy Group.

The Formation has not previously been reported although it outcrops well in the Minilya Syncline and to the east of the eastern Scarp of the Kennedy Range. Because it is of the typical lithology of the Byro Group, it is included as the uppermost Formation of that group.

The type section is continuous with the type section of the Norton Greywacke, at the head of 'Blackheart Creek', a southern tributary of Norton Creek. It is in the southwestern, unfenced part of Williambury Station, south of the southern fence of Kimbers Paddock, at Lat. $24^{\circ}13\frac{1}{4}$'S., Long. $115^{\circ}02\frac{3}{4}$'E. The sequence from top to bottom is as follows:

	Friable to medium-hard grey medium-grained to fine-grained thin-bedded to laminated quartz greywacke of the COOLKILYA GREYWACKE, conformably overlying
23 feet of	friable grey medium-grained quartz greywacke and soft dark grey siltstone;
5 feet of	medium-hard purplish-grey medium-grained quartz greywacke, cross-bedded;
18 feet of	soft dark-grey laminated siltstone with thin beds of fine-grained quartz greywacke;
6 feet of	medium-hard light-grey medium-grained quartz greywacke;
10 feet of	soft dark-grey laminated siltstone and laminated fine-grained quartz greywacke;
18 feet of	medium-hard light-grey massive-weathering thin-bedded medium-grained quartz greywacke with a 3" bed of *Chonetes* coquinite near the top;
30 feet of	soft dark-grey to black laminated micaceous carbonaceous siltstone with laminae and thin beds of fine-grained quartz greywacke;
12 feet of	soft dark-grey siltstone and laminated medium-grained quartz greywacke in beds to 2' thick;
21 feet of	soft dark-grey laminated micaceous carbonaceous siltstone;
2 feet of	friable light-grey fine-grained quartz greywacke;
53 feet of	soft dark-grey to black laminated micaceous carbonaceous siltstone with laminae and thin beds of fine-grained quartz greywacke and a thin *Chonetes* coquinite near the base;
	conformably overlying 5 feet of medium hard grey calcareous medium-grained greywacke of the NORTON GREYWACKE.
198 feet -	type section of BAKER FORMATION

The thickness of the Baker Formation is 153 feet in the Minilya Syncline, about 210 feet 7 miles north-east of Paddy's Outcamp, 198 feet in the type locality 11 miles west-north-west of Merlinleigh Homestead, 122 feet $9\frac{1}{2}$ miles south-south-west of Merlinleigh Homestead, and 85 feet 14 miles north of Gascoyne Junction. These thicknesses suggest that the shoreline during the deposition of the Baker Formation swung in a curve through Wyndham River, Eudamullah, Lyndon and Winning Pool.

The base of the formation is marked by the change in lithology from quartz greywacke in the Norton to dominant siltstone in the Baker. A hard calcareous bed at the top of the Norton makes the boundary easy to map in areas of poorly exposed outcrop. The top of the Baker Formation is placed at the top of those beds which include siltstone beds. In poorly exposed outcrop, the boundary is marked by the more resistant strata, including thin hard calcareous beds, of the base of the Coolkilya Greywacke.

No detailed work has been done on the petrology of the rocks of the Baker Formation. The siltstone is generally medium-grained and laminated and includes quartz, mica, and carbon. The quartz greywacke consists dominantly of subangular quartz, with an appreciable proportion of silty matrix and minor amounts of felspar, white mica, and black chert. It is generally fine-grained and laminated. The beds of quartz greywacke in the middle of the formation are calcareous in lenses.

Only Chonetes was found in the type section, but along the east side of the Kennedy Range a richer fauna was found, including spiriferids, small productids, ?Aulosteges, Chonetes, and pectenids, in a quartz greywacke member in the middle of the formation. As with the lower formations the age of the Baker Formation is fixed by its stratigraphical position immediately below the Artinskian Coolkilya Greywacke: it is therefore referred to the Artinskian.

The Baker Formation may be correlated with the uppermost part of the Noonkanbah Formation of the Fitzroy Basin. No equivalent formation is known in the Irwin Basin.

Kennedy Group

This name was first used by Maitland (1919, p.5), who described this group as "the sandstones of the Kennedy Range". The unit was first formally named by Condit (1935, p.870) as 'Kennedy Sandstone', consisting of "massive to thin-bedded sandstones; ferruginous, fossiliferous concretions in lower part; forms Kennedy Range". Raggatt (1936, p.141) gave it the invalid name 'Kennedy Stage'. He stated that "the sandstones which compose the (Kennedy) range overlie the more shaly strata of the Byro 'Stage', the contact being conformable". He described a section of the Cundlego Formation on the Minilya River as belonging to the 'Kennedy Stage' and this led him to place the 'Wandagee Stage' above the Kennedy. His 'Wandagee Stage' is now known to be part of the Byro Group, stratigraphically lower than the Kennedy. As there is a big thickness, including many arenaceous formations, in the strata of the Kennedy Range above the Byro Group, it is proposed to re-name this unit the Kennedy Group and to define it thus : the Kennedy Group consists of predominantly arenaceous sediments conformably overlying the Byro Group. In outcrop, no Permian formation of different lithological type is known overlying the rocks of the Kennedy Group: the top of the uppermost formation of the Kennedy Group in outcrop is an erosion surface. For the present, the upper formations are not being named separately. The formations included in the Kennedy Group are the lowermost Coolkilya Greywacke, the Mungadan Sandstone, and the Binthalya Subgroup.

The name is taken from the Kennedy Range - a flat-topped, steep-sided plateau about 60 miles long and from 12 to 20 miles wide between the Minilya and Gascoyne Rivers on the 115° meridian. Sediments of the Kennedy Group form the bulk of the range except in its north-eastern corner.

The maximum thickness of the Kennedy Group, in the vicinity of Venny Peak, is about 2540 feet. As it is only in this area that the uppermost formations are exposed, there are no data available on the variation of thickness of the group.

<u>Coolkilya Greywacke</u>

This formation was named as 'Coolkilya Sandstone' by Teichert (1950, p.1791) to replace the informal '*Linoproductus* beds', which he described (Teichert, 1946, p.99) as consisting of "1000 feet of fine to medium grained sandstones, in many places strongly ferruginous". No type section was described or located apart from the general "vicinity of the Minilya River". Teichert at the same time re-named his '*Schizodus* Stage', calling it 'Nalbia Sandstone'. In the type locality - Wandagee Hill to Minilya River - there is no single section in reasonably exposed outcrop showing the relationship between the '<u>Schizodus</u> Stage' and the '<u>Linoproductus</u> Stage', and it is very doubtful if a composite section covering the whole sequence could be built up in this area.

The Coolkilya Greywacke is defined as the basal formation of the Kennedy Group, consisting of friable thin-bedded to laminated quartz greywacke, thin hard calcareous beds, and many fossiliferous beds, and resting conformably between the Baker Formation below and the Mungadan Sandstone above.

The name Coolkilya (pronounced kōōl-kil'-ya) is taken from Coolkilya Paddock on Wandagee Station, the southeastern corner of which is six miles west-south-west of Wandagee Homestead.

The following part sections have been measured in the original type locality. The first section, of the upper part of the formation, is on the north-eastern flank of Wandagee Hill (Lat. 23°50' S., Long. 114°27'E.) where the sequence from top to bottom is:

Thin-bedded medium-hard medium-grained silty quartz sandstone of the MUNGADAN SANDSTONE conformably overlying

2 feet of hard, dark red-brown ferruginous coarse-grained quartz greywacke, with interior and exterior moulds of spiriferids, pectenids and <u>Oriocrassatella</u> (Sample MG/196);

40 feet of thin-bedded friable grey medium-grained quartz greywacke, with few thin beds of friable white medium-grained quartz sandstone;

28 feet of thin-bedded friable grey medium-grained to coarse-grained quartz greywacke, with few thin beds of hard calcareous quartz greywacke;

25 feet of thin-bedded friable grey medium-grained and coarse-grained quartz greywacke;

75 feet of thin-bedded friable grey medium-grained quartz greywacke with few beds of hard calcareous coarse-grained and medium-grained quartz greywacke (Sample MG/197);

3 feet of hard grey calcareous medium-grained quartz greywacke (ferruginous at surface);

10 feet of friable grey medium-grained quartz greywacke;

7 feet of hard brown calcareous medium-grained to coarse-grained quartz greywacke with many <u>Chonetes</u> and few orthotetids (Sample MG/198);

60 feet of thin-bedded to laminated friable grey fine-grained to coarse-grained quartz greywacke with very few thin beds of hard grey calcareous coarse-grained quartz greywacke (Sample MG/199);

55 feet of laminated grey fine-grained quartz greywacke with thin beds of hard calcareous fine-grained quartz greywacke; gastropods and pelecypods at the top;

3 feet of hard brown calcareous fine-grained quartz greywacke with grains of coarse quartz sand and brachiopods and bryozoa (Sample MG/200);

Bottom of exposed section

308 feet - section of upper part of COOLKILYA GREYWACKE in Teichert's type locality.

As there is no place in the original type locality in the vicinity of Wandagee Hill where the complete section between the Baker Formation and the Mungadan Sandstone is exposed, it is proposed to describe such a section from the north-western end of the Kennedy Range as the amended type section of the Coolkilya Greywacke. This type section is in the area from 8000 feet north-north-west of Southern Cross Bore, Middalya Station (Lat. 24°06½'S., Long. 114°49½'E.) to 4800 feet south of the bore. Almost the whole of the formation is exposed in small creeks in this area and in the main scarp of the Kennedy Range, although there is no single continuously exposed section through the whole formation. The sequence in descending order is as follows (lines of dashes separate the parts of the sequence which were measured in different exposures):

Medium-hard pale brown fine-grained silty quartz sandstone in beds about 6" thick with many invertebrate burrows and trails, ripple marking and cross-bedding (MUNGADAN SANDSTONE) conformably overlying

10 feet of thin roughly-bedded grey and white fine-grained quartz greywacke with several beds of very-coarse-grained quartz greywacke;

3 feet of hard calcareous fine-grained quartz greywacke weathering ferruginous at surface;

5 feet of friable white and grey thin-bedded fine-grained quartz greywacke;

10 feet of medium-hard to hard calcareous coarse-grained quartz greywacke;

2 feet of medium-hard yellow-brown laminated clay-ironstone (probably weathering of laminated siltstone);

41 feet of medium-hard pale-brown fine-grained silty quartz sandstone in beds about six inches thick;

3 feet of hard, slightly calcareous, coprolitic fine-grained micaceous quartz greywacke;

23 feet of thin-bedded fine-grained quartz greywacke with several thin hard beds of calcareous coarse-grained quartz greywacke with large ripple marks;

14 feet of medium-hard to hard calcareous fine-grained quartz greywacke (Sample TJ/198);

16 feet of friable thin-bedded to laminated fine-grained quartz greywacke;

5 feet of medium-hard very coprolitic fine-grained quartz greywacke;

38 feet of friable to medium-hard thin-bedded fine-grained quartz greywacke with few thin hard calcareous beds and few thin very-fine-grained beds;

5 feet of friable fine-grained quartz greywacke with thin Chonetes coquinites at top and bottom (Sample ML/121 - Chonetes and streptorhynchid);

33 feet of friable thin-bedded fine-grained quartz greywacke and laminated fine-grained micaceous quartz greywacke;

1 foot of hard calcareous coquinoid quartz greywacke containing <u>Neospirifer</u>, <u>Chonetes</u>, bellerophontids, pectenids, <u>Stuctchburia</u> (Sample ML/120);

16 feet of friable grey thin-bedded fine-grained silty-quartz greywacke, some beds slightly calcareous;

1 foot of hard calcareous "Myalina" coquinite (Sample ML/120A);

18 feet of thin-bedded friable grey fine-grained silty micaceous quartz greywacke;

8 feet of hard calcareous quartz greywacke with four thin <u>Schizodus</u> coquinites (Samples ML/118 and 119) and thin-bedded friable grey fine-grained silty micaceous quartz greywacke; Coquinites contain <u>Schizodus</u>, <u>Stutchburia</u>, bellerophontids, <u>Neospirifer</u>, <u>Chonetes</u>;

(Base of scarp of Kennedy Range);

53 feet of thin-bedded friable grey fine-grained to medium-grained silty micaceous quartz greywacke generally very poorly exposed;

15 feet of friable grey fine-grained silty micaceous quartz greywacke with several lenticular beds up to two feet thick of hard greenish-grey calcareous quartz greywacke with several coquinoid beds containing abundant <u>Oriocrassatella</u>, <u>Schizodus</u>, <u>Neospirifer</u>, <u>Cleiothyridina</u>, <u>Linoproductus</u>, pectenid, <u>Calceolispongia</u> cf. <u>rotundata</u> (Sample ML/117);

\- - - - - - - - - - - - -

130 feet of thin-bedded friable and medium-hard grey fine-grained and medium-grained quartz greywacke, some micaceous, few hard calcareous beds;

10 feet of friable grey fine-grained quartz greywacke with lenticular beds of hard calcareous quartz greywacke containing pelecypods and small gastropods (Sample ML/116);

35 feet of friable thin-bedded grey fine-grained dirty quartz greywacke with few thin hard calcareous lenticular beds;

25 feet of thin-bedded friable to medium-hard grey silty quartz greywacke with lenticular beds to two feet thick of hard calcareous quartz greywacke containing <u>Pachydomus</u>, <u>Neospirifer byroensis</u>, <u>Linoproductus</u> cf. <u>cancriniformis</u>, small gastropods (Sample ML/115);

\- - - - - - - - - - - - -

60 feet of friable thin-bedded light-grey fine-grained quartz greywacke;

\- - - - - - - - - - - - -

10 feet of thin-bedded friable fine-grained quartz greywacke with lenticular thin beds of hard calcareous quartz greywacke containing abundant <u>Pachydomus</u> and <u>Nuculana</u>, <u>Atomodesma</u>, pectenid, <u>Neospirifer byroensis</u>, <u>Linoproductus</u> cf. <u>cancriniformis</u> (Sample ML/114);

15 feet of thin-bedded friable grey silty quartz greywacke;

45 feet of friable thin-bedded grey silty quartz greywacke with lenticular thin beds of hard calcareous quartz greywacke with spherical concretions to 5 inches in diameter containing ?<u>Astartila</u> (Sample ML/113); conformably overlying soft dark-grey laminated siltstone (Sample ML/112) of the BAKER FORMATION.

650 feet - amended type thickness of COOLKILYA GREYWACKE

The base of the Coolkilya Greywacke is placed at the base of the thin-bedded fine-grained silty quartz greywacke containing no appreciable siltstone beds and at the top of the uppermost siltstone bed of the Baker Formation. The lowermost part of the Coolkilya Greywacke contains lenticular hard calcareous beds which generally contain small spherical concretions. The top of the Coolkilya Greywacke is marked by the change from thin-bedded silty quartz greywacke of dark colour and variegated weathering colours to quartz sandstone of light colour in thicker beds and somewhat coarser grain. The uppermost part of the Coolkilya contains many beds of very coarse grain and the top bed is calcareous, weathering ferruginous, and forms a prominent ledge in the scarp where it mainly outcrops.

The typical rock type of the Coolkilya Greywacke is dark grey micaceous silty quartz greywacke which weathers to a dark brown, or greenish or purplish brown and a very 'dirty' appearance. It consists mainly of angular to subrounded quartz grains, some with quartz overgrowths. The quartz constitutes about 50 to 70% of the rock. Silty matrix composed of quartz, mica and clay makes up 20% to about 35%, felspar 5% to 15% and mica (muscovite and bleached biotite) 5% to 12%. Heavy minerals are fairly abundant (up to about 3% excluding the micas) and include mainly leucoxene, iron oxides, garnet, tourmaline, and zircon. Rock fragments are minor in amount - chert (up to about 5%) is the main type.

The Coolkilya Greywacke has a thickness of about 620 feet at Wandagee Hill, 650 feet at Southern Cross Bore, and 430 feet on the south-east side of the Kennedy Range three miles west of K-37. A westward divergence of 11 feet per mile is indicated for the Kennedy Range area and a south-westward divergence in the area between Wandagee Hill and Southern Cross Bore.

The Coolkilya Greywacke has a fairly rich fauna, dominated by the Mollusca which favour the sandy bottom and shallow water indicated by the sedimentary structures. The main genera so far recognized include : <u>Oriocrassatella</u>, <u>Schizodus</u>, <u>Aviculopecten</u>, Astartila, Nuculana, Pachydomus, Warthia and other bellerophontids, cf. Baylea (J.M. Dickins, personal communication), Cleiothyridina, Linoproductus cf. cancriniformis, Neospirifer spp., Calceolispongia, Spiriferella, Dielasma, and fenestellid and stenoporid bryozoa and small gastropods. This does not include genera from Teichert's "Nalbia Sandstone" some of which have been included in previous lists of the Coolkilya fauna. The Coolkilya Greywacke has previously been referred to the Artinskian Stage with some certainty because of the reported occurrence of diagnostic ammonoids and Helicoprion, but as these fossils appear to be restricted to the "Nalbia Sandstone" which may probably be correlated with the Norton Greywacke it is possible that the Coolkilya Greywacke is younger than Artinskian.

The sediments of the Coolkilya Greywacke, with an average grain-size larger than that of the sediments of the Byro Group, indicate the incoming of a new environment of sedimentation, shallower and closer to the shoreline than during the deposition of the underlying Byro Group. This environment is reflected in the dominance of the pelecypods in the fauna. Such isopachs as can be established suggest that, during the deposition of the Coolkilya Greywacke, the shoreline followed a curve through Wyndham River, Moogooree and Mia Mia (or perhaps Winning Pool).

The Coolkilya Greywacke is very similar lithologically to the lowermost part of the Liveringa Group of the Fitzroy Basin. The Lower Liveringa fauna is not so varied as that of the Coolkilya but a tentative correlation may be made between them.

Mungadan Sandstone

Teichert (1950) gave this name to the formation overlying the Coolkilya Greywacke. Previously (1946) he had named this unit 'Wandagee Hill series' (informally) and described it as consisting of "700 feet of coarse-grained sandstones, partly cross-bedded. Few fossils." In 1952, Teichert described the Mungadan Sandstone as "consisting of 700 feet of medium to coarse-grained rocks which vary between quartz sandstones and sub-greywackes ... deeply ferruginized

... deep brown or purple ... bedding well developed ... little current bedding ... poorly fossiliferous".

The boundary between the Coolkilya 'Sandstone' and the Mungadan 'Sandstone' defined by Teichert (1952), is not a main lithological boundary and therefore it is proposed to revise the definition of these two formations to include mainly quartz greywacke in the Coolkilya Greywacke and quartz sandstone in the Mungadan Sandstone. The Mungadan Sandstone thus restricted consists, in the type section on the east side of Wandagee Hill from the trig. cairn down, of 145 feet of thin-bedded medium-grained quartz sandstone resting conformably between the Coolkilya Greywacke below and the Binthalya Subgroup above. The top of the type section is at the trig. cairn and the base is immediately above a thick hard ferruginous bed with fossils, forming a prominent bench about 100 feet below the cairn on the east side.

The name (pronounced mun'-ga-dan) is taken from Mungadan Paddock (Wandagee Station) the north-eastern corner of which is 7 miles south-westward from Wandagee Homestead.

The type section of the Mungadan Sandstone is on the east side of Wandagee Hill, at Lat. 23°50'S., Long. 114°27'E., from the trig. cairn downwards to a prominent bench about 100 feet below the cairn. In the type section, the sequence is as follows, from above downwards :

	Hard dark-brown ferruginous coarse-grained quartz greywacke, 5 feet thick, of the BINTHALYA SUBGROUP, conformably overlying
15 feet of	thin-bedded friable pale-grey to pale-brown silty quartz sandstone (Sample MG/193);
80 feet of	friable to hard white to light red-brown medium-grained quartz sandstone (Sample MG/194);
10 feet of	friable white fine-grained silty quartz sandstone with few poorly preserved pelecypods and *Serpulites*;
40 feet of	thin-bedded medium-hard to hard, white, light yellow brown, and purple, medium-grained quartz sandstone with little white silt matrix and few thin beds of grey quartz greywacke near the bottom; invertebrate trails near the top (Sample MG/195); conformably overlying - hard dark-brown ferruginous quartz greywack with several species of *Neospirifer*, pelecypods and *Serpulites*, at the top of the Coolkilya Greywacke.
145 feet	- amended type thickness of the MUNGADAN SANDSTONE.

The base of the Mungadan Sandstone is placed at the change in lithology from the quartz greywacke of the Coolkilya to the quartz sandstone of the Mungadan. The boundary is marked by a thick bed of hard ferruginous quartz greywacke at the top of the Coolkilya. This bed in unweathered exposures is a hard calcareous quartz greywacke. The top of the Mungadan Sandstone is placed at the change in lithology from the quartz sandstone of the Mungadan to the coarse quartz greywacke of the lowermost formation of the Binthalya Subgroup. The boundary is marked by a thick bed of hard ferruginous (calcareous where unweathered) coarse-grained quartz greywacke.

In hand specimen, the sediments of the Mungadan Sandstone consist predominantly of medium-grained quartz sandstone composed mainly of rounded to sub-rounded quartz (in some beds with a red, hematitic film around the grains), very minor amounts of felspar, up to 2% of heavy minerals - mainly leucoxene and limonite, zircon and ilmenite (Higgins and Carroll, 1940, p.149, Samples 19, 20 and 21) and a variable but small proportion of white silt matrix (mainly quartz and kaolin). In many places some of the beds are silicified on the surface to a depth of several inches.

The thickness of the Mungadan Sandstone is 145 feet at Wandagee Hill, 163 feet three miles south of Bakers Bore, Middalya, 145 feet 15 miles north-west of Lyons River Homestead, and 185 feet 3 miles south-west of K-37.

Fossils are rare in the Mungadan Sandstone. Pelecypods and Serpulites are found at Wandagee Hill but only invertebrate trails and burrows have been found elsewhere.

Binthalya Subgroup

The Binthalya Subgroup is defined as the sequence of arenaceous sediments resting conformably on the Mungadan Sandstone. It is the youngest exposed part of the Permian sequence in the Carnarvon Basin and is mainly cut by an erosion surface. Several formations of quartz greywacke and quartz sandstone can be separated out of this Subgroup but it is unnecessary to name these at present, although field names have been applied to them.

The main outcrop area of the Binthalya Subgroup is the Kennedy Range, the bulk of which, apart from the eastern scarp and north-eastern corner, has sediments of the Binthalya Subgroup at or near the surface. The base of the subgroup is exposed on the top of Wandagee Hill to the west of the cairn.

The name (pronounced bin-thal'-ēa) is taken from Binthalya Station, the homestead of which is at Lat. $24^{\circ}41'$S., Long. $114^{\circ}15\frac{1}{4}'$E. The Binthalya Subgroup outcrops on the western edge of the Kennedy Range in the eastern part of Binthalya Station.

The type section is east of Venny Peak (Lat. $24^{\circ}47\frac{3}{4}'$S., Long. $114^{\circ}57'$E.) in the unfenced southeastern part of Binthalya Station. There the sediments dip fairly steeply (9° to 27°) to the east on the east side of one of the larger faults. In the type section the sequence in descending order is as follows:

Top of outcrop - erosion surface; (7500 feet east-north-east of Venny Peak)

21 feet of hard dark-grey silty fine-grained quartz sandstone (lateritized);
43 feet of bedded and laminated fine-grained quartz greywacke with coarse quartz grains (Sample G/109);
53 feet of poorly exposed bedded white sandstone and quartz greywacke (Sample G/110);
21 feet of medium-hard bedded white sandstone and quartz greywacke;
18 feet of cross-bedded dark-grey silty fine-grained quartz sandstone in beds to 1 foot thick (Sample G/111);
25 feet of bedded white sandstone and quartz greywacke in alternating beds up to 1 foot thick;
12 feet of friable dark red-brown fine-grained quartz sandstone in beds up to 1 foot thick;
25 feet of medium-hard alternating white quartz sandstone and fine-grained quartz greywacke (Sample G/112);
71 feet of medium-hard alternating white quartz sandstone and grey quartz greywacke in beds up to 1 foot thick;
20 feet of friable cross-bedded light-brown fine-grained quartz sandstone (Sample G/113);
4 feet of medium and coarse-grained quartz sandstone;
25 feet of thin-bedded white fine-grained silty quartz sandstone;
8 feet of light-brown fine-grained quartz sandstone;
57 feet of medium-hard, pale yellow-brown fine-grained silty quartz sandstone (Sample G/114);
12 feet of friable pale-brown fine-grained to medium-grained silty quartz sandstone;

FORMATION BOUNDARY

66 feet of thin-bedded light purplish-grey coprolitic micaceous fine-grained quartz greywacke (Sample G/115A) with thin beds of

white and red brown micaceous fine-grained quartz sandstone (Sample G/116) near the bottom;
2 feet of brown medium-grained quartz sandstone;
30 feet of thin-bedded, medium-hard to friable, light-brown and dark-grey micaceous fine-grained quartz greywacke (Sample G/117);
11 feet of bedded friable fine-grained quartz sandstone with bed of medium-grained quartz sandstone at the top;
11 feet of laminated and thin-bedded friable grey quartz greywacke;
35 feet of massive-weathering medium-hard purplish-grey micaceous fine-grained quartz greywacke in beds from 6" to 18" thick (Sample G/118);
10 feet of laminated friable dark-grey micaceous fine-grained quartz greywacke;
4 feet of hard grey fine-grained quartz sandstone;
8 feet of laminated friable white and grey fine-grained quartz greywacke;
17 feet of light-brown silty fine-grained quartz sandstone in beds to 1' thick;
21 feet of thin-bedded and laminated micaceous fine-grained quartz greywacke;
10 feet of cross-bedded firm to friable pale yellow-brown medium-grained silty quartz sandstone (Sample G/119);
33 feet of bedded dark-brown micaceous fine-grained quartz greywacke;
47 feet of thin-bedded and laminated grey coprolitic micaceous fine-grained and very-fine-grained quartz greywacke (Sample G/120);
8 feet of ripple-marked thin-bedded red-brown fine-grained quartz sandstone;
11 feet of thin-bedded light brown and grey micaceous fine-grained quartz greywacke;
20 feet of bedded medium-hard pale cream fine-grained quartz sandstone (Sample G/121);
25 feet of thin-bedded and laminated grey, blue, and dark brown micaceous very fine-grained and fine-grained quartz greywacke;
52 feet of bedded red-brown fine-grained quartz sandstone (Sample G/123) and laminated medium-hard white coprolitic micaceous fine-grained quartz greywacke (Sample G/122);
18 feet of thin-bedded white micaceous very-fine-grained quartz greywacke;
12 feet of medium-hard bedded orange-brown medium-grained quartz sandstone with few coarse grains (Sample G/124);
21 feet of bedded grey silty fine-grained quartz sandstone;
15 feet of laminated and thin-bedded white micaceous fine-grained quartz greywacke (Sample G/125);

FORMATION BOUNDARY

22 feet of thick-bedded (18") and cross-bedded light-brown fine-grained quartz sandstone;
138 feet of firm to friable red-brown to pale cream fine-grained quartz sandstone some silty (Samples G/126, 127);
20 feet of thin-bedded grey and white micaceous very fine-grained quartz greywacke (Sample G/128);
38 feet of thin-bedded, finely cross-bedded, friable brown to pale cream fine-grained to medium-grained quartz sandstone with coarser grains (Sample G/129);
30 feet of bedded dark red-brown fine-grained quartz sandstone with limonite matrix and laminae of grey very fine-grained quartz greywacke on bedding planes;
5 feet of laminated white and grey micaceous very fine-grained quartz greywacke;

19 feet of dark red brown bedded fine-grained limonitic quartz sandstone with laminae of very fine-grained quartz greywacke (Sample G/130);
16 feet of laminated and thin-bedded grey micaceous fine-grained quartz greywacke;
59 feet of bedded grey and reddish fine-grained quartz sandstone;
27 feet of bedded, cross-bedded, friable red-brown fine-grained to medium-grained quartz sandstone with coarse grains (Sample G/81);

FORMATION BOUNDARY

32 feet of massive-weathering laminated multicoloured micaceous very fine-grained quartz greywacke with small fragments of siltstone (Sample G/82);
10 feet of hard, strongly cross-bedded fine-grained quartz sandstone;
70 feet of massive-weathering laminated dark-grey micaceous very fine-grained sandstone with several thin beds of medium-grained and coarse-grained quartz sandstone (Sample G/83);
27 feet of bedded medium-hard medium-grained quartz sandstone with laminae of coarser grains (Sample G/84);
75 feet of thin-bedded pink and pale grey fine-grained quartz sandstone with several thin beds of coarser quartz sandstone (Sample G/85);
17 feet of thin-bedded, cross-bedded white clean very-fine-grained quartz sandstone;
22 feet of thin-bedded pale-grey coprolitic micaceous very-fine-grained quartz greywacke with some ferruginous laminae (Sample G/86);
70 feet of massive-weathering bedded fine-grained quartz sandstone with coarse grains;
10 feet of thin-bedded pale brown limonitic fine-grained quartz greywacke and grey micaceous fine-grained quartz greywacke;
19 feet of friable red-brown medium-grained sandstone with laminae of coarse grains (Sample G/87);
12 feet of thin-bedded grey micaceous fine-grained quartz greywacke;
7 feet of friable fine-grained quartz sandstone;
19 feet of bedded grey fine-grained quartz greywacke;
14 feet of massive-weathering bedded fine-grained quartz sandstone with laminae of fine-grained quartz greywacke;
7 feet of medium-hard pale-brown coprolitic micaceous very fine-grained quartz greywacke (Sample G/88);
36 feet of massive-weathering medium-hard thick-bedded (18") fine-grained quartz sandstone with limonite;
9 feet of bedded kaolinitic fine-grained quartz sandstone;
5 feet of thin-bedded grey micaceous fine-grained quartz greywacke;
12 feet of massive-weathering resistant thick-bedded pale brown fine-grained quartz sandstone;
5 feet of thin-bedded grey fine-grained quartz greywacke;
15 feet of massive-weathering, resistant, pale brown fine-grained quartz sandstone (Sample G/89);
16 feet of thin-bedded and laminated grey micaceous fine-grained quartz greywacke;

1725 feet - type thickness of Binthalya Subgroup

FORMATION BOUNDARY - between BINTHALYA SUBGROUP above and MUNGADAN SANDSTONE below

16 feet of friable red brown medium-grained quartz sandstone with coarse and very coarse grains (Sample G/140A);
46 feet of friable medium-grained quartz sandstone;
30 feet of thick-bedded (2'), cross-bedded medium-grained light red-brown quartz sandstone;

2 feet of thin-bedded blue and brown mottled micaceous fine-grained quartz greywacke;
25 feet of thick-bedded (2'), cross-bedded friable light red-brown medium-grained quartz sandstone with coarse and very coarse grains;
10 feet of thin-bedded mottled blue and brown micaceous fine-grained quartz greywacke;
55 feet of thick-bedded (2'), cross-bedded medium-grained friable light red-brown quartz sandstone with coarse grains (Sample G/133);
conformably overlying medium-hard bedded dark brown micaceous quartz greywacke of the COOLKILYA GREYWACKE

184 feet - thickness of Mungadan Sandstone below type section of Binthalya Subgroup

The section of the Mungadan Sandstone is included in the above type section to show the relationship to the fossiliferous Coolkilya Greywacke.

The base of the Binthalya Subgroup is placed at the change in lithology from the predominant quartz sandstone of the Mungadan Sandstone to the dominantly quartz greywacke lithology of the lowermost formation of the Subgroup. As indicated in the type section above, there are four formations in the exposed Binthalya Subgroup - two mainly of quartz sandstone and two mainly of quartz greywacke. As the maximum section is exposed only in the type locality there is no information on thickness variations of the subgroup. The lowermost formation varies from about 400 feet thick near Mooka Homestead to 625 feet about 9 miles east-south-east of Binthalya Homestead and about 600 feet 3 miles south-west of Bakers Bore, Middalya.

Fossils, apart from invertebrate trails and burrows, are rare in the sediments of the Binthalya Subgroup. Sparse pelecypods are found in the lowermost formation about 200 feet above the base and a bed with large Neospirifer and large pelecypods is about 300 feet above the base.

JURASSIC :

Curdamuda Sandstone

The only Jurassic sediments so far discovered in the Carnarvon Basin are in a small fault block between Permian and Cretaceous sediments immediately south of the Minilya River, 550 yards south-east of Curdamuda Well, Wandagee Station, at Lat. 23°00'S., Long. 114°27'E. (Teichert, 1940b).

Teichert described this exposure in the following terms : "Immediately east of the (Cretaceous) greensand there is a narrow strip, about 13 feet wide on the surface, of unfossiliferous, greenish weathering grey hard sandstone and to the east of this again a strip, likewise about 13 feet wide, of calcareous sandstone which yielded the Jurassic fossils Parachaetetes megalocytus Pia, Echinotis sinuata Teichert, and Ostrea tholiformis Eth.jr." Although many exposures of the sediments immediately above the surface of unconformity truncating the Permian sediments have been examined particularly in the area along the western side of the Kennedy Range, no sign of this calcareous sandstone or of similar fossils has been seen. It is possible that the marine Jurassic was deposited only in narrow gulfs or estuaries or that a once continuous sheet has been removed by erosion except where it has been protected in the fault block. As the Cretaceous sediments are affected by the same faulting, the first explanation is more likely.

The presence of this small outcrop indicates a marine transgression in the Middle Jurassic followed by a regression until possibly the Aptian Stage of the Cretaceous.

CRETACEOUS :

The Cretaceous System in the Carnarvon Basin comprises the following stratigraphical units, in ascending order:- Birdrong Formation, Winning Group (Muderong Shale, Windalia Radiolarite and Gearle Siltstone) and Korojon Calcarenite and Miria Marl of the Cardabia Group.

Birdrong Formation

The Birdrong Formation is defined as the formation, consisting of quartz sandstone, glauconitic sandstone, quartz greywacke and siltstone, which rests unconformably on the Permian sediments and conformably beneath the Muderong Shale.

The name (pronounced ber'd-rong) is taken from Birdrong

Spring on Hill Springs Station at Lat. $24^{\circ}14\frac{1}{2}$'S., Long. $114^{\circ}50$'E.

The Birdrong Formation crops out mainly on the Western side of the Kennedy Range in the scarps surrounding mesas and along faults. The outcrops on the slopes of mesas are usually soft and poorly exposed except in scoured gullies. The outcrop along fault lines consists mainly of hard ferruginous sandstone (of the basal part of the formation). There is a small area of outcrop of this formation on the south bank of the Minilya River in a fault block between the Permian on the east and the Windalia Radiolarite on the west. This outcrop includes some beds of greensand. The Birdrong Formation crops out at the base of the mesas of Cretaceous sediments between Kialiwibri Creek and Lyndon River and in a creek valley 13 miles north-westward from Williambury Homestead.

The type section is in a scarp at the north end of a mesa, 0.6 mile south-west of Birdrong Spring and 22 miles north of east of Hill Springs Homestead, at Lat. $24^{\circ}15$'S., Long. $114^{\circ}50$'E. There the sequence in descending order is as follows:

	Soft dark-brown siltstone of the base of the Muderong Shale, conformably overlying
24 feet of	friable to firm medium-grained quartz sandstone with little clay matrix and with ferruginous mottlings;
4 feet of	friable reddish fine-grained iron-stained quartz sandstone;
$5\frac{1}{2}$ feet of	friable yellow medium-grained quartz sandstone;
$1\frac{1}{2}$ feet of	friable grey siltstone with sand grains and salty efflorescence;
6 feet of	friable yellow-green medium-grained quartz sandstone containing small lenses of grey silt;
5 feet of	friable apple-green medium-grained quartz sandstone weathering reddish (?glauconitic);
16 feet of	friable greyish-white fine-grained silty quartz greywacke with salty efflorescence and ferruginous beds (Sample G/36);
18 feet of	friable medium-grained quartz sandstone, cross-bedded, with beds and balls of siltstone in top-set and bottom-set beds;
15 feet of	friable medium-grained and coarse-grained quartz sandstone (Sample G/35);
1 foot of	friable grey medium-grained micaceous quartz greywacke;
1 foot of	friable to loose cross-bedded coarse-grained quartz sand with small fragments of the underlying greywacke; unconformably overlying firm grey fine-grained quartz greywacke of the Permian Coolkilya Greywacke.
97 feet -	type thickness of the BIRDRONG FORMATION

In the outcrop area along the western side of the Kennedy

Range, the base of the Birdrong Formation is a coarse to very coarse quartz sandstone with fragments of the underlying Permian sediments, resting on a somewhat irregular erosion surface of the Permian strata with an angular unconformity generally of about 5 degrees but varying from 0 up to about 20 degrees. In some areas west of the area of outcrop the Birdrong Formation may rest on the Jurassic Curdamuda Sandstone. The top of the Birdrong Formation is placed at the change in lithology from medium-grained and fine-grained sandstone below to the siltstone and shale of the Muderong Shale above. There is no very prominent bed at the boundary, which can be located only where there is a good exposure.

The thickness of the Birdrong Formation is very variable. The greatest thickness measured is 105 feet measured by C.E. Prichard about 20 miles east of Mardathuna Homestead. This thickness has little regional significance since in the same area thicknesses as low as 22 feet were measured. The variations are related mainly to irregularities in the surface of unconformity, some of the biggest of which are related to fault lines. The fault line scarps had not been completely reduced by erosion before the deposition of the Birdrong Formation. In the area between Kialiwibri Creek and Lyndon River the maximum thickness measured is 36 feet, mainly of greensand and glauconitic sandstone. The base of the Birdrong Formation is not exposed in this area.

The only fossils so far found in the Birdrong Formation are pieces of silicified wood which are fairly common especially in the lower part of the formation.

There is no direct evidence of the age of the Birdrong Formation. It rests unconformably on the upper part of the Permian (Artinskian) succession and conformably below the Muderong Shale which is referred to the Lower Cretaceous (Albian). As there is no sharp break between the Birdrong and the Muderong they are regarded as belonging to a continuous deposition and therefore the Birdrong is referred to the Lower Cretaceous. It has been suggested by Sturmfels (1952) that the Birdrong Formation is the equivalent of the Jurassic

Curdamuda Sandstone which is known only from a small fault block in the Wandagee area. The differences in lithology, especially the presence of glauconite, and the absence of any break between the Birdrong and Muderong make this correlation very unlikely.

Winning Group

The Winning Group consists of the Muderong Shale, Windalia Radiolarite and Gearle Siltstone. This sequence was named "Winning Series" by Raggatt (1936), but as it contains three separate but related formations it should be re-named 'Winning Group' (Condon, Johnstone, Prichard and Johnstone, 1954).

The name is taken from Winning Station (homestead at Lat. 23°09¼'S., Long. 114°33¼'E.). There is no single well-exposed section including the whole group.

The Group is characterized by very fine-grained sediments (shale, siltstone, and radiolarite). The Formations forming the Group are conformable and the base of the Group rests conformably on the Birdrong Formation. There is a disconformity probably associated with regression at the top of the Winning Group.

Muderong Shale

The Muderong Shale is the formation of bentonitic shale, claystone and siltstone conformable between the Birdrong Formation below and the Windalia Radiolarite above.

The Muderong Shale is generally poorly exposed, forming the lower, rubble-covered slopes of mesas capped by lateritized Windalia Radiolarite. Good exposures are found only in scoured gullies. The Muderong Shale outcrops along the western side of the Kennedy Range from near Paddy's Outcamp to the vicinity of Binthalya Woolshed. The other area of outcrop is at the north end of the outcrop area of the basin, from 12 miles east of Moogooloo Peak to Winning Pool.

The name (pronounced mū'-der-ong) is taken from Muderong Bore, on Middalya Station, at Lat. 24°07¾'S., Long. 114°46¾'E.

The type section of the Muderong Shale is in a scoured gully on the northern slope of an isolated hill at Lat. 24°08'S., Long. 114 45¾'E., one mile south-west of Muderong Bore and five miles south-east of Paddys Outcamp. There the sequence in descending order is:

	Firm light blue-grey thin-bedded radiolarite of the Windalia Radiolarite, conformably overlying
40 feet of	soft grey bentonitic shale and claystone, silty towards the base (Sample MG/272); conformably overlying friable light grey silty sandstone of the Birdrong Formation.
40 feet -	type thickness of the MUDERONG SHALE

The base of the Muderong Shale is placed at the change in lithology from sandstone below to silty shale above. The top of the Muderong is placed at the lithological change from the soft dark shale of the Muderong below to the firm light blue-grey thin-bedded radiolarite of the Windalia above. This boundary is fairly sharp and easy to locate except where the Muderong Shale has been hardened by lateritization.

Much of the Muderong Shale appears massive, but weathering or close inspection shows that most of it is finely laminated. Some beds (of claystone) are not laminated. No detailed petrographical examination of the Muderong Shale has been carried out.

The Muderong Shale varies in thickness from 3 feet to 50 feet in the Kennedy Range area, from 15 feet to 40 feet in the northern outcrop area, and from about 40 to possibly 220 feet in bores in the western parts of Winning and Mia Mia Station. Like the underlying Birdrong the thickness is variable over short distances and indicates significant unevenness of the surface of deposition even after the deposition of the Birdrong Formation. There is a greater average thickness in the northern outcrop area than in the Kennedy Range area and the rather doubtful information from drillers' bore logs indicates an appreciable thickening towards the west.

The only fossils so far found in the Muderong Shale are foraminifera and radiolaria. H.S. Edgell (1952) identified the following foraminifera:

<u>Haplophragmoides eggeri</u>

<u>Haplophragmoides excavata</u>

<u>Ammobaculites coprolithiformis</u>

Ammodiscus cretaceus

Eggerellina oroidea

Pleurostomella subnodosa

Globigerina washitensis

These indicate an Upper Albian to Cenomanian age (Edgell, 1952).

Following the transgressive Birdrong Formation the Muderong Shale indicates either deep water, great distance from shoreline or very reduced hinterland. It seems from the distribution of Cretaceous sediments generally that the main factor determining the type of sediment was the very low relief of the hinterland as it is unlikely that the shoreline was far removed from the present outcrop area or that the water was very deep.

Windalia Radiolarite

The Windalia Radiolarite was defined by Condon, Johnstone, Prichard and Johnstone (1954) as consisting of "vari-coloured, permeable, micaceous radiolarite, sandy radiolarite and chert, containing radiolaria, foraminifera, pelecypods, belemnites and ammonites". It "conformably overlies the Muderong Shale and is overlain conformably by the Gearle Siltstone".

The name (pronounced win-dā'-lē-a) is taken from Windalia Hill (trig. point A-46) at Lat. 23°16'S., Long. 114°48'E.

There is no known well-exposed section of the whole formation including the boundaries with the Muderong Shale and the Gearle Siltstone. The type section at Windalia Hill includes only the lower boundary. The upper boundary is well-exposed only in the Giralia Anticline.

The top part of the formation is well exposed 3¾ miles north-east of No. 2 Deep Bore, Cardabia Station (at Lat. 23°04¼'S., Long. 114°09'E.) where the sequence in descending order (measured by D. Johnstone) is as follows:

Soft dark grey bentonitic siltstone with belemnites (Gearle Siltstone) conformably overlying

15 feet of firm white, blue, pink, buff, and green radiolarite with thin beds of hard brown crystalline limestone and thin beds of friable greensand; contains pelecypods and belemnites;
35 feet of firm and friable thin-bedded light-coloured radiolarite;

Bottom of exposure at anticlinal axis.

There is a gap, probably quite large, between this section and the top of the type section at Windalia Hill where the sequence (measured by D. Johnstone) in descending order is as follows:

Lateritized erosion surface with post-Cretaceous sandstone above.
4 feet of hard cream opaline chert (lateritized radiolarite);
8 feet of white and buff thin-bedded radiolarite;
2 feet of soft white laminated porous fine-grained radiolarite;
5 feet of firm light coloured bedded radiolarite;
100 feet (approximately) of firm and friable light blue grey and purple radiolarite with belemnites, ammonites and pelecypods;
conformably overlying soft dark grey bentonitic shale (Muderong Shale)

The total thickness in these two sections is about 170 feet. Bores in the same area indicate that the thickness of the Windalia Radiolarite is probably about 170 feet in the vicinity of Mia Mia Homestead and probably about 210 feet 12 miles west of Winning Homestead.

The top of the Windalia Radiolarite is placed at the change in lithology from the firm thin-bedded radiolarite below to the soft dark-grey bentonitic siltstone. As the radiolarite is much more resistant to erosion than the Gearle Siltstone, this boundary is easy to locate and map although good exposures of the boundary are rare.

Fresh specimens of the radiolarite are light blue-grey firm, medium hard or friable, easily scratched with the finger nail and, in spite of the very fine grain, having a rather rough fracture and a relatively high permeability - they stick to the tongue by absorption of the saliva. The apparent specific gravity is low. Under the microscope the fresh rock is seen to consist largely of a very fine-grained ground mass consisting of particles of amorphous silica which have the same colour and refractive index as the amorphous silica composing the radiolarian tests which are scattered, usually sparsely, through the rock. In addition to the radiolarians there are usually a few foraminifera and sponge spicules and rare diatoms. In many specimens the terrigenous material is confined to a very few very small grains of quartz and felspar and a small percentage of disseminated mica. In some specimens, particularly those from the eastern part of the area of outcrop, there is more terrigenous material of silt and clay size. These rocks include some types which may be described as silty radiolarite. Specimens from the lateritic profile are of two types - the opaline chert in which the silica has been re-deposited as common opal, and in which most trace of the original texture is gone, and the leached white type which is white and much more permeable than the fresh rock and in which much of the fragmental organic silica has been removed. Examination of specimens of these types led Edwards (1952) to believe that the rocks are not radiolarites, whereas the fresh material leaves no doubt, since it agrees in most particulars with the typical radiolarian ooze described by Murray and Renard (1891).

As no complete sections are known in outcrop, only approximate thicknesses can be indicated, especially as no reliable marker beds have been found within the formation to enable it to be subdivided. Thicknesses measured in the western Kennedy Range area vary between 30 feet and 111 feet. None of these is the full thickness of the formation. In the Windalia Hill area measured part-thicknesses range from 26 to about 100 feet. In bores in the western parts of Winning and Mia Mia Stations, drillers' bore logs indicate that the thickness of Windalia Radiolarite is from 166 to 210 feet thick. In the Centenary Bore, Cardabia Station, the thickness of the Windalia Radiolarite is probably 286 feet, and in Brickhouse Bore No. 4 probably 340 feet.

Fossils from the Windalia Radiolarite have not been examined in much detail. The following microfossils have been identified by Miss Irene Crespin (Crespin, 1946):

Radiolaria :

Amphibracium sp.

Astrophacus sp.

Cenosphaera sp. (common)

Dictyomitra australis Hinde

Dictyomitra triangularis Hinde

Lithocampe fusiformis Hinde

Lithocyclia exilis Hinde (common)

Porodiscus sp.

Spongodiscus expansus Hinde

Spongodiscus spp.

Staurodictya sp.

Stichocapsa pinguis Hinde

Stichocapsa sp.

Edgell (1952) identified the following in the Windalia Radiolarite:

Foraminifera :

Ammobaculites sp. (common)

Ammomarginulina sp.

Haplophragmoides spp. (common)

Pelosina lagenoides Crespin

R.O. Brunnschweiler (personal communication) has examined fragmentary Ammonites which he believes to have either upper Albian or Cenomanian affinities.

Other fossils so far not examined include pelecypods, ostracods and belemnites.

The fragmentary ammonites and the microfossils indicate that the age of the Windalia Radiolarite is probably either upper Albian or Cenomanian.

Gearle Siltstone

The Gearle Siltstone was defined (Condon, Johnstone, Prichard, and Johnstone, 1954) as consisting of "soft dark bentonitic siltstone and claystone with secondary gypsum and, in the upper third, barytes nodules. The formation conformably overlies the Windalia Radiolarite and is overlain disconformably by the Korojon Calcarenite."

The name (pronounced gē-ar'-le) is taken from Gearle Paddock on Cardabia Station.

The Gearle Siltstone crops out in the axial area of the Giralia and Marrilla Anticlines, in the area west and south-west of Winning Homestead, and is exposed in dam excavations west of Wandagee Hill (at Cundy and Warrarie Dams, Wandagee Station). A very poorly exposed outcrop extends from Warrarie Dam on the Barrabiddy Creek to five miles east of Mardathuna Homestead. The outcrop area of the Gearle Siltstone is generally a reduced flat area with 'salt-bush' vegetation and many 'crab-holes' caused by the shrinkage cracking during dry periods.

The type section of the Gearle Siltstone is in the upper part of C. Y. Creek on the western limb of the Giralia Anticline, at Lat. 22°54'S., Long. 114°09'E. The sequence in descending order is as follows:

	Alternating friable light-grey calcarenite and soft grey marl, with Inoceramus fragments and prisms (Korojon Calcarenite);
	Thin interformational conglomerate of brown calcareous and hematite nodules and quartz and sandstone pebbles; disconformably overlying
160 feet of	soft dark-grey laminated bentonitic siltstone and claystone with barytes concretions derived from thin beds of evaporite barytes, and much secondary gypsum; foraminifera, radiolaria, ostracoda;
375 feet of	soft dark-grey bentonitic siltstone and claystone with few barytes concretions; foraminifera, radiolaria, ostracoda, belemnites; conformably overlying thin-bedded firm light-grey radiolarite with thin beds of hard brown limestone and friable green greensand. (Windalia Radiolarite).
535 feet	- type thickness of the GEARLE SILTSTONE.

The top of the Gearle Siltstone is marked by the change in lithology from soft dark-grey siltstone to friable light coloured calcarenite and marl. The boundary is marked by a thin interformational conglomerate consisting of nodules of brown calcite and hematite and pebbles of quartz and sandstone.

In outcrop on the Giralia Anticline, the thickness of the

Gearle Siltstone cannot be measured directly since reliable dips cannot be measured in this formation. The type thickness is representative of the probable thickness of this formation in that area. In the western Kennedy Range area the Gearle Siltstone is probably quite thin (less than 100 feet thick) but in bores in the western part of the basin from Carnarvon to Cardabia and Winning the thickness of the Gearle Siltstone ranges from about 300 feet at Brickhouse Bore No. 4 to 600 feet 12 miles west of Winning Homestead and possibly 1150 feet at Centenary Bore, Cardabia.

The following fossils from the Gearle Siltstone have been identified:

Foraminifera (Edgell, 1952) :

Ammobaculites sp. (common)

Ammodiscus cretaceus (Reuss)

Gaudryinella irregularis (Marsson)

Globigerina cretacea d'Orb.

Globotruncana spp.

Haplophragmoides sp.

Spiroplectammina grzybowskii Frizzell (abundant).

Radiolaria :

Radiolaria are relatively abundant especially in the lower part but species have not been determined.

Pelecypoda :

A few pelecypods including Pectenids are present.

Belemnites :

Dimitobelus sp. nov. (R.O. Brunnschweiler - personal communication) is common in the lower part of the Gearle Siltstone.

It is most probable that the age of the Gearle Siltstone is Turonian with possibly some overlap into the Cenomanian below and the Coniacian above. However, the absence from the collections of ammonites and doubts about the specific determination of the *Globotruncana* prevent any precise statement about the age relationships of the Gearle Siltstone.

The Gearle Siltstone was deposited probably in fairly deep water where the supply of fine-grained terrigenous sediment was continuous and abundant. On the other hand, the information on formation thickness indicates that the deposition of the Gearle Siltstone was restricted to the area west of Longitude 115°30'E. A possible explanation of the absence of benthonic forms from the fauna is that the coast line was far to the east. It is possible that the continental slope developed along the fault from Wogoola to Mooka and that east of this was an erosional marine environment where no sediments were deposited. Bentonite has been regarded as being developed from fine volcanic ash, but as its essential constituents are montmorillonite and beidellite it seems possible at least that it could result from the rapid deposition of terrestrial clays. Montmorillonite is a common constituent of residual clays but has not so far been reported from recent marine sediments. The inundation of an old land surface by a shallow sea, resulting in marine erosion of the soils, may be sufficient to preserve the montmorillonite. In any case, a non-volcanic origin for the bentonite in the Gearle Siltstone and Muderong Shale is necessary as there is no likelihood of extensive explosive volcanism in this region during this period. It is perhaps significant that the Gearle Siltstone probably correlates in age with the Benton Shale of U.S.A. from which bentonite was first described, although the Benton Shale definitely includes volcanic material.

Cardabia Group

The name 'Cardabia Group' is proposed by Condon et al (1954) for the mainly calcareous sediments included in the "Cardabia Series" of Raggatt (1936). The Cardabia Group may be defined as the sediments which disconformably overlie the Gearle Siltstone of the Winning Group and disconformably underlie the Giralia Calcarenite. The age of the sediments of the group ranges from Campanian to Danian. Formations included in the Cardabia Group are : Korojon Calcarenite, Miria Marl, Boongerooda Greensand, Wadera Calcarenite, Pirie

Calcarenite, Cashin Calcarenite, and Jubilee Calcarenite (Condon et al, 1954).

The name (pronounced kar'-da-bī-a) is taken from Cardabia Station where, on the Giralia Anticline, the group is well exposed.

The group is characterized by calcarenites, generally glauconitic, with minor calcilutites, marl and greensand. There is generally a minor proportion of terrigenous matter (quartz and clay) in the sediments but they mainly consist of broken invertebrate tests.

The definition and description of the formations composing the Cardabia Group as they are exposed in the Giralia and Marrilla Anticlines are contained in the report by Condon et al (1954). Only the occurrences outside those areas will be discussed here.

The only formation of the Cardabia Group which is known to outcrop beyond the coastal anticlines is the Korojon Calcarenite. In the area north of the Gascoyne River, the Korojon Calcarenite outcrops on both flanks of the Giralia and Marrilla Anticlines, in the crestal areas of the Warroora, Chargoo and Yankie Tank Anticlines, in a synclinal area east of Cardabia Creek, and in a strike ridge from 12 miles west of Mia Mia Homestead to two miles west of Hill Springs Homestead and from there to Rocky Pool on the Gascoyne River. Another strike ridge runs from 8 miles north of Hill Springs Homestead to 10 miles west of Binthalya Homestead. In the south-eastern outcrop area the Korojon Calcarenite is very thin - only about 30 feet - and from there it increases in thickness to 200 feet at the north end of the Giralia Anticline. There is a thickness of 200 feet in the Brickhouse Bore No. 4 near the Gascoyne River (I. Crespin - personal communication), and probably 235 feet in the Centenary Bore, Cardabia.

There is a disconformity between the Korojon Calcarenite and the overlying Miria Marl in the type locality. This disconformity is reflected in the restriction of outcrop area of the younger formations which are known only from the coastal area. The few ammonites so far found in the Korojon Calcarenite indicate a Santonian age for this formation (R.O. Brunnschweiler - personal communication).

The Miria Marl is a very thin formation but contains a very rich fauna including foraminifera, brachiopods, pelecypods, gastropods, nautiloids, ammonites, and shark teeth. The age of the Miria Marl indicated by the ammonites is lower Maestrichtian (Brunnschweiler - personal communication). There is a disconformity between the Miria Marl and the overlying Boongerooda Greensand. The Miria Marl is known in outcrop only from the type area (the Giralia and Marrilla Anticlines) and from the Chargoo and Warroora Anticlines.

The Boongerooda Greensand outcrops in the Giralia, Marrilla, Chargoo, and Warroora Anticlines. It has a rich foraminiferal fauna and also some brachiopods, pelecypods, corals, and annelids. It is very thin (usually less than 10 feet) but because of its lithology and its association with the Miria Marl containing ammonites is the best marker bed in the post-Permian sequence. It is possible that the Boongerooda Greensand may be correlated with the upper greensand at Gingin and Dandarragan (Teichert, 1946) but the absence of fossils in these areas precludes any definite correlation.

From the top of the Boongerooda Greensand to the top of the Cardabia Group there are only minor variations in lithology. Calcarenite, of which there are two main types, is predominant. The friable calcarenite consisting of uncemented fragments of invertebrate tests is the dominant type but the hard crystalline calcarenite composed of fragments of invertebrate tests with a calcite cement is more commonly well-exposed. The upper part of the Cardabia Group is exposed only in the Giralia, Marrilla, Warroora, and Chargoo Anticlines. The thickness ranges from about 50 feet on the Chargoo Anticline to about 80 feet on the Warroora Anticline and up to about 200 feet on the Giralia Anticline.

Bryozoa are very abundant in parts of the upper Cardabia Group but have not been examined for determination. Foraminifera are abundant. Of the many species identified by Edgell (1952) Anomalinoides danica, Bulimina midwayensis, Citharina plummoides, Discorbis midwayensis, Globorotalia membranacea, G. spinulosa, G. wilcoxensis, Gümbelina venezuelana, Karreria cubensis are the more significant since many of them are recorded from the Palaeocene of Denmark and Sweden (Seelandian), North Africa (Danian) and U.S.A. (Midway formation). Echinoids are well represented: Brunnschweiler (personal communication) has identified Echinocorys sulcatus from immediately above the Boongerooda Greensand and Cardiaster spp., Centrechinoidea sp. Cidaris spp., nov. gen. aff. Schizaster, Hemiaster spp., Holaster spp., nov. gen. aff. Hemipatagus, Phymosoma sp. and Salenia spp. from the other formations. Other forms identified by Brunnschweiler include brachiopods - Liothyrina sp. Terebratulina spp., and Zeilleria spp. - , pelecypods - Diploschiza sp., Gryphea sp., Lima sp. and Ostrea spp. - , gastropods - Gisortia spp., Procerithium sp., and Tympanotonus sp. - , and cephalopods - Aturoidea sp., and Deltoidonautilus sp.

With few exceptions the fauna is of Danian type, and therefore the upper part of the Cardabia Group, from the Boongerooda Greensand to the Jubilee Calcarenite is referred to the Danian Stage. The writer believes that the Danian should be regarded as a stage and age of the Palaeocene Series and Epoch. (It is hoped to discuss this in a later publication.)

TERTIARY:

The Tertiary System in the Carnarvon Basin comprises the Danian upper part of the Cardabia Group (discussed above), the Eocene Giralia Calcarenite, the Miocene Cape Range Group, the Miocene Merlinleigh Sandstone and the Miocene and possibly Pliocene Yardie Group. As the detailed stratigraphy of most of the Tertiary sediments has been described by Condon, Johnstone and Perry (1953) and Condon, Johnstone, Prichard and Johnstone (1954), only the regional aspects of the Tertiary stratigraphy will be discussed here.

EOCENE:

Giralia Calcarenite

The Giralia Calcarenite, named by Singleton (1941) and re-defined by Condon et al (1954), outcrops in the Giralia, Chargoo, Warroora, Chirrida and Cuvier Anticlines.

Its thickness ranges from about 50 feet on the Chirrida Anticline to 200 feet on the west flank of the Giralia Anticline.

The more important fossils in a rich fauna include foraminifera - Alveolina cf. timorense, Asterocyclina spp., Assilina orientalis, Discocyclina spp. Nummulites aff. irregularis, Globorotalia spinulosa and Victoriella plecte (Edgell, 1952); gastropod Vicetia depressa and cephaloped Hercoglossa n. sp. (Brunnschweiler, personal communication).

This fauna places the Giralia Calcarenite in the "a" to "b" stage of the East Indies (van der Vlerk, 1948) which is probably middle to upper Eocene (van Bemmelen, 1949).

In all areas of outcrop the Giralia Calcarenite is overlain unconformably by formations belonging to the upper part of the Cape Range Group.

The only other occurrence of Eocene sediments in Western Australia is in the Kings Park Bore in Perth (Parr, 1938).

MIOCENE:

Cape Range Group

The Cape Range Group named by Clapp (1925) and re-defined by Condon et al (1953) comprises the Tertiary limestones of the Cape Range which have been separated into the Mandu Limestone, the Tulki Limestone and the Trealla Limestone.

The definition of the base of the Cape Range Group must await subsurface exploration as the lowermost of the outcropping formations (the Mandu Limestone) does not outcrop elsewhere and therefore the relationship between this formation and the Eocene Giralia Calcarenite is not known. For the same reason the total thickness of the Cape Range Group in the Cape Range is not known. The maximum known thickness of the Cape Range Group, including about 150 feet penetrated in a bore, is 1015 feet. On the Giralia, Warroora, Chargoo, Gerardi, Chirrida, Yankie Tank, and Grierson Anticlines only the Trealla Limestone crops out unconformably above pre-Miocene sediments. In the Cuvier Anticline at Cape Cuvier and Red Bluff, Trealla and Tulki Limestones disconformably overlie the Giralia Calcarenite. The thickness of the Group ranges from less than 50 feet on the Yankie Tank Anticline to about 70 feet on the Giralia Anticline, about 220 feet at Red Bluff and more than 1015 feet in the Cape Range.

The sediments of the Cape Range Group contain a very rich fauna of foraminifera, bryozoa, corals, pelecypods, gastropods and echinoids as well as calcareous algae. The age of the group, based on foraminiferal correlation, is "e-stage" to "f-2-stage" of the East Indies (Condon et al, 1953).

As the sediments of the "Mandu Limestone" are soft to friable calcarenite and calcilutite with thin coquinoid beds a better name for this formation would be 'Mandu Calcarenite'. This would emphasize the difference between this formation and the overlying hard crystalline limestone of the Tulki and Trealla Limestones.

Merlinleigh Sandstone

The Merlinleigh Sandstone was named by Teichert (1950). It consists of coarse and medium-grained quartz sandstones containing corals, pelecypods, Aturia, and silicified wood. It rests unconformably on the upper Formations of the Permian sequence.

The name is taken from Merlinleigh Homestead (Lat. 24° $18\frac{3}{4}$'S., Long. $115^{\circ}11\frac{1}{2}$'E.). The type section, one mile east-south-east of Merlinleigh Homestead, at the top of a scarp at the edge of a mesa, consists from top downwards of:

5 feet of hard light red-brown silicified medium-grained quartz sandstone forming the top surface of the mesa;
5 feet of hard mottled red and white fine-grained quartz sandstone;
15 feet of medium-hard to hard white fine-grained and medium-grained quartz sandstone with Aturia, corals, pelecypods and fossil wood with boring organisms;
5 feet of friable to medium-hard white silty fine-grained quartz conglomerate with small pelecypods; unconformably overlying siltstone of the Wandagee Formation.

30 feet - type thickness of the MERLINLEIGH SANDSTONE.

Thickness variations in the Merlinleigh Sandstone are very rapid because of the irregularity of the surface of unconformity and the variable thickness removed by erosion since deposition. The thickness is generally under 50 feet. Where the Merlinleigh Sandstone is resting on Permian sandstone and the latter is leached the unconformity is not easy to locate. This has resulted in greater thicknesses being ascribed to the Merlinleigh in some localities, but several of these have been examined and nowhere is the thickness more than 50 feet.

The Merlinleigh Sandstone crops out at the top of scarps at the north end of the Kennedy Range. Good exposures are near Merlinleigh Homestead, 6 and 7½ miles west of Moogooree Homestead, and near Kimbers Well, Williambury. Small low outcrops of silicified quartz sandstone with silicified wood in the area 8 miles east of Mardathuna Homestead may belong to the Merlinleigh Sandstone. The Lamont Sandstone, a lenticular quartz sandstone between the Trealla Limestone and the surface of unconformity on the Giralia Anticline, may be correlated with the Merlinleigh Sandstone.

Teichert, on the basis of the affinities of *Aturia clarkei*, placed the Merlinleigh Sandstone in the Miocene.

At the base of the Merlinleigh Sandstone in the north end of the Kennedy Range there are boulders of white quartz and quartzite up to about 18 inches in diameter. These were probably rafted to their present position attached to the roots of floating trees - the presence of silicified wood in the formation lends validity to this explanation.

Much of the lateritized sandstone capping the mesas and high-level plain may belong to the Merlinleigh Sandstone, but as some of this sandstone is definitely Birdrong Formation unfossiliferous sandstone cappings unconformably overlying the Palaeozoic sediments may belong to either of these Formations.

Yardie Group

The Yardie Group was defined (Condon, Johnstone and Perry,

1953) as consisting of calcareous sandstone and sandy limestone outcropping on the west flank and northern plunge of the Cape Range Anticline.

The name is taken from Yardie Creek, which enters the Indian Ocean at Lat. 22°20'S., Long. 113°48½'E.

The Group consists of two (un-named) Formations. The lower consists of medium to very coarse-grained calcareous sandstone with beds of hard white limestone believed to be wedges of Trealla Limestone; the upper Formation consists of medium-grained calcareous sandstone with thin beds of quartzite. There is a disconformity between the two Formations but as it was very difficult to follow in the field the two Formations generally were not separated and therefore have not been named.

The lower Formation of the Yardie Group is almost certainly of the same age as the Trealla Limestone - East Indies "f-1" to "f-2" stage. The age of the upper Formation is not fixed because of the absence of large foraminifera other than Amphistegina and the uncertainty of identification of small foraminifera in thin section in the hard rock. Though it is possible that its age is as young as Pleistocene, its stratigraphical and structural position relative to the Exmouth Sandstone makes it likely that the age of the upper Formation of the Yardie Group is Pliocene.

QUATERNARY:

Deposits of probable Quaternary age cover a very large part of the area of the Carnarvon Basin but, as they are generally only a thin veneer over the older sediments they have not generally been given formation names. There has been practically no palaeontological age determination of these deposits. Probable age of the various deposits has been determined by their mutual relationships and by their relationship to the development of the physiography.

? Pleistocene:

Deposits probably of Pleistocene age include Exmouth Sandstone, Joolabroo Formation, Walatharra Formation and high-level marine sands and shell beds.

Exmouth Sandstone

The Exmouth Sandstone is the Formation, consisting of reddish quartz sandstone calcareous in places and containing foraminifera, which unconformably overlies the sediments of the Yardie and Cape Range Groups in the coastal area west of Exmouth Gulf to Salt Lake. A bore put down on the beach ridge 1 mile north of Learmonth penetrated 300 feet of Exmouth Sandstone. In outcrop there is generally very much less thickness than this.

The Exmouth Sandstone contains small foraminifera, few larger foraminifera (Amphistegina and Marginopora), and fragments of bryozoa. No direct age determination is possible from the fossils.

The Exmouth Sandstone is involved in the late stages of the folding of the Cape Range and Rough Range Anticlines, after post-Miocene folding and erosion. As there is good physiographical evidence of two main uplift movements in the folding of the Cape Range (Condon et al, 1953, p.11) it is almost certain that the Exmouth Sandstone was deposited in the time between these two movements. As the late Pleistocene to Recent high-level marine deposits include pebbles of Tulki Limestone which was not exposed until after the second movement, it seems likely that the Exmouth Sandstone, deposited immediately before the second uplift movement, is of Pleistocene age.

Joolabroo Formation

The Joolabroo Formation is a high-level alluvium outcropping in the valleys of the Lyndon and Minilya Rivers within the area of outcrop of the Permian sediments. It rests unconformably on Permian sediments. In some places it is covered by (?) Recent red sand deposits.

The name (pronounced jōō'-la-brōō) is taken from Joolabroo Paddock, south-east of Wandagee Homestead. The name was first used in the field, as Joolabroo Conglomerate, by Dr. C. Teichert.

The Joolabroo Formation outcrops from about five feet above the present river bed to about 100 feet above. It has been much dissected by the rivers and minor drainage following the Recent rejuvenation of the drainage upstream from the Wandagee Hill fault. It remains as capping along divides between streams of the minor drainage. The higher outcrop is well exposed in the vicinity of the road from Wandagee to Middalya.

The type section of the Joolabroo Formation is on the left (south) bank of the Minilya River, five miles west-north-west of Wandagee Homestead, at Lat. 23°44½'S. Long. 114°28½'E. There the sequence in descending order is as follows:

	Loose red coarse-grained sand (?Recent) overlying
3 feet of	roughly-bedded loose pebbly coarse-grained quartz sand with calcareous sand in the lower part;
2 feet of	firm pebbly sandy clay loam;
3 feet of	firm yellow-brown sandy clay loam;
3 feet of	firm yellow-brown pebbly sand;
3 feet of	mottled yellow brown and light greenish grey silty sand; unconformably overlying soft dark-grey Bulgadoo Shale
14 feet -	type thickness of JOOLABROO FORMATION

Along the road between Wandagee and Middalya from six to 14 miles from Wandagee Homestead, the section of Joolabroo Formation exposed consists of friable white pebbly limestone (travertine) at the base, overlying Cundlego Formation or Bulgadoo Shale, with from 10 to 15 feet of friable pebbly sand above.

The Joolabroo Formation consists mainly of pebbly sand, fairly well consolidated. The sand consists mainly of sub-angular quartz grains of medium to coarse grain-size with pebbles, mainly about one to two inches diameter, of quartz, quartzite, sandstone, 'billy' (quartzite formed by lateritization), and limestone, of the Callytharra Formation. The matrix is mainly of yellowish silty clay. In some areas the basal travertine is relatively thick (about 10 feet).

No fossils have been seen in the Joolabroo Formation, the age of which is deduced from its physiographical position. As it contains pebbles of rock from the laterite profile it must be younger than the laterite and, particularly, related to the dissection of the lateritized surface. Dissection due to the latest rejuvenation of the river is still progressing but is already well advanced, including attack on the Permian sediments between Middalya and Curdamuda Well, Wandagee. The beginning of that dissection probably coincided with the cessation of deposition of the Joolabroo Formation. The Joolabroo Formation was thus probably deposited during the Pleistocene after the main (post-Miocene) differential uplift of the area east of the Wandagee Hill fault and after the major dissection of the surface of lateritization but before the latest appreciable uplift rejuvenation of the rivers.

Walatharra Formation

The Walatharra Formation is a probably Pleistocene Formation consisting of at least four thick beds of limestone pebble conglomerate with calcarenite between. It is known to outcrop in only one small area on the eastern flank of the Giralia Anticline about 2½ miles south of the Giralia-Bullara road and 6½ miles west of Giralia Homestead.

The Walatharra Formation was defined and described by Condon, Johnstone, Prichard and Johnstone (1954).

It rests unconformably on the Trealla Limestone and is overlain with marked angular and erosional unconformity by the Recent alluvium.

No fossils, except derived material, were found in the outcrop. Its age, therefore, cannot be fixed more precisely than post-Miocene on palaeontological evidence. As there were two main uplift movements on the Giralia Anticline after the deposition of the Trealla Limestone as well as on the Cape Range Anticline, it is probable that they occurred at the same time on the two anticlines and that therefore the Walatharra Formation is of the same age as the Exmouth Sandstone, i.e. Pleistocene.

Pleistocene to Recent:

Marine Deposits

On the shores of the Salt Lake is a deposit, extending from below the level of the lake floor to about 20 feet above it, consisting of thin-bedded, cross-bedded calcarenite and molluscan coquinite. They are marine shell beds and shell sands deposited when the Salt Lake was open to the sea. As barometric levels indicate that the floor of the Salt Lake, at least at its southern end, is very close to ordinary high-tide level, these deposits are all well above present sea level and are related to a eustatically higher sea level. As this deposit in several places rests unconformably on the Trealla Limestone, it is post-Miocene in age and, because of its elevation, almost certainly pre-Recent.

The fossils of this deposit have not been examined. They include gastropods and pelecypods, echinoids, and foraminifera.

These deposits may perhaps be correlated with the Bundera Calcarenite and Mowbowra Conglomerate which like them extend from below sea level to about 20 feet above. In the description of these formations (Condon et al, 1953) they were referred tentatively to the Recent but it is possible that they are of late Pleistocene age.

Bundera Calcarenite

The Bundera Calcarenite was defined and described by Condon et al (1953) as Bundera Limestone. As the dominant lithology of the formation is calcarenite, the more precise formation name is preferred.

The shelly calcarenite of the Bundera Calcarenite contains molluscs, bryozoa, corals and foraminifera. Only the foraminifera have been examined. They give no precise age determination as they are all of living species.

The physiographical position of the Bundera Calcarenite suggests that it may be of late Pleistocene age, related to a high sea level during one of the interglacial stages.

Mowbowra Conglomerate

The Mowbowra Conglomerate, defined and described by Condon et al (1953), is a marine limestone conglomerate with calcarenite matrix containing oysters, other molluscs, and colonial corals.

Like the Bundera, the Mowbowra Conglomerate was referred tentatively to the Recent but its elevation above sea level (up to about 25 feet) indicates that it is likely to be related to the large eustatic movements of sea level associated with the Pleistocene glaciation.

Recent:

Sand

Of the superficial deposits sand covers the largest area. Physiographically and lithologically there are several varieties: red sand in longitudinal sand ridges, red sand in flat or hummocky sand plains, and white sand in dunes along the coast.

The sand of the longitudinal sand ridges almost certainly is of two different ages. That on the high-level plain on top of the Kennedy Range and Pleiades is probably older (as a sand deposit) than the beginning of the major erosional dissection of the area. The sand of the low-level plain is older than the beginning of the latest rejuvenation of the drainage but younger than the high-level sand. It is possible that the high-level sand was a residual sand soil formed during the Pliocene above the laterite and that the low-level sand was deposited during the early Recent epoch.

The development of the longitudinal ridges in the sand almost certainly took place in late Recent times during a very arid period. At present the ridges are fixed by vegetation but during their formation there must have been very little vegetation. The mechanics of the development of these longitudinal sand ridges is not understood. It is almost certain that the length of the ridges is related, perhaps not directly, to the direction of prevailing winds. Bagnold (1941) suggested that they developed from barcans by the effect of two main wind directions from the same quadrant and separated by a moderate angle.

The sand of the sand plains is of the same age as the low-level sand-ridge sand and in many places is continuous with it. Vegetation during the period of formation of the sand ridges may have been the factor preventing development of ridges in these areas. It is particularly related to main rivers and creeks which perhaps supplied enough ground water to maintain a vegetative cover during that very arid period.

The red sand consists predominantly of iron-stained quartz grains ranging from fine-grained to medium-grained. The grains are round to sub-angular. Coarse grains are common at the base of the red sand. In the sand-ridge areas the flats between the ridges commonly have a thin cover of sand but in many places the underlying rock is exposed.

The high-level red sand is probably a residual sand from the lateritization of the Merlinleigh Sandstone and Kennedy Group which form the rock surface of the Kennedy Range and Pleiades. The low level red sand is a transported sand. It could have reached its present location in one of two ways : by river transportation, deposition in river levees and lateral spreading by wind action, or by spreading by wave action of a sand deposited in the sea from the rivers. In the case of some small areas of residual sand (e.g. in the lower Lyons River valley) there has been very little mass movement of sand away from the source area. In only a very few cases have the sand ridges poured over the scarp of the Kennedy Range. As this indicates that there was very little mass movement of the sand in these areas by the wind it is unlikely that the wind could have effected the widespread distribution of sand over the low-level plain from Yanrey and Exmouth to the lower Gascoyne River. The only likely agent for distributing such a widespread, thin and even layer of sand is shallow marine wave and current action. In support of this, the truncation of the Cretaceous formations in the area west of the Wandagee Hill fault is most easily explained by marine erosion.

This inundation probably took place in the late Pleistocene or early Recent - the large quantity of sand probably came from the dissection of the Palaeozoic sediments in the outcrop area during the Pleistocene. No marine fossils have been reported from this sand but in general fossils are rare in this type of sediment and the subsequent action of the wind would have exposed fossils and caused their weathering and destruction.

The white sand of the coastal dunes is completely different from the red sands. It is composed of fragments of invertebrate tests and quartz grains and represents beach sands which have been blown inland and formed into small longitudinal dunes. In some places, e.g. at the Point Cloates Whaling Station, these dunes extend for one mile from the beach. In many places only the dune parallel to the beach is present (as along the western shore of Exmouth Gulf). A high dune of white sand, probably built on a sand spit, has cut off the Salt Lake from the sea at its south end.

Alluvium

Deposits of alluvium cover large areas in the lower reaches of the main rivers, around the larger coastal structures and along the rivers.

These deposits are very variable in thickness and lithology. The thickness ranges from a few feet up to perhaps 250 feet (in the delta of the Gascoyne River). The lithology is dominantly arenaceous but with much silt and clay both in the matrix and as beds.

The alluvial deposits with their deep and balanced soils are generally more densely covered with natural vegetation than any other deposit. For this reason and because of the availability of good water in the alluvial sands and gravels, the only extensive agriculture in the area is confined to the alluvial delta of the Gascoyne River, where bananas and vegetables are grown successfully.

The alluvium is being deposited at present: the beginning of deposition of the Recent alluvium followed the deposition of the red sand. This is particularly noticeable in the Gascoyne delta where the alluvium is deposited around and over the base of the sand ridges.

Wash

Wash, the very thin veneer of alluvial gravel, sand, and clay, over bedrock, covers large parts of the area of outcrop. It consists mainly of the coarser and more resistant components of the bedrock of the vicinity. In general it covers the lower slopes of the erosion scarps and the broad flat areas of sheet-flow drainage between the scarps and the main drainage. In some parts bedrock crops out through it intermittently but in other places it covers large areas completely so that no exposures are available. It tends to be sparsely covered with vegetation, though the herbaceous type of vegetation flourishes after rain.

Residual soil

In a few areas, a residual soil covers the underlying rock. In places where the formations are of similar lithology, this soil cover prevents accurate mapping of the boundary. Areas covered by residual soil are generally flat, not dissected even by minor drainage, and usually underlain by a permeable formation, although some areas of shale also are covered by a residual soil consisting mainly of gypsite.

The residual soil reflects the lithology of the underlying rocks - sandstone weathers to a sand, greywacke to a sandy loam, limestone usually to a clay loam, shales to clay or gypsite.

The thickness of the residual soil is generally less than 20 feet. In any area which has been eroded below the laterite, there has not been sufficient time for the development of a mature surface and a very deep soil profile.

Marine muds and sands

At the head of Exmouth Gulf and along its eastern shore, and in several relatively small areas (known locally as 'Salt marsh') where bay-heads or small gulfs have been cut off from the sea by sand dunes, there is a deposit of dark ligneous silt, clay, and shell sand.

Around the shores of Exmouth Gulf this sediment is being deposited at present, but in the 'Salt marshes' deposition has been stopped by the sand dunes.

Generally this deposit is probably not thicker than 20 feet. It is formed in the zone between high and low tide level and usually supports dense mangrove from which some of the carbonaceous material comes. Sea-weed drifted inshore in storms is caught on the mangrove roots and adds to the carbonaceous material. Much of the silt is a fine lime silt formed by the abrasion of invertebrate tests.

In the 'Salt marshes' the surface layer is generally gypsite, probably formed by evaporation of sea water during the time when the dunes were forming and the sea had intermittent access to the 'Salt marsh' area. The only vegetation on these 'Salt marshes' is stunted saltbush of various types.

Because of the surface layer of gypsite, fossils are rarely found on the salt marshes. Shallow excavations reveal mollusca, foraminifera, and echinoids of living species. This and the physiographical position of the deposits fixes their age as Recent.

Lake Deposits

The floors of the Salt Lake and of the larger 'clay pans' (e.g. those 3 to 8 miles north and 7 miles west of Winning Homestead) are covered by a deposit of thin-bedded clay or silt and evaporites.

These lake deposits are brought into the lake in the inflowing streams in flood flows. The coarse material carried by the streams is deposited close to the stream mouths but the fine sediment is carried out into the lake and deposited very slowly as a thin layer of clay. As the water evaporates the salts carried in solution crystallize out. When the lake is dry the floor is covered by a thin layer of white salts of which the less soluble gypsum resists solution by rain showers. The resulting deposit consists of many thin beds of salty clay or silt slternating with thin beds mainly of gypsum. The deposit is probably quite thin (not more than 10 feet), but no excavation has been made in this material.

No fossils have been found in this deposit, although the fact that it is related to flood flows of the inflowing drainage makes it likely that vertebrate and insect remains would be present.

Its physiographical position, and the fact that its deposition continues at the present time, fix the age of this deposit as Recent.

LATERITE :

Laterite, the mature soil profile developed by weathering probably under humid tropical conditions, forms the surface of much of the high-level plain generally with a thin veneer of red sand. It has developed in many different types of rock so that there are many differences in the profile. In the Carnarvon Basin, rocks of age ranging from pre-Cambrian to Miocene are lateritized. The following profiles are regarded as typical of the profiles developed in rocks of comparable lithology (sections in descending order):

East scarp of mesa east of Kimbers Well, Williambury Station :

3 feet of hard light grey medium-grained to very coarse-grained quartzite ("billy");
1 foot of hard brown pisolitic ironstone; (ferruginous zone)
7 feet of hard silicified coarse sandstone;
friable white fine-grained sandstone (pallid zone).

This section comprises 11 feet of Merlinleigh Sandstone overlying Mallens Greywacke.

Mesa 20 miles south-south-east of Moogooree Homestead:

1 to 5 feet of hard light-grey fine-grained to coarse-grained quartzite (billy);
1 foot of medium-hard ferruginous sandstone (ferruginous zone);
medium-hard red-brown and yellow quartz sandstone (mottled zone).

This profile is developed in Munabia Sandstone. The thickness of the billy varies in different steeply dipping beds so that low ridges of billy follow the beds which are more deeply silicified.

K-49, 3½ miles south of Moogooree Homestead:

10 feet of hard pale-grey pebbly quartzite (billy);
2 feet of red-brown pisolitic ironstone (ferruginous zone); cream and yellow brown pebbly sandstone (? mottled zone);
white friable pebbly sandstone (pallid zone);
light-grey pebbly greywacke (Lyons Group).

This section is developed in a sandy tillite of the Lyons Group.

At the scarp south-east of K-55:

3 to 5 feet of hard red-brown to dark-brown pisolitic to nodular ironstone (fèrruginous zone);

5 to 8 feet of medium-hard white, red-brown, and yellow-brown medium-grained sandstone (mottled zone);
25 feet of hard light-coloured coarse silicified sandstone with coarse sand;
3 inches of pebble conglomerate (well-rounded quartz and quartzite) at base of Merlinleigh Sandstone;
2 feet of hard light-grey silicified fine-grained sandstone;
1 foot of hard reddish yellow-brown ferruginous fine sandstone (? ferruginous zone);
20 feet of soft white and reddish purple (mottled) fine-grained quartz sandstone (mottled zone);
friable white fine-grained and medium-grained quartz sandstone (Wooramel Sandstone).

This section shows the development of two laterite profiles - one in the Wooramel Sandstone and the other in the Merlinleigh Sandstone - indicating that the lateritization was going on both before and after the deposition of the Miocene Merlinleigh Sandstone.

On the ridge 2½ miles east-south-east of Merlinleigh Homestead:

10 feet of hard dark-brown sandy pisolitic ironstone (ferruginous zone);
20 feet of medium-hard rust-brown oolitic and amorphous clayey limonite (ferruginous zone);
20 feet of medium-hard red-brown and white siltstone (mottled zone);
soft white siltstone (pallid zone) grading downwards to soft dark grey carbonaceous siltstone of the Bulgadoo Shale.

This section shows the deep laterite profile developed in siltstone where there was no cover of Merlinleigh Sandstone.

Above the type section of the Muderong Shale (five miles south-east of Paddys Outcamp):

8 feet of hard pale-grey medium-grained to coarse-grained quartzite (billy);
1 foot of hard dark-brown pisolitic ironstone (ferruginous zone);
2 feet of hard pale-grey medium-grained to coarse-grained quartzite (probably Merlinleigh Sandstone);
13 feet of hard white, cream, and pale-grey chert;
30 feet of thin-bedded medium-hard white radiolarite;
60 feet of medium-hard and friable light blue-grey radiolarite (Windalia Radiolarite).

This section shows the development of the laterite profile in the Windalia Radiolarite overlain by sandstone. It is not certain in this locality whether the lateritization occurred only in post-sandstone time or in two periods one before and one after the deposition of the ?Merlinleigh Sandstone. However the presence of angular chert fragments in the basal conglomerate of the sandstone points to the probability of lateritization prior to the deposition of this sandstone, as the Windalia Radiolarite in its fresh state or under ordinary weathering is soft and would not give angular detritus. In other places this is confirmed by the presence of friable sandstone above the cherty lateritized radiolarite. No ferruginous zone has been seen in the radiolarite profile but this may be because the upper part of the profile was removed by transgressive erosion.

In most cases where an arenaceous sedimentary rock has been lateritized, the upper zone as at present preserved is "billy" - hard pale-grey chalcedonic quartzite with grains of a size related to the grain-size of the formation. Under this is a thin pisolitic ferruginous zone, a silicified mottled zone and a friable white pallid zone grading down into the parent rock. In profiles developed from siltstone, the profile is very much deeper, with a thick ferruginous zone at the present surface overlying a hardened mottled zone, a soft pallid zone grading down into the dark parent rock. No profile in limestone is described because no detailed section has been measured, but the profile consists of a thick pisolitic ferruginous zone, a very thick mottled zone in which practically all lime has been removed, and a thin pallid zone grading down into the parent limestone. Good examples of the laterite profile in calcareous rocks are available in the areas 7 miles north of Mount Sandiman Woolshed and near Billidee Well, 5 miles south of Moogooree Homestead.

It is certain that lateritization was active before and after the deposition of the Miocene Merlinleigh Sandstone. It is also reasonably certain that there was no noticeable lateritization of the Palaeozoic sediments before the deposition of the ?Lower Cretaceous Birdrong Formation. The Upper Cretaceous Korojon Calcarenite is strongly lateritized in the crestal area of the Yankie Tank Anticline. This laterite underlies lower Miocene Trealla Limestone. On the Giralia Anticline the Miocene Lamont Sandstone is silicified above a ferruginous zone at the erosion surface of the

Eocene Giralia Calcarenite or Palaeocene upper Cardabia Group. The middle Eocene Giralia Calcarenite contains much limonite as pisolites, infillings and replacement of fossils and disseminated grains. This probably came from a lateritized surface. There is no sign of this in the Danian upper Cardabia Group. These facts taken together probably fix the beginning of the lateritization in the Eocene. It continued, in the terrestrial parts of the basin, until the late Miocene or possibly Pliocene. In the larger part of the basin the process was interrupted by the Miocene marine inundation, but re-commenced when the sea retreated.

This is one of the few areas in Australia where this period of lateritization, which probably extended over most of the present continent, affected Cretaceous and Tertiary marine sediments which can be used to date the age and duration of the process fairly accurately.

STRUCTURE

The Carnarvon Basin is a large epicontinental sedimentary basin. Its present dimensions, limited by the coastline and the pre-Cambrian basement, are : maximum length north to south - 450 miles; maximum width - Dirk Hartog Island to Byro - 200 miles; maximum thickness - about 20,000 feet, beneath the Giralia Anticline.

The basin consists of two main parts areally and vertically: 1. The Palaeozoic basin with an axis of sedimentation, indicated by the gravity reconnaissance (Thyer, 1951b), running from Exmouth Gulf to Carnarvon. Only the rocks of the eastern part of this basin are exposed. 2. The Cretaceous - Tertiary basin with an axis of sedimentation west of the present coastline. Sediments of this basin cover the area from the coast to the western edge of outcrop of the Palaeozoic rocks.

In the eastern part of the basin, where the Palaeozoic sediments outcrop, the regional dip is to the west. This regional dip ranges from about 40° at the eastern edge of the Devonian sediments to about 3° in the Permian sediments of the Kennedy Range.

The regional dip is interrupted by a number of major faults, many of which have caused synclinal drag on the eastern side of the fault and repetition of parts of the sequence. A very few of the faults cause loss of outcrop of parts of the sequence. The gravity reconnaissance indicates that the regional dip of the Palaeozoic sediments in the coastal region may be expected to be towards the east. The reduction in regional dip from east to west in the area of outcrop of the Palaeozoic sediments is interpreted as being the expression of the flexure of the basin floor of pre-Cambrian rocks. The structural deformation caused by later faulting affects this regional dip only locally.

FAULTS :

The sediments of the Carnarvon Basin are cut by faults, the more important of which are of five different types. The majority of the major faults are acutely oblique or strike faults with the downthrown block on the east side. The strata on the downthrown side are dragged into a syncline which from fault to axis is up to two miles wide. Good exposures of the fault plane are rare. The fault seven miles east of Lyons River Homestead can be mapped although the plane itself is not exposed. From a distance this fault can be seen to be dipping westward at a rather low angle (about 40^{o}); as the pre-Cambrian basement is on the up-throw side of this fault this gives an indication of the dip of fault planes in the basement. The dip of fault planes within the Palaeozoic sediments is likely to be much steeper. As outcrops of the fault trace are rare there is little confirmation of this except in the closely-faulted Wandagee Hill area, where the dip of a few fault planes may not be of regional significance. The effect of the faults of this type, apart from the drag syncline, is to repeat part of the sequence in outcrop; this is well shown east of Wandagee Hill where the boundary between the Bulgadoo Shale and the Cundlego Formation is repeated three times, and other small parts of the sequence between the Cundlego Formation and the Coolkilya Greywacke are repeated two or three times.

Stratigraphical throw on this type of fault ranges up to about 10,000 feet, on the fault which outcrops from Williambury Homestead northward. On the fault 7 miles east of Lyons River Homestead, the stratigraphical throw may be of the same order, as Coyrie Formation is faulted against pre-Cambrian gneiss. If, as seems likely, the Devonian Gneudna Formation is present in this area, the stratigraphical throw on this fault may be up to 10,000 feet also. The fault on the west side of the Kennedy Range near Mooka Homestead has a stratigraphical throw of about 3000 feet.

The second main type of fault is the oblique fault, parallel to faults of the first type but with the downthrown side to the west of the fault. In the block between 5 and 7 miles east of Lyons River Homestead, the pre-Cambrian basement is exposed in the up-thrust block between faults of first and second type. There is no noticeable drag on the strata near the fault in the downthrown block. This type of fault results in the faulting out of parts of the sequence in outcrop. Apart from the major faults between Lyons River and Arthur River Homesteads the only faults of this type are the relatively small fault 12 miles east of Mia Mia Homestead which faults out the Coyrie Formation between the Wooramel Sandstone and the Mallens Greywacke and the small fault 15 miles south-west of Moogooree Homestead which faults out the top of the Wandagee Formation.

The third main type of fault comprises those major faults on which post-Cretaceous movement resulted in downthrown blocks to the west of the faults. The only area where this type of fault can be established is where the Cretaceous and Permian outcrop together - west of Wandagee Hill, and along the western side of the Kennedy Range. The fault separating the ?Lower Cretaceous Birdrong Formation on the west from Permian ? Wandagee Formation on the east is of this this type. The Cretaceous strata near the fault dip at a steep angle to the west; the Permian strata are contorted and possibly overturned. This relationship suggests that the eastern block was upthrust over the Cretaceous. The Middalya Fault, 5 miles east of Paddy's Outcamp, dips at 30° to the east: Permian Coolkilya Greywacke is upthrust over Lower Cretaceous Birdrong Formation and Muderong Shale. Further south the Muderong Shale and Windalia Radiolarite on the west side of this fault dip steeply to the west. Near Yabba Well, the upturning of the Birdrong Formation is well exposed; here also the fault plane dips to the east at about 30°. In these areas, the stratigraphical and structural relationships of the Permian strata on either side of the fault indicate that, as regards the Permian strata, the downthrown block is to the east. It seems possible that the reversal of throw results from upthrusts from opposite directions and probably on different fault planes although the fact that similar relationships are observed on several different faults makes this explanation less likely. The observed fault-drag dips in the Cretaceous near the faults (ranging up to vertical) indicate that it is extremely unlikely that the post-Cretaceous fault movement was a normal, gravity-type movement of the western block down a west-dipping fault plane. As most of the epi-Permian fault planes are west-dipping it is probable that the post-Cretaceous movement was an up-thrusting of eastern blocks along east-dipping fault planes. The outcrop of the two separate fault planes, dipping in opposite directions, can be seen five miles east-south-east of Paddy's Outcamp. This up-thrusting of the eastern block along the western edge of the Kennedy Range possibly resulted from the isostatic adjustment to the load, on the area to the west of the Kennedy Range - Wandagee Hill-Winning Pool line, of the Cretaceous and Tertiary sediments.

The only other fault type of some importance consists of relatively small dip and oblique faults - steeply-dipping normal faults, including the small faults cutting the Wooramel Sandstone south of Moogooloo, and probably steeply-dipping compressional oblique faults which are developed at marked changes of strike (e.g. immediately north of Mt. Sandiman Homestead) and in areas of closely-spaced strike faults (as in the Wandagee Hill area, Watermelon

Creek area, and the area west and north of Williambury Homestead).

In spite of the fact that the geometry of the faults and of the strata on either side of the faults indicates that the major faults are up-thrust, there is a marked absence within the sediments of evidence of compression such as compressional joint systems, cleavage and drag-folds. The evidence on the eastern edge of the outcrop area of Palaeozoic sediments indicates definitely that the pre-Cambrian basement is involved in the major faults. The absence of evidence of compression within the sediments and the evidence that the basement was faulted with the sediments leads to the conclusion that the stress which caused the faulting was carried mainly by the pre-Cambrian basement and that the faults in the sediments result from the faulting of the basement. The stress in the basement probably was produced by the bending caused by the load of sediment and by isostatic adjustment of the source area to the east.

The type and cause of faulting has important bearings on the possibility of oil accumulation in the Carnarvon Basin. The absence of compression within the sediments ensures that there will be little consolidation other than by the weight of the overlying sediments, and that calcite and silica are not likely to have recrystallized, and so reduced the permeability of otherwise permeable sediments. The nature of the epi-Permian faulting - high angle up-thrusting - ensures that formation fluids including water, gas, and oil will not have escaped via the faults. This could be the reason for the absence of seepages in the outcrop area.

FOLDS :

The stress environment of the Carnarvon Basin, in which all lateral stresses were carried by the pre-Cambrian basement, could result in folds only as a direct result of faulting. Other folds could have been formed by deposition over basement hills, differential compaction, deposition over coral reefs, or deposition over hills on an unconformity.

In the outcrop area of the Palaeozoic sediments, folds resulting from faulting are the only ones of any significance. In general the up-thrust fault caused an upward drag of the strata on the downthrown (eastern) block, resulting in a syncline of which the eastern limb is the regional dip and the western limb, terminated by the fault, is the expression of the fault-drag. Some of these synclines are quite wide (up to about 2½ miles, in the syncline east of Paddy's Outcamp, between fault and synclinal axis). Most of them plunge gently southward from the Lyndon to Hill Springs and gently northward from the Gascoyne River to Hill Springs. Possibilities for structural closure for oil accumulation, therefore, are generally restricted to minor anticlinal reversals of plunge. There is only one major anticlinal plunge reversal on a syncline - in the area 10 miles west of Paddy's Outcamp.

Along the eastern side of some of the main faults, relatively small dome and basin structures have developed: the basin is the more common structure. Areas where this type of structure is developed include Round Hill (Winning Station, 14 miles east of Mia Mia Homestead), the area between Wandagee Hill and Barrabiddy Creek, 6 to 14 miles south of Paddy's Outcamp, and from 8 miles east of Lyons River Homestead to K-34. These basin and dome structures developed only along short lengths of long faults, probably where transverse faulting in the basement caused north-south compression of the sediments at the same time as the fault-drag caused the synclinal folding. Small faults have been observed running from the main upthrust between the basin and dome structures. Sturmfels (1952) suggested that the shape of the domes south of Paddy's Outcamp was possibly caused by the upward movement of salt, originating in the Bulgadoo Shale, in the crestal region of an anticlinal drag fold. The absence of a tensional fault system across the apex of these domes makes the presence of salt plugs very unlikely. Nearly all the basins and domes are asymmetrical with the steeper flank on the west side against the fault. The axial planes of the folds are probably nearly parallel to the fault plane, as 'similar folding' would be developed by fault drag.

It is possible that the development of the Hill Springs domes (south of Paddy's Outcamp) is related to one of the post-Cretaceous east-dipping up-thrusts which are known to produce steep dips in the Cretaceous strata. In the aerial photographs, there is a suggestion of a dome in Cretaceous sediments; this could explain the dominance of anticlinal structures in this area but does not explain the domed shape.

The two Round Hill basins have Coyrie Formation in the centre with Wooramel Sandstone and Cordalia Greywacke on the flanks. The two Wandagee Hill basins, at Wandagee Hill and ¾ to 3 miles north of the Hill, have Nalbia Greywacke or Mungadan Sandstone in the centre and upper Byro Group on the flanks. Of the small anticlines in this area one has Wandagee Formation, one Bulgadoo Shale, and one Cundlego Formation in its centre. The Hill Springs domes have either uppermost Byro Group or lowermost Kennedy Group in their centres. The one dome in the area east of Lyons River Homestead has uppermost Lyons Group in the centre and the three main basins there have Coyrie Formation or Wooramel Sandstone in the centre.

Anticlines :

In the coastal area between North West Cape and Carnarvon there are a number of anticlines in Cretaceous and Tertiary sediments. They are all related structurally and stratigraphically.

The coastal anticlines may be divided into two groups which are probably genetically related. The western group comprises the Cape Range, Rough Range, Warroora, and Cuvier Anticlines and is separated from the eastern group by a topographically and structurally low area which includes the Exmouth Gulf and Salt Lake and the alluvial area between them on the west side of the Giralia Anticline. For this feature the name 'Bullara Syncline' is proposed. The eastern group of anticlines comprises the Giralia, Marrilla, Chargoo, Gerardi, Chirrida, Minilya, Homestead, Yankie Tank, and Grierson Anticlines.

It is mechanically impossible for anticlines of the size and shape of the Cape Range and Giralia Anticlines to be folded by the application of compressional stress to the sediments composing the folds: therefore some other explanation of their formation must be sought. There are several possibilites:

1. Deposition over pre-existing hills. It is unlikely that a range of the size of the Cape Range Anticline would be unbroken by erosional dissection, which should be apparent in the details of the structure. Deposition over hills produces, almost without exception, marked thinning in all formations. This is probably not the case in the Cape Range Anticline and certainly not the case in the Giralia Anticline.

2. Differential compaction. Probably the only sediments which could compact at such different rates as to result in the observed structural closure (1500 feet) would be a coral reef mass and the accompanying fine clastics. As the limestones of these anticlines are not reef limestones this could not be the primary cause of the structures and an old buried reef mass would be just another form of pre-existing hill.

3. By vertical uplift over folds developed in subjacent strata. In the area of outcrop of the Palaeozoic sediments the only folding known is drag folding along thrust faults. As the stress environment of the Palaeozoic sediments in the coastal region is not likely to be very different from that in the area of outcrop, it is unlikely that compressional folding of the Palaeozoic sediments could have taken place.

4. Vertical uplift by thrust faulting. The dominant fault type in the area of outcrop of the Palaeozoic sediments is the high-angle up-thrust resulting from the failure under compressional stress of the pre-Cambrian basement. It is almost certain that this type of upthrust, cutting completely through the Palaeozoic sediments, caused the asymmetrical types of anticlines. The larger symmetrical anticlines are probably produced by basement upthrusts which have

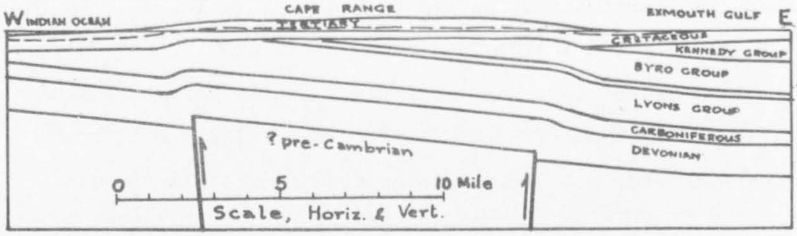
caused folding instead of faulting in the upper part of the Palaeozoic sediments.

It is thought that the two groups of anticlines are located above two large thrust wedges with a rift valley between (see sections, Plate 2). The western wedge is rather simple, but the eastern wedge is broken by a number of minor faults which allow of differential movement within the main wedge. The Pelican Hill Bore, in which Devonian sediments have been proved immediately beneath the Mesozoic at a depth of 1400 feet, is situated on the eastern upthrust wedge. This indicates that the upthrust movement was strongly positive in the main epi-Permian period of faulting. The presence of a big negative anomaly in this area (Thyer, 1951b) possibly indicates a thick pre-Devonian sedimentary sequence in the vicinity of Carnarvon. If this is so, the up-dip basal sands of the Middle Devonian may have received oil draining from these older sediments.

Cape Range Anticline

The stratigraphy and structure of the Cape Range Anticline, which extends 65 miles from Vlaming Head to Point Cloates and has an outcrop width of 13 miles, has been described by Condon et al (1953).

As a result of the reconnaissance gravity survey (Thyer, 1951b) and the seismic survey carried out for West Australian Petroleum Company, the understanding of the stratigraphical and structural foundations of the Cape Range Anticline has developed. At the time the report on the Cape Range Anticline was written, it was believed that the regional westerly dip continued to the coast. The gravity reconnaissance indicated a trough of minimum gravity anomaly from Exmouth Gulf to Carnarvon. The West Australian Petroleum Company's seismic survey confirms that this trough is the axis of the basin and that to the west of this line the regional dip is to the east (personal communication of seismic sections - M.G. Smith). This has several important consequences. First, the east dip indicated by the seismic surveys is steep enough (about 5 degrees average) to bring all the Palaeozoic sequence up to the main unconformity east of the 500 fathom bathymetric contour. This possibility enormously increases the importance of the unconformity as a target for oil



Text Figure 2. Re-interpretation of the structure of the Capė Range Anticline.

production while at the same time increasing the possibility of pre-Cretaceous seepage and depletion of oil sands in the Palaeozoic sequence on this west side of the basin. Secondly, the significant east dip in the Palaeozoic sediments significantly changes the structural environment below the unconformity and, assuming that the main cause of the Cape Range Structure was the up-thrusting of a wedge of the basement at a depth of about 20,000 feet (Condon et al, 1953, p.37), would result in the location of the axis of the fold in the Palaeozoic sediments under the anticlinal bend on the west flank, (Text figure 2). Closure on a large scale is only likely if the strike of the Palaeozoic strata is very close to the longitudinal direction of the anticlinal bend. If the strike of the Palaeozoic strata diverges from this direction the structure in the Palaeozoic sediments can only be an anticline plunging either northward or southward (depending on whether the strike diverged to the west or east of the direction of the anticlinal bend). To determine if there is closure in the Palaeozoic strata under the Cape Range anticline, therefore, a seismic survey of the western flank, especially in the area between Pilgramunna Creek and Milyering Well, west of the surface apex, would be necessary. The reconnaissance gravity map (Thyer, 1951b) possibly indicates that the strike of the Palaeozoic strata is north-eastward, but this needs to be checked by seismic survey.

Thirdly, in the axial area in the Palaeozoic sediments it is probable that most if not all of the Permian sequence has been removed by erosion. (see Text Figure 2). Fourthly, while the anticline in the Palaeozoic sediments is probably under the western anticlinal bend, the anticline in the Cretaceous and in the sands above the unconformity is almost certainly related to the axis at the surface. Separate bores would be required adequately to test the unconformity and the Palaeozoic sediments.

Rough Range Anticline

The Rough Range Anticline, described by Craig (1950), is a relatively small anticline extending from Exmouth Gulf Homestead for about 10 miles southward. Miocene Trealla Limestone and Tulki Limestone are exposed. Structural closure of the order of 400 feet in the Miocene limestone has been mapped.

It is now known that regional eastward dip may be expected in the Palaeozoic sediments in the vicinity of the Rough Range.

The almost symmetrical shape of the anticline in the Tertiary limestone suggests that it may have been developed over a single high-angle up-thrust. The absence of steep dips at the surface indicates that the fault has not broken through to the main unconformity and that therefore the structure in the Palaeozoic sediments is likely to be a fold structure. Because of the regional east dip, an asymmetrical anticline with a steeper east flank may be expected.

It is likely that most of the Byro Group or its equivalent underlie the Rough Range and that therefore on this anticline conditions may be optimum for testing the main Cretaceous/Permian unconformity and the Permian sequence.

However, in this anticline as in the Cape Range Anticline, any appreciable divergence of the strike of the Palaeozoic strata from the axial direction of the anticline will have resulted in an unclosed plunging anticline. Seismic results to date (personal communication - M.G. Smith, West Australian Petroleum Ltd.) indicate a well-developed north-plunging anticline in the Palaeozoic sediments with little if any southern closure. This probably indicates a regional strike to the west of north in the Palaeozoic sediments.

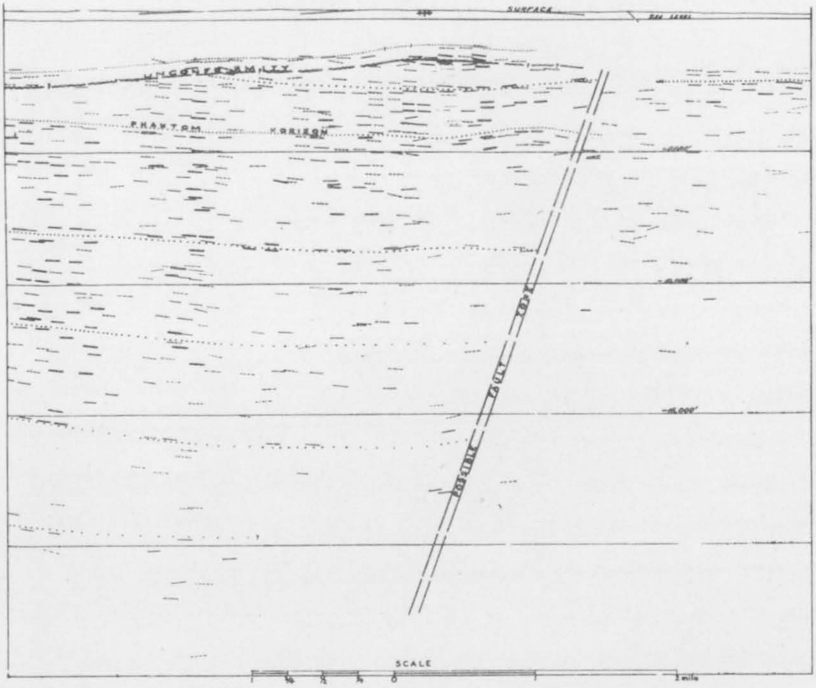
Giralia Anticline

The structure and stratigraphy of the Giralia Anticline has been described by Condon et al (1954). The Giralia Anticline is an asymmetrical anticline extending from the head of Exmouth Gulf southward for 78 miles. Its maximum outcrop width is 14 miles.

Sediments of the Upper Cretaceous Winning Group are exposed in the crestal region, Upper Cretaceous and Danian Cardabia Group, Eocene Giralia Calcarenite, and Miocene Trealla Limestone, on the flanks and north and south noses.

There are several culminations along the crest; the highest of these has a total closure on the Boongerooda Greensand of about 700 feet.

The western flank is gently dipping (average dip about 3 degrees) and the greater part of the east flank also dips gently but, at a distance of about one mile from the crest, there is a narrow, steep anticlinal bend and synclinal bend which appear in outcrop as a narrow zone of steep dips. Dips in this zone are from about 10° on the Giralia - Bullara road to about 80° east of the apex. There is no evidence of actual faulting along this zone, but the very steep dips are almost certainly a reflection of a fault at very shallow depth. In all probability, a fault cutting completely through the Palaeozoic sediments up to the main unconformity was absorbed in the soft Muderong Shale and above this the movement was taken up by folding. This is confirmed by the seismic section (Vale, 1951, and M.G. Smith, personal communication) which have a zone of no reflections dipping steeply west beneath the surface zone of steep dips. (Text Figure 3).



Text Figure 3. Seismic Section, Giralia to Bullara Road, Giralia Anticline.

The seismic sections and the reconnaissance and detailed gravity surveys (Thyer, 1951 a and b) show that the main structure in the Palaeozoic sediments beneath the Giralia Anticline is synclinal. The regional gravity survey indicates that this syncline is the axis of the Palaeozoic basin of sedimentation. The anticlinal form of the unconformity between the Palaeozoic and Mesozoic sediments is almost certainly due to the up-thrust fault movement and not to the shape of the unconformity before the late Tertiary fault movement. Some of the smaller culminations along the crest may have resulted from irregularities in the surface of unconformity. The up-thrust block is on the western side of the fault and in this respect this fault is very similar to the dominant type of fault in the area of outcrop of

Palaeozoic rocks.

Conformable reflections down to 22,000 feet below sea level in the syncline below the Giralia Anticline indicate that probably the full sequence of Permian, Carboniferous, and Devonian sediments observed in outcrop is present in this syncline. Alternative possibilities include additional younger Permian strata, or pre-Devonian strata or both. As Lower Devonian and Ordovician strata are present in outcrop in the Fitroy Basin it is not impossible that sediments of these systems may occur in the central part of the Carnarvon Basin.

The only structure at all favourable for oil accumulation on the Giralia Anticline in the Palaeozoic strata is the small drag anticline immediately to the west of the fault. Structural closure has not been proved on this. The unconformity with its water-bearing sands has the same general form as the outcropping strata and it may well be the most promising possibility for oil accumulation as any seepage from the Palaeozoic strata between the Giralia Anticline and the Bullara Syncline would have migrated up towards the apex. There is some evidence (in the No. 2 Deep Bore, Cardabia) that the basal sand is not present near the crestal area. Investigation of the unconformity would not require deep drilling.

<u>Marrilla Anticline</u>

The stratigraphy and structure of the Marrilla Anticline have been described by Condon et al (1954). The Marrilla Anticline is an asymmetrical anticline with a gentle western flank and steeper eastern flank. In outcrop, it extends west of south for 20 miles from four miles south-west of Giralia Homestead. Its maximum outcrop width is about four miles.

Gearle Siltstone is exposed in the apical area and Cardabia Group on the flanks and north and south noses. Miocene Trealla Limestone crops out on the northwestern flank.

The western flank has an average dip of about 2 degrees and the eastern flank is mainly gently dipping except at the eastern edge of outcrop where there is an anticlinal bend resulting in a zone of steep dips as in the Giralia Anticline.

The subsurface structure may be expected to be less complicated than in the Giralia Anticline because the Marrilla Anticline is in the area of regional west dip. The shape of the unconformity between the Palaeozoic and Mesozoic sediments is almost certainly similar to the structural shape of the Cretaceous to Tertiary sediments which outcrop on this anticline. Below the unconformity there is possibly a drag anticline on the west side of the steeply west-dipping thrust fault and a drag syncline on the east side. The axial plane of these folds would be parallel to the fault plane. Closure in the Palaeozoic strata would be dependent on the strike of the strata.

Chargoo Anticline

The Chargoo Anticline is an asymmetrical anticline with a gently dipping eastern flank and steeper western flank including a steep anticlinal bend. This anticline extends northward from six miles north of Minilya Homestead for 15 miles. The maximum outcrop width is about 2½ miles. The name is taken from Chargoo Pool on the lower Lyndon River, east of the north end of the anticline.

Upper Cretaceous Korojon Calcarenite and Miria Marl are exposed in the crestal region and Danian upper Cardabia Group and Miocene Trealla Limestone on the flanks and noses.

There are two separate culminations on the crest of the anticline. Closure has been established in the Trealla Limestone but not in the Cretaceous strata which form a north-plunging nose.

The subsurface structure is probably controlled by a steeply-east-dipping up-thrust fault and the position close to the axis of the basin. The fault probably consists of two north-south faults en echelon, possibly joined by a north-west fault. The Chargoo Anticline is probably immediately to the east of the axis of the basin. The main Palaeozoic/Mesozoic unconformity probably reflects the shape of the structure as exposed at the surface except that the surface anticline bend is replaced by a fault. Below the unconformity, the Palaeozoic strata are probably dragged into a syncline on the west side of the fault and possibly into a narrow anticline on the east side. Closure in the Palaeozoic strata is only possible if the strike is parallel to the fault.

Gerardi Anticline

The Gerardi Anticline is a slightly asymmetrical anticline six miles long and 2 miles wide, about 11 miles north-north-west of Minilya Homestead, and west of the southern part of the Chargoo Anticline.

The name (pronounced je-rar'-dē) is taken from Gerardi Bore on Minilya Station at the south-eastern end of the anticline.

Only Miocene Trealla Limestone is exposed on the Anticline, which has been very little dissected. Flank dips are about $1\frac{1}{2}^{\circ}$ east and 3° west.

The subsurface structure on this anticline is probably very similar to that of the adjacent Chargoo Anticline, except that the throw on the fault is probably much less than on the fault under the Chargoo.

Chirrida Anticline

The Chirrida Anticline, a slightly asymmetrical anticline with steeper west flank, borders the east side of Salt Lake west of Minilya Homestead. It is 11 miles long, up to 2 miles wide and has flank dips of 2° east and up to 7° west.

The name (pronounced chi'-ri-d$\underline{a}$) is taken from Chirrida Paddock, Minilya, where the main part of the anticline outcrops.

The Miocene Trealla Limestone crops out over most of this anticline. In deeply dissected small stream valleys Eocene Giralia Limestone is exposed, disconformably under the Trealla.

There are two culminations on the crest of the Chirrida Anticline.

Subsurface structure is probably very similar to that under the Chargoo Anticline. It is possible that the Chirrida

Anticline is on the west side of the axis of the basin.

Minilya Anticline

The Minilya Anticline is a small, nearly symmetrical anticline five miles long and one mile wide, the south end of which is $3\frac{1}{4}$ miles west of Minilya Homestead.

Only Miocene Trealla Limestone is exposed on this anticline.

The subsurface structure is probably similar to that under the Gerardi Structure but with very little late Cainozoic movement on the fault.

Homestead Anticline

The very small anticline $1\frac{1}{2}$ to 4 miles north of Minilya Homestead is here named the Homestead Anticline.

It appears to be quite symmetrical, but is so low that any asymmetry in the subsurface structure would not be expressed at the surface.

The surface is mainly covered by travertine probably derived from Trealla Limestone.

This structure, like the other small structures in this vicinity, probably resulted from a very small upthrust movement in the basement, transmitted, partly as a fault and partly as a fold, through the Palaeozoic and Mesozoic sediments to the surface. Structural closure is obvious in the Trealla Limestone at the surface but may not reflect closure in either the Mesozoic or Palaeozoic strata below.

Yankie Tank Anticline

The Yankie Tank Anticline is an asymmetrical anticline with steeper east flank, 6 to 21 miles south of Minilya Homestead.

The name is taken from Yankie Tank, a water tank and catchment on the old Carnarvon to Minilya road 18 miles south of Minilya Homestead.

Upper Cretaceous Korojon Calcarenite is exposed in the crestal area, and Miocene Trealla Limestone as outliers along the crest and on the flanks and noses.

The western flank dips gently (at up to 2°); the eastern flank generally dips gently but has a steeper anticlinal bend at the eastern edge of outcrop.

The subsurface structure is probably controlled by an upthrust in the basement which has resulted in a steeply west-dipping fault in the Palaeozoic sediments with downthrow to the east. The sediments above the Palaeozoic/Mesozoic unconformity have not been faulted but have been folded into a fairly sharp anticlinal bend and synclinal bend. In the Palaeozoic strata the structure is probably a drag anticline on the west side of the fault and a small drag syncline on its east side with structural closure depending on the parallelism of the fault and the strike of the strata. This structure is structurally similar to the Giralia and Marrilla Anticlines.

Grierson Anticline

The Grierson Anticline, named after Grierson Bore, Boologooro Station, is a small, nearly symmetrical, anticline bordering the east shore of Salt Lake for 12 miles north from a point 20 miles north of west of Boologooro Homestead.

This anticline has not been examined on the ground, but aerial photographs show that Trealla Limestone is probably exposed at the surface and there is probably a slightly steeper west flank although both flanks dip very gently. This anticline is very similar to the low structures near Minilya Homestead.

Warroora Anticline

The Warroora Anticline is an asymetrical anticline extending south-south-west for 24 miles from six miles east of Warroora Homestead. The maximum width of the anticline in outcrop is 11 miles. It occupies the area between the north end of Salt Lake and the coast.

The name (pronounced wo'-roo-ra) is taken from Warroora Station.

Upper Cretaceous Korojon Calcarenite and Miria Marl are exposed in the apical area. Most of the crestal area near the apex has sediments of the upper Cardabia Group outcropping. Trealla Limestone covers the gentle western flank and northern and southern noses, and outliers of Trealla Limestone cap ridges on the lower part of the eastern flank.

In the apical area the dips are of the order of 5° west and 12° east. There is an angular unconformity between the Cardabia Group and the Trealla Limestone which has a dip of less than 2° west and about 3° east. The steep dips on the east flank indicate a west-dipping fault in the Palaeozoic sediments underlying the Warroora Anticline. The absence of Eocene Giralia Calcarenite and the angular unconformity indicate upthrusting in the Lower Tertiary. This anticline is probably immediately to the west of the axis of the basin. The main Palaeozoic/Mesozoic unconformity about 1700 feet below the top of the Trealla probably conforms closely to the structural shape of the strata of the Cardabia Group except that the fault probably breaks through the unconformity. There is probably a sharp drag anticline in the Palaeozoic strata on the west side of the fault and a drag syncline on the east.

Cuvier Anticline

The Cuvier Anticline is only seen in outcrop in the cliff section east of Cape Cuvier. Sediments of its eastern flank outcrop at Red Bluff, 13 miles to the north.

Dips up to 5° on either flank in the Cape Cuvier cliff section indicate a possibly symmetrical fold, but as the lower parts of the flanks are under water or under a cover of Quaternary sediments there could be an anticlinal bend on one flank or both.

Sediments ranging in age from Eocene to Miocene, with at least one disconformity, are well exposed in the cliffs near Cape Cuvier and Red Bluff.

This anticline is in line with the anticlinal bend on the west flank of the Cape Range Anticline and may be related to the same fault in the basement.

ECONOMIC GEOLOGY

The economic geology of the Carnarvon Basin will be treated fully in a later report. For the present only a brief statement of mineral deposits in this basin will be made. The basin is part of the Gascoyne Goldfield as proclaimed and although there is no possibility of sedimentary gold deposits within the sediments of the basin, the pre-Cambrian rocks of the eastern margin of the basin are known to contain ore minerals although to date no important deposits have been located. As no work was done in the pre-Cambrian rocks, no additional information can be given. In the sediments of the basin the following minerals and rocks of some economic value have been found : water, gypsum, bentonitic clay, radiolarite, barytes, phosphates, and limestone. In addition the following are possibly present : rock salt, potassium salts, oil and natural gas.

Oil and Natural Gas

No definite seepage or oil or gas show in a bore has been reported from the north part of the Carnarvon Basin. Gas has been reported from a bore on Coburn Station in the south part of the basin.

Formations of the type generally regarded as source beds for petroleum comprise Coyrie Formation, Bulgadoo Shale, Quinnanie Shale, Wandagee Formation, Baker Formation, Muderong Shale, Gearle Siltstone and possibly Korojon Calcarenite and Mandu Calcarenite. Gneudna Formation and Callytharra Formation are richly fossiliferous in outcrop but were probably deposited in an oxidizing environment. Farther out in the basin these formations may have source-bed equivalents.

Munabia Sandstone, Harris Sandstone, sandstone in the Lyons Group, Wooramel Sandstone, Mallens Greywacke, Norton Greywacke, Birdrong Formation and Boongerooda Greensand are permeable formations which could act as reservoir beds for oil.

The various shale formations would act as cap rocks to prevent the upward escape of oil or gas. The only possible source bed which does not have adequate cover is the Mandu Calcarenite.

Structural closure has been established in the Tertiary and Mesozoic sediments of the Coastal anticlines. The structure in the underlying Palaeozoic strata is probably controlled by faulting in the basement which has resulted in faults or folds in the Palaeozoic strata and folds in the Mesozoic and Tertiary strata. Structural closure in the Palaeozoic strata depends on the parallelism of the strike of the strata and the fault. In all cases, seismic investigation is desirable to prove structural closure before drilling for oil. In the area of outcrop of Palaeozoic sediments, small anticlines near faults provide immediate drilling possibilities. Thrust faults may provide adequate structural closure in some cases.

Because of the angular unconformity between the Palaeozoic sediments and the overlying Mesozoic sediments to the west of the axis of the basin, in this area, roughly west of Exmouth Gulf, Salt Lake, and a line from the head of the gulf to the northern end of the Salt Lake, any oil contained in Palaeozoic formations is likely to have migrated into the sands overlying the unconformity. These sands, therefore, constitute perhaps the most promising formation for the accumulation of oil and natural gas. As the structure of this unconformity is probably close to that revealed at the surface, sites to test this sand may be located by surface structure, but sites at which both the sands at the unconformity and the underlying Palaeozoic sediments may be tested on structure will be more difficult to locate and will require adequate seismic survey. In this connexion, the smaller structures are probably more promising in the initial stages of subsurface investigation than the larger, because in the smaller structures the structure of the unconformity is more likely to be close to the structure in the Palaeozoic sediments, geographically if not geometrically.

Despite the absence of seepages, which may be a reflection of the very moderate deformation and of the thrust faulting, the geological conditions which in other parts of the world are associated with oil accumulations are present in the Carnarvon Basin. It is likely that oil was formed accumulated and preserved in the Palaeozoic sediments and possibly also in the Cretaceous sediments of the Carnarvon Basin. Only adequate testing of proved structures by drilling can prove the presence or absence of oil or natural gas accumulations in this basin.

Water.

The Carnarvon Basin is one of the biggest of the artesian basins of Australia. Artesian water was first produced at Pelican Hill Bore, eight miles north of Carnarvon, in 1903. Since then about 65 successful artesian bores have been drilled, producing flows of up to two million gallons per day. The water is hot (about 130 degrees Fahr.) and brackish with some hydrogen sulphide and magnesium, iron, and sodium salts. Flowing in an open ditch, the hydrogen sulphide evaporates before the water reaches a drinkable temperature and then the water is quite acceptable to stock.

The main artesian aquifer is the basal sand above the Palaeozoic-Mesozoic unconformity. In some places permeable Palaeozoic sandstones, dipping down from the unconformity, are also good aquifers.

Apart from the artesian water, which is exploited mainly in the area near the coast, sub-artesian and ground water is of very great importance to the pastoral industry in this area, as there is no permanent running water and very few permanent pools even in the rivers. All the pastoralists use ground and sub-artesian water, obtained by shallow drilling or shaft-sinking, for watering the sheep and horses. Ground water is obtained mainly from alluvial flats along rivers or creeks. It is generally, but not invariably, potable but is commonly restricted in supply. Subartesian water is obtained from the more permeable formations. In order of importance, having regard to available area, quality and supply of water, the aquifers are : Wooramel Sandstone, Mallens Greywacke, Harris Sandstone, Norton Greywacke and Munabia Sandstone. Less important are thin aquifers in the Wandagee Formation, Cundlego Formation, Coyrie Formation and

Lyons Group. Formations which are dry or saline and thick enough to discourage drilling include Gneudna, Willaraddie, Moogooree, Williambury, large parts of the Lyons Group, Callytharra and Bulgadoo. No attempt has been made in the outcrop area to obtain artesian water from a deep aquifer although the Wooramel Sandstone is within 4000 feet of the surface between its outcrop and the western edge of the outcrop of Permian sediments.

Gypsum

Evaporite gypsum has been found in the Bulgadoo Shale and the Wandagee Formation. Secondary gypsum is developed at the surface of the Bulgadoo Shale, Quinnanie Shale, Wandagee Formation, Baker Formation, and Gearle Siltstone.

Bentonitic clay

The Muderong Shale and Gearle Siltstone consist of bentonitic shale, claystone and siltstone in which the proportion of bentonite is reported (Condon et al, 1954) to range up to about 50% although the average appears to be about 25%. These formations are exposed over large areas in the Giralia and Marrilla Anticlines and along the western side of the Kennedy Range.

Radiolarite

Radiolarite is exposed in the apical area of the Giralia Anticline, in the scarp to the west of Winning Homestead, and in mesa scarps from Winning to the Pleiades and along the western side of the Kennedy Range. As radiolarite is similar to diatomite in composition and texture, except that it contains radiolaria instead of diatoms, it may have an economic value as filtering agent, light-weight filler and insulation. It has not been used in these ways to date. It also makes a very good building stone - it is light in weight, of attractive light colours, and a good insulator.

Barytes

Barytes, as large nodules at the surface and as thin beds probably of evaporite barytes, forms part of the Gearle Siltstone. The nodular barytes is common on the western flank of the Giralia

Anticline.

Phosphates

Beds of red phosphatic, calcareous siltstone are common in shales of the Byro Group. Only one sample, from the Bulgadoo Shale on the Minilya River west of Wandagee Homestead, has been analysed. This specimen contained 7.35% of P_2O_5 (Simpson, 1926, p.93).

Limestone

The Moogooree Limestone, Korojon Calcarenite, and the formations of the upper Cardabia Group and the Cape Range Group are fairly pure limestones. The Moogooree Limestone and the Trealla and Tulki Limestones of the Cape Range Group are hard white crystalline limestones; the Korojon Calcarenite, upper Cardabia Group and Mandu Calcarenite of the Cape Range Group are friable clastic limestones. These pure limestones are all suitable for lime-burning; the clastic limestones would be easier to excavate.

Limestone from the Gneudna Formation, Callytharra Formation and Giralia Calcarenite has some silicate sand and silt. Parts of these formations would probably be suitable for cement manufacture.

Hard crystalline limestone from the Gneudna Formation, Moogooree Limestone, Callytharra Formation and Cape Range Group would make excellent road metal, especially for bitumen-sealed roads or air-strips, and good building stone, either broken or cut.

Salts

The presence of evaporite gypsum in outcrop in the Bulgadoo Shale and Wandagee Formation indicates that there is a possibility that below the water table the soluble evaporites (rock salt, potassium salts, iodides etc.) may be present with the gypsum. The occurrence of brine in bores drilled for water in the Wandagee Formation on Lyons River Station indicates that rock salt, at least, is almost certainly present in the evaporite sequence in that formation. It is possible that the domes on Hill Springs Station owe their form to uprising salt plugs (Sturmfels, 1952).

REFERENCES

ADMIRALTY, 1901 - Bedout Island to Cape Cuvier, North West Coast, Australia. Chart No. 1055, Admiralty, Lond.

BAGNOLD, R.A., 1941 - THE PHYSICS OF BLOWN SAND AND DESERT DUNES. New York, William Morris and Co.

BEMMELEN, R.W. VAN, 1949 - THE GEOLOGY OF INDONESIA, Vol 1A. The Hague, Govt. Printing Office.

BENSON, W.N., 1921 - A census and index of the Lower Carboniferous Burindi fauna. Rec.geol.Surv.N.S.W., 10 (1), 12-74.

CLAPP, F.G., 1925 - Geology and geography of the North West and Desert Basins of Western Australia. Proc.Linn.Soc. N.S.W., 50, 47-66.

__________, 1926a - Oil prospects of the North West Basin of Western Australia. Bull.Amer.Assoc.Petrol.Geol., 10 (11), 1136-1149.

__________, 1926b - The oil problem of Western Australia. Econ.Geol., 21 (5), 409-430.

CLARKE, E. de C., 1926 - Natural Regions in Western Australia. J.roy. Soc.W.Aust., 12, 117-132.

______________, K.L. PRENDERGAST, C.TEICHERT AND R.W.FAIRBRIDGE, 1951 - Permian succession and structure in the northern part of the Irwin Basin, Western Australia. J.roy.soc.W.Aust., 35, 31-84.

CONDIT, D.D., 1935 - Oil possibilities in the North West District, Western Australia. Econ.Geol., 30 (8), 860-878.

__________, H.G. RAGGATT AND E.A. RUDD, 1936 - Geology of the North West Basin, Western Australia. Bull.Amer.Assoc. Petrol.Geol., 20 (8), 1028-1070.

CONDON, M.A., 1952 - Nomenclature of the fragmental silicate rocks. Aust.Sci., 15, 53.

CONDON, M.A., D. JOHNSTONE and W.J. PERRY, 1953 - The Cape Range Structure. Part I - Stratigraphy and structure. Bur. Min.Resour.Aust.Bull. 21, 6-42.

CONDON, M.A., D. JOHNSTONE, C.E. PRICHARD and M.H. JOHNSTONE, 1954 - The Giralia and Marrilla Anticlines, North-West Division, Western Australia. Bur.Min.Resour.Aust. Bull. (in ms.)

CRESPIN, IRENE, 1946 - A Lower Cretaceous fauna in the North-West Basin of Western Australia. J. Palaeont., 20 (5), 505-509.

______________, 1947 - Foraminifera in the Permian rocks of Australia. Bur.Min.Resour.Aust.Bull., 15, 1-26.

DAPPLES, E.C., W.C. KRUMBEIN, and L.L. SLOSS, 1948 - Tectonic control of lithologic associations. Bull.Amer.Assoc.Petrol. Geol., 32, 1924-1947.

____________________________________, 1950 - The organization of sedimentary rocks. J.sediment.Pet. 20 (1), 3-20.

EDGELL, H.S., 1952 - The micropalaeontology of the Giralia Anticline, North-West Australia. Bur.Min.Resour.Aust.Rec. 1952/75 (Unpublished).

EDWARDS, A.B., 1952 - Sandstones from the North-West Basin, Western Australia. Sci.ind.Res.Org.Melbourne, Mineragr. Inv.Rep. No. 498. (Unpublished)

FAY, A.H., 1920 - Glossary of the mining and mineral industry. Bull. U.S. Bur.Min., 95.

FISCHER, G., 1933 - Die Petrographie der Grauwacken. Jb.preuss.geol. Landesanst., 54, 320-343.

GARDNER, C.A., 1942 - The Vegetation of Western Australia. J.roy.Soc. W.Aust., 28, xi-lxxxvii.

GLAESSNER, M.F., H.G. RAGGATT, C. TEICHERT, and D.E. THOMAS, 1948 - Stratigraphical nomenclature in Australia. Aust. J. Sci., 11 (1), 7.

GRABAU, A.W., 1904 - Classification of sedimentary rocks. Amer.Geol., 33, 228-247.

GREGORY, F.T., 1861 - On the geology of part of Western Australia. Quart.J.geol.Soc.Lond., 17, 475-483.

GUPPY, D.J., A.W. LINDNER, J.H. RATTIGAN, and J.N. CASEY, 1952 - The Stratigraphy of the Mesozoic and Permian sediments of the Desert Basin of Western Australia. Int.geol.Congr., 19th Sess., Symposium on the Gondwana series, p.107-114.

HIGGINS, H.G., and DOROTHY CARROLL, 1940 - Mineralogy of some Permian sediments from Western Australia. Geol.Mag. 77 (2), 145-160.

HILL DOROTHY, 1942 - Further Permian corals from Western Australia. J.roy.Soc.W.Aust., 27, 57-72.

______________, 1953 - Devonian corals from Western Australia and Silurian corals from New South Wales. Bur.Min. Resour.Aust.Bull. 23 (in press).

HUDLESTON, W.H., 1883 - Notes on a collection of fossils and rock specimens from Western Australia, north of the Gascoyne River. Quart.J.geol.Soc.Lond., 39, 582-595.

MAITLAND, A.G., 1901 - Annual progress report of the Geological Survey for the year 1900. Ann.Rep.Dep.Min.W.Aust. for 1900.

______________, 1903 - Pelican Hill Bore, Carnarvon. Ann.Rep.Dep. Min. W.Aust. for 1902, 91-92.

______________, 1904 - Pelican Hill Bore, Carnarvon. Ibid. for 1903, 150-151.

______________, 1909 - Geological investigations in...parts of the Gascoyne, Ashburton and West Pilbara Goldfields. Bull.geol.Surv.W.Aust., 33, 8-23.

______________, 1919 - Artesian water resources of Western Australia. Mem.geol.Surv.W.Aust., 1, Chapter 2.

MURRAY, J. and A. F. RENARD, 1891 - Deep sea deposits. CHALLENGER REPORT. Lond., H.M. Stationery Office, 203-208 and 283-284.

ORIEL, S.S., 1949 - Definitions of Arkose. Amer.Sci. 247 (11), 824-829.

PARR, W.J., 1938 - Upper Eocene Foraminifera from deep borings in Kings Park, Perth, Western Australia. J.roy.Soc.W. Aust., 24, 69-101.

PRENDERGAST, K.L., 1944 - Permian Productinae and Strophalosiinae of Western Australia. J.roy.Soc.W.Aust., 28, 1-61.

RAGGATT, H.G., 1936 - Geology of the North West Basin, Western Australia... J.roy.Soc.N.S.W., 70 (1), 100-174.

____________, 1950 - Stratigraphical nomenclature. Aust.J.Sci. 12, 170.

____________, and H.O. FLETCHER, 1937 - Contribution to the Permian - Upper Carboniferous problem and an analysis of the fauna of the Permian of North West Basin, Western Australia. Rec.Aust.Mus. 20, 150-184.

RICE, C.M., 1940 - DICTIONARY OF GEOLOGICAL TERMS. Ann Arbor, Michigan. Edwards Bros.

RICH, J.L., 1951 - Three critical environments of deposition and criteria for recognition of rocks deposited in each of them. Bull.geol.Soc.Amer., 62, 1-20.

SIMPSON, E.S., in H.W.B. TALBOT, 1926 - A geological reconnaissance of part of the Ashburton drainage basin. Bull.geol. Surv.W.Aust., 85, 93.

STREICH, V., 1893 - Scientific results of the Elder Exploring Expedition - Geology. Trans.roy.Soc.S.Aust., 16,92.

STURMFELS, E.K., 1952 - Report on investigations on evaporites in the North-West Basin, W.A., during May, June and July, 1951. Aust.Min & Smelting Co. Ltd. (Unpublished).

TEICHERT, C., 1940a - "Helicoprion" in the Permian of Western Australia. J.Palaeont., 14, 140-149.

____________, 1940b - Marine Jurassic in the North-West Basin, Western Australia. roy.Soc.Aust. 26, 17-25

____________, 1941 - Upper Palaeozoic of Western Australia - Correlation and palaeogeography. Bull.Amer.Assoc.Petrol. Geol., 25, 371-415.

TEICHERT, C., 1942a - Permian ammonoids from Western Australia. J.Palaeont. 16, 221-232.

__________, 1942b - Gangamopteris in the marine Permian of Western Australia. Geol.Mag., 79, 321-327.

__________, 1943 - Bradyodont sharks in the Permian of Western Australia. Amer.J.Sci., 241, 543-552.

__________, 1944a - Two new ammonoids from the Permian of Western Australia. J.Paleont., 18, 83-89.

__________, 1944b. - Permian trilobites from Western Australia. J. Paleont., 18, 455-463.

__________, 1946 - Stratigraphy of Western Australia. J.roy.Soc. N.S.W., 80, 81-142.

__________, 1949a - Permian Crinoid Calceolispongia. Mem.geol.Soc. Amer. 34.

__________, 1949b - Discovery of Devonian and Carboniferous rocks in the North West Basin, Western Australia. Aust.J.Sci., 12 (2), 62-65.

__________, 1950 - Some recent additions to the stratigraphy of Western Australia. Bull.Amer.Assoc.Petrol.Geol., 34, 1787-1794.

__________, 1951 - The marine Permian faunas of Western Australia. Paläont. Z., 24, 76-90.

__________, 1952 - Carboniferous, Permian and Jurassic in the Northwest Basin, Western Australia. Int.geol.Congr. 19th Sess., Symposium on the Gondwana series.

THOMAS, G.A., and C.E. PRICHARD, 1953 - Geology of the Williambury and Moogooree one-mile map areas. Rec.Bur.Min.Resour. Aust., 1953/60 (Unpublished).

THYER, R.F., 1951a - Detailed gravity traverse, northern end Giralia Structure, North-West Basin, Western Australia. Ibid., 1951/68 (Unpublished).

__________, 1951b - Gravity reconnaissance (1950), North-West Basin, Western Australia. Ibid., 1951/69 (Unpublished).

TWENHOFEL, W.H., 1932 - TREATISE ON SEDIMENTATION. Baltimore, Williams and Wilkins. 2nd Ed.

VALE, K.R., 1951 - Report on Giralia-Bullara seismic reflection traverse, Western Australia. Rec.Bur.Min.Resour. Aust., 1951/62. (Unpublished).

VLERK, I.M. VAN, 1948 - Stratigraphy of the Cainozoic of the East Indies based on the Foraminifera. Int.geol.Congr. 18th Sess, Proc. Int. Palaeont. Union, 61-63.

WOOLNOUGH, W.G., 1933 - Report on aerial survey operations in Australia during 1932. Commonwealth of Aust. Govt. Printer, Canberra.

TABLE 1A. STRATIGRAPHY OF THE CARNARVON BASIN

ERA	PERIOD	EPOCH	AGE	ROCK UNITS			
				Coastal Area	Giralia Area	Central Area (Mia Mia to Jimba Jimba)	East Margin of Basin
CAINOZOIC	QUATERNARY	RECENT		Alluvium; Lake deposits; Marine deposits;	Travertine; Sand	Alluvium; Sand; Residual Soil; Travertine	Alluvium; Sand; Travertine;Residual Soil
		RECENT or Pleistocene		Bundera Calcarenite; Mowbowra Formation - - - - - - - UNCONFORMITY - - - - - - -			
		PLEISTOCENE		Exmouth Sandstone; Walatharra Formation - - - - - - - UNCONFORMITY - - - - - - -	Walatharra Formation - - - - - - - -	Joolabroo Formation; Sand - - - - - - - -	Joolabroo Formation; Sand - - - - - - - -
	TERTIARY	PLIOCENE(?)		Vlaming Sandstone DISCONFORMITY · · · · } YARDIE GROUP			Fresh-water Limestone
		MIOCENE	Lower(?Burdigalian)	Pilgramunna Formation; Trealla Limestone · · · · DISCONFORMITY · · · · · · · · CAPE RANGE GROUP { Tulki Limestone	Trealla Limestone · · · · · · · · · · · · Lamont Sandstone - - - UNCONFORMITY - - - -	Merlinleigh Sandstone - - - - - - - - UNCONFORMITY - - - - - -	
			(?Aquitanian)	Mandu Calcarenite ? ? ? ? ? ? ? ? ?			
		EOCENE	Middle		Giralia Calcarenite · · · DISCONFORMITY · · · · · ·		
		PALAEOCENE	Danian		CARDABIA GROUP { Jubilee Calcarenite Cashin Calcarenite Pirie Calcarenite Wadera Calcarenite Boongerooda Greensand · · · · · · DISCONFORMITY · · · ·		
MESOZOIC	CRETACEOUS	UPPER	Maestrichtian		Miria Marl · · · · · · DISCONFORMITY · · · ·		
			?Santonian		Korojon Calcarenite · · · · DISCONFORMITY · · · ·	Korojon Calcarenite · · · · · · · · · · · · · · · · · ·	
			?Turonian ?Cenomanian		WINNING GROUP { Gearle Siltstone Windalia Radiolarite	Gearle Siltstone Windalia Radiolarite	Windalia Radiolarite
		LOWER	Albian		Muderong Shale Birdrong Formation ? ? ? DISCONFORMITY ? ? ? ? ?	Muderong Shale Birdrong Formation ? ? ? ? ? ? ? DISCONFORMITY ? ? ? ? ? ?	Muderong Shale Birdrong Formation
	?JURASSIC	MIDDLE	Bajocian(?)		Curdamuda Sandstone - - - - - - - - - U N C O N	Curdamuda Sandstone F O R M I T Y - - - - - - - -	- - - - - - - - - - - - -
PALAEOZOIC	PERMIAN	MIDDLE	?Kungurian			Binthalya Sub-group Mungadan Sandstone Coolkilya Greywacke } KENNEDY GROUP	
		LOWER	Artinskian			Baker Formation Norton Greywacke,Nalbia Gwke. Wandagee Formation Quinnanie Shale Cundlego Formation Bulgadoo Shale Mallens Greywacke Coyrie Formation } BYRO GROUP Wooramel Sandstone Cordalia Greywacke · · · · · · · · DISCONFORMITY · · · · · · · · Callytharra Formation	Mallens Greywacke Coyrie Formation Wooramel Sandstone · · · · · · DISCONFORMITY · · · · · · · · Callytharra Formation
			Sakmarian			LYONS GROUP Harris Sandstone · · · · · · · · DISCONFORMITY · · · · · · ·	LYONS GROUP Harris Sandstone - - UNCONFORMITY - - -
	CARBONIFEROUS	LOWER				Yindagindy Formation Williambury Formation Moogooree Limestone	Yindagindy Formation Williambury Formation Moogooree Limestone
	DEVONIAN	UPPER MIDDLE				Willaraddie Formation Munabia Sandstone Gneudna Formation Nannyarra Greywacke - - - - - - - UNCONFORMITY - - - - - - - -	Willaraddie Formation Munabia Sandstone Gneudna Formation Nannyarra Greywacke - - - - - - - - - - - - - - - - -
PROTEROZOIC						Schist and Granite	Schist, gneiss and granite

TABLE 1B. FORMATIONS OF THE CARNARVON BASIN, WESTERN AUSTRALIA

AGE (See Table 1A)	GROUP	FORMATION	THICKNESS (in feet) Cape Range	Giralia	Lyndon	Minilya	Kennedy Range	LITHOLOGY	FOSSILS	SYMBOL
RECENT		Alluvium	up to about 250					Sand, gravel, silt, clay	Living species	Qra
		Marine muds	possibly up to about 50					Ligneous silt, clay		Qrm
		Residual soil	up to about 20					Clay, loam, gypsite		Qrr
		Wash	up to about 10					Gravel, sand, clay		Qrw
		Travertine	up to about 10					Travertine, some sandy		Qrt
		Lake deposit	?? possibly 20					Clay, evaporites		Qrl
		Sand	up to about 100 in dunes					Red quartz sand, white shell sand		Qrs
RECENT TO PLEISTOCENE		Bundera Calcarenite	16+	?30	?30	?30		Calcarenite, molluscan coquinite, sand, clay	Molluscs, echinoids, forams	Q-b
		Mowbowra Conglomerate	25+	?	---	---	---	Limestone conglomerate, calcarenite	Oysters, molluscs, corals	Q-c
		Sand	20	30	50	---	50	Red quartz sand		Qps
PLEISTOCENE		Joolabroo	---	---	20	20	50	Sand, pebbly sand, calcareous sand		Qpj
		Marine shelly deposits	---	---	?30	?30	---	Calcarenite, shell beds	Molluscs, echinoids	Qpm
		Exmouth Sandstone	400	?	?	---	---	Red calcareous sandstone, limestone conglomerate	Forams, corals	Qpe
		Walatharra Formation	---	90	---	---	---	Limestone conglomerate, calcarenite		Qpw
?PLIOCENE	YARDIE	Vlaming Sandstone	240	---	---	---	---	Calcareous sandstone	Forams	Tpy
LOWER MIOCENE	YARDIE	Pilgramunna Formation	100	---	---	---	---	Calcareous sandstone, sandy limestone, fine conglomerate	Forams	Tmy
	CAPE RANGE	Trealla Limestone	180	40	20-40	0-40	---	Hard foraminiferal limestone	Forams, molluscs, corals	Tmt
			10	---	---	---	---	Hard limestone	Fresh-water gastropods	
		Tulki Limestone	420	---	?40	---	---	Hard foraminiferal limestone	Forams, echinoids, molluscs	Tmk
		Mandu Calcarenite	400	---	?30	---	---	Friable coquinoid calcarenite	Forams, echinoids, bryozoa	Tmm
?MIOCENE		Merlinleigh Sandstone	---	---	---	20	50	Friable quartz sandstone	Nautiloid, corals, pelecypods	
EOCENE		Giralia Calcarenite	?	240	50	?20	---	Friable and hard foraminiferal calcarenite	Forams, bryoz.a, echinoid, *Aturia*, molluscs	Teg
DANIAN	CARDABIA	Jubilee Calcarenite	?	0-35	---	---	---	Friable and hard calcarenite	Brachiopods, forams, bryozoa, echinoids, corals	Taj
		Cashin Calcarenite	?	0-50	---	---	---	Friable and hard calcarenite	Bryozoa, brachiopods, forams, crabs	Tac
		Pirie Calcarenite	?	100	90	---	---	Friable calcarenite	Bryozoa, echinoids, forams, radiolaria	Tap
		Wadera Calcarenite	?	100	25	---	---	Friable and hard calcarenite	Bryozoa, brachiopods, forams, echinoids, molluscs, corals	Taw
		Boongerooda Greensand	?	10	10	---	---	Friable glauconite sand	Forams, brachiopods, molluscs	Tab
UPPER CRETACEOUS		Miria Marl	?	10	5	---	---	Friable fossiliferous glauconitic marl	Ammonites, forams, molluscs, brachiopods, nautiloids, corals, shark teeth	Kum
		Korojon Calcarenite	?	127	50	50	30	Friable coquinoid calcarenite	*Inoceramus*, forams, brachiopods	Kuk
	WINNING	Gearle Siltstone	?	550	?	?	?30	Soft dark bentonitic siltstone	Forams, radiolaria, belemnites	Kug
		Windalia Radiolarite	?	50+	120+	(60)	110+	Thin bedded radiolarite, silty radiolarite	Radiolaria, forams, ammonites, belemnite	Kuw
LOWER CRETACECUS		Muderong Shale	?	(220)	40	(80)	3-50	Bentonitic shale & siltstone	Forams, radiolaria	Klm
		Birdrong Formation	?	(131)	40	(40)	20-105	Quartz sandstone, glauconitic sandstone, siltstone	Fossil wood	Klb
??JURASSIC		Curdamuda Sandstone	?	?	?	25+	---	Hard calcarecus sandstone	Molluscs, algae	Jmc
?MIDDLE PERMIAN	KENNEDY	Binthalya Sub-group	?	?	?	---	1725	Quartz sandstone & quartz greywacke	Few pelecypods	Pat
		Mungadan Sandstone	?	?	?	145	184	Quartz sandstone	Few pelecypods	Pas
		Coolkilya Greywacke	?	?	?	?620	625	Quartz greywacke, greywacke	Pelecypods, brachiopods, ammonoids, trilobite, shark	Pal
LOWER PERMIAN (Artinskian)	BYRO	Baker Formation	?	?	?	153	210	Siltstone, quartz greywacke	Brachiopods, molluscs	Pak
		Norton Greywacke	?	?	?	177	250	Greywacke, quartz greywacke	Pelecypods, bryozoa, brachiopods	Pan
		Wandagee Formation	?	?	?	425	545	Siltstone, quartz greywacke	Brachiopods, crinoids, forams, molluscs	Pag
		Quinnanie Shale	?	?	?	515	85	Shale, thin quartz greywacke	Lingula, brachiopods, forams, crinoids	Paq
		Cundlego Formation	?	?	1250	1090	700	Quartz greywacke (some calcareous), siltstone	Bryozoa, crinoids, brachiopods, molluscs	Pau
		Bulgadoo Shale	?	?	?	1000	500	Siltstone, carbonaceous shale, thin quartz greywacke	Forams, bryozoa, corals, crinoids, brachiopods, nautiloid, ammonoid	Pab
		Mallens Greywacke	?	?	700	??	300	Quartz greywacke	Pelecypods, brachiopods, gastropods	Pam
		Coyrie Formation	?	?	1000	855	500	Siltstone, quartz greywacke	Ammonoid, nautiloid, forams, molluscs, brachiopods, wood, *Glossopteris*	Par
		Wooramel Sandstone	?	?	140	250	122	Quartz sandstone	Wood	Paw
		Cordalia Greywacke	?	?	200	35	nil	Quartz greywacke	Bryozoa, brachiopods	Pad
		Callytharra Formation	?	?	765	540	250-400	Calcarenite, quartz greywacke, Limestone	Bryozoa, brachiopods, forams, corals, crinoids, molluscs, nautiloids, ammonoid, *Gangamopteris*	Pac
LOWER PERMIAN (Sakmarian)	LYONS		?	?	5700	4600	?3700	Silty & sandy tillite, quartz greywacke, varved siltstone, thin fossiliferous limestone	Bryozoa, brachiopods, *Calceolispongia*, forams, molluscs corals	Psl
		Harris Sandstone	?	?	?	280	?	Clean quartz sandstone	Lepidodendron	Psh
CARBONIFEROUS		Yindagindy Formation	?	?	?	260	?	Coarse greywacke, quartz greywacke, sandy oolitic limestone	Crinoids, brachiopods, gastropods, nautiloid, ostracods	Cuy
		Williambury Formation	?	?	?	600-1200	?	Pebbly greywacke, siltstone, conglomerate		Cuw
		Moogooree Limestone	?	?	?	1180	?	Hard bedded limestone	Bryozoa, corals, brachiopods	Clm
DEVONIAN		Willaraddie Formation	?	?	?	980	?	Greywacke, siltstone, sandstone, conglomerate	Bryozoa, brachiopods (few)	Duw
		Munabia Sandstone	?	?	?	1900	?	Quartz sandstone	Club-moss	Dum
		Gneudna Formation	?	?	?	1750	930	Greywacke, limestone, siltstone	Stromatoporoids, corals, brachiopods, nautiloids	Dmg
		Nannyarra Greywacke	?	?	?	265	170	Greywacke, siltstone		Dmn
PROTEROZOIC			---	---	---	---	---	Quartzite, greywacke, slate, limestone		Bsed
			---	---	---	---	---	Basic dyke rocks, Pegmatite, Granite, Gneiss, Schist		Pgr Pgs Psch

TABLE 2.

STRATIGRAPHICAL NOMENCLATURE, CARNARVON BASIN

Condit 1935	Raggatt 1936	Teichert 1939, 1940	Teichert 1941, 1947, 1949	Teichert 1950, 1952	Condon 1954	
					Binthalya Subgroup	KENNEDY GROUP
Kennedy Sandstone	Kennedy 'Stage'	Helicoprion-Fenestella beds'	Wandagee Hill 'Series'	Mungadan Sandstone	Mungadan Sandstone	KENNEDY GROUP
			'Linoproductus Stage'	Coolkilya Sandstone	Coolkilya Greywacke	KENNEDY GROUP
Wandagee Formation	Wandagee 'Stage'	'Lamellibranch beds'	'Schizodus Stage'	Nalbia Sandstone	Baker Formation Norton Greywacke	BYRO GROUP
		'Calceolispongia beds'	'Calceolispongia Stage'	Wandagee Formation	Wandagee Formation	BYRO GROUP
		'Lingula beds'	'Lingula Stage'	Quinnanie Shale	Quinnanie Shale	BYRO GROUP
[Kennedy Sandstone]	[Kennedy 'Stage']	[Kennedy 'Stage']	Cundlego 'Series'	Cundlego Formation [Mallens Sandstone]	Cundlego Formation	BYRO GROUP
	Byro 'Stage'			Bulgadoo Shale [Coyrie 'Shale']	Bulgadoo Shale	BYRO GROUP
					Mallens Greywacke	BYRO GROUP
					Coyrie Formation	BYRO GROUP
	Wooramel 'Stage'			Wooramel Sandstone	Wooramel Sandstone Cordalia Greywacke	
	Callytharra 'Stage'			Callytharra 'Limestone'	Callytharra Formation	
	Lyons 'Series'			LYONS GROUP		LYONS GROUP
				'Red Hill Sandstone'	Harris Sandstone	
				'Yindagindy Limestone'	Yindagindy Formation	
				'Williambury Sandstone'	Williambury Formation	
				'Moogooree Limestone'	Moogooree Limestone	
				Munabia Sandstone	Willaraddie Formation Munabia Sandstone	
				'Gneudna Limestone'	Gneudna Formation	
				'Nannyarra Sandstone'	Nannyarra Greywacke	
				Pre-Cambrian	Pre-Cambrian	

NOTES: Names in inverted commas are informal
Formation names in square brackets indicate incorrect correlation
Dashed line indicates boundary not defined
The names according to the various authors are shown against the parts of the sequences as at present known in outcrop, to which the authors referred them.

SCALE - Stratigraphical Column

1 0 1 2 3 4 5 6 7 8 9 10 thousand feet

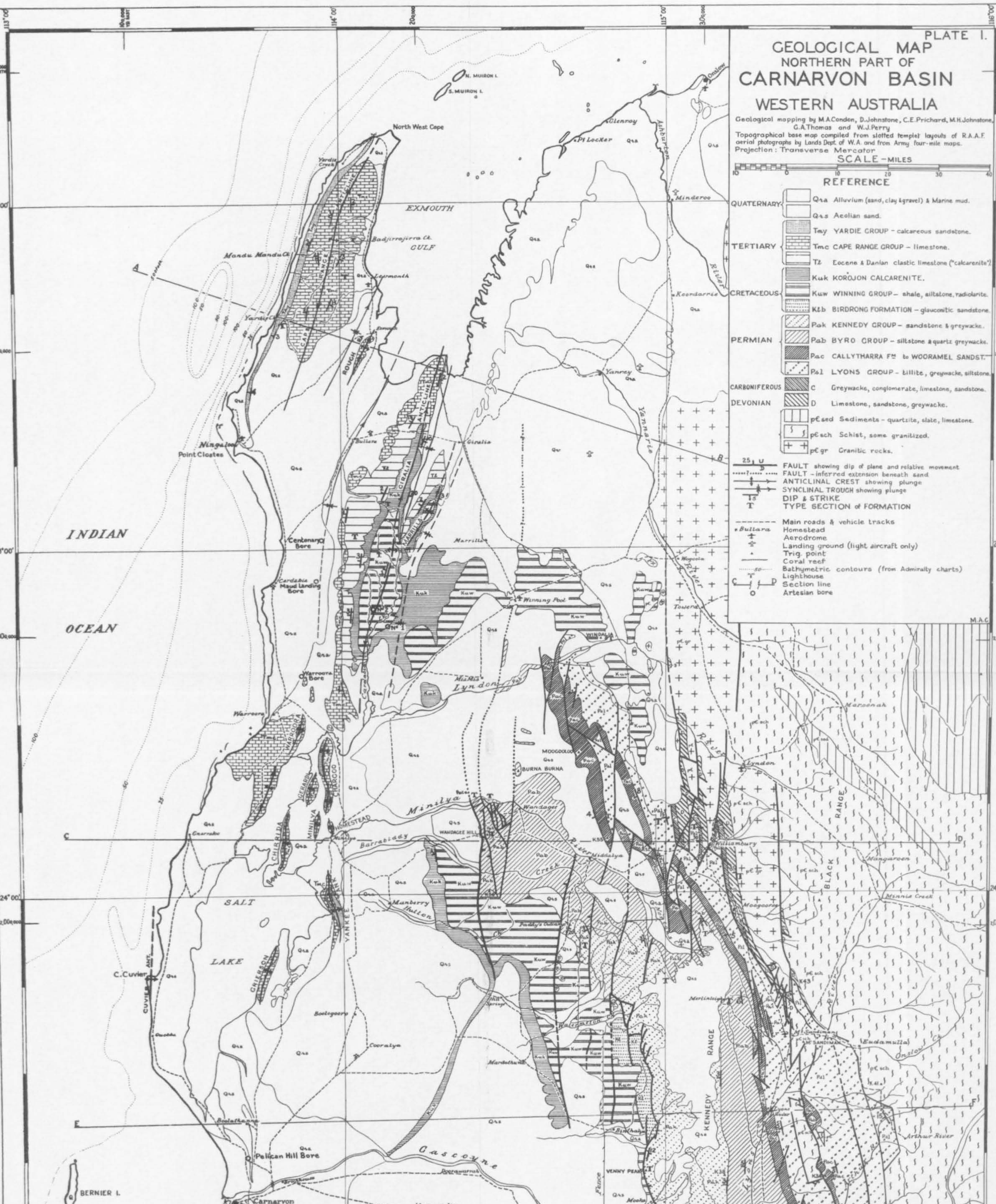


PLATE I.
GEOLOGICAL MAP
NORTHERN PART OF
CARNARVON BASIN
WESTERN AUSTRALIA
Geological mapping by M.A.Condon, D.Johnstone, C.E.Prichard, M.H.Johnstone, G.A.Thomas and W.J.Perry
Topographical base map compiled from slotted templet layouts of R.A.A.F. aerial photographs by Lands Dept. of W.A. and from Army four-mile maps.
Projection: Transverse Mercator
SCALE - MILES
10 0 10 20 30 40
REFERENCE
QUATERNARY
Qra Alluvium (sand, clay & gravel) & Marine mud.
Qrs Aeolian sand.
TERTIARY
Tmy YARDIE GROUP - calcareous sandstone.
Tmc CAPE RANGE GROUP - limestone.
Tl Eocene & Danian clastic limestone ("calcarenite")
CRETACEOUS
Kuk KOROJON CALCARENITE.
Kuw WINNING GROUP - shale, siltstone, radiolarite.
Klb BIRDRONG FORMATION - glauconitic sandstone.
PERMIAN
Pak KENNEDY GROUP - sandstone & greywacke.
Pab BYRO GROUP - siltstone & quartz greywacke.
Pac CALLYTHARRA Fm to WOORAMEL SANDST.
Pal LYONS GROUP - tillite, greywacke, siltstone.
CARBONIFEROUS
C Greywacke, conglomerate, limestone, sandstone.
DEVONIAN
D Limestone, sandstone, greywacke.
p€sed Sediments - quartzite, slate, limestone.
p€sch Schist, some granitized.
p€gr Granitic rocks.
FAULT showing dip of plane and relative movement
FAULT - inferred extension beneath sand
ANTICLINAL CREST showing plunge
SYNCLINAL TROUGH showing plunge
DIP & STRIKE
TYPE SECTION of FORMATION
Main roads & vehicle tracks
Bullara Homestead
Aerodrome
Landing ground (light aircraft only)
Trig. point
Coral reef
Bathymetric contours (from Admiralty charts)
Lighthouse
Section line
Artesian bore
M.A.C.
113°00'
114°00'
115°00'
116°00'
22°00'
23°00'
24°00'
25°00'
N. MUIRON I.
S. MUIRON I.
North West Cape
Onslow
Glenroy
Pt Locker
EXMOUTH
GULF
Minderoo
Mandu Mandu Ck
Yanrey
Point Cloates
Ningaloo
Giralia
Bullara
INDIAN
OCEAN
Centenary Bore
Marrilla
Winning Pool
Maud Landing Bore
WINDALIA
Lyndon
Warroora
Mooroonah
MOOGOOLOO
BURNA BURNA
Minilya
Barrabiddy
Wandagee
Williambury
Mangaroon
BLACK RANGE
SALT
LAKE
Manberry
C.Cuvier
Minnie Creek
Boologooro
Cooralya
Mardathuna
KENNEDY RANGE
Eudamullah
Arthur River
Cascoyne
River
Pelican Hill Bore
BERNIER I.
Carnarvon
VENNY PEAK
DORRE I.
Cascoyne Junction
SHARK BAY
Rabbit Proof Fence
WA 4-39

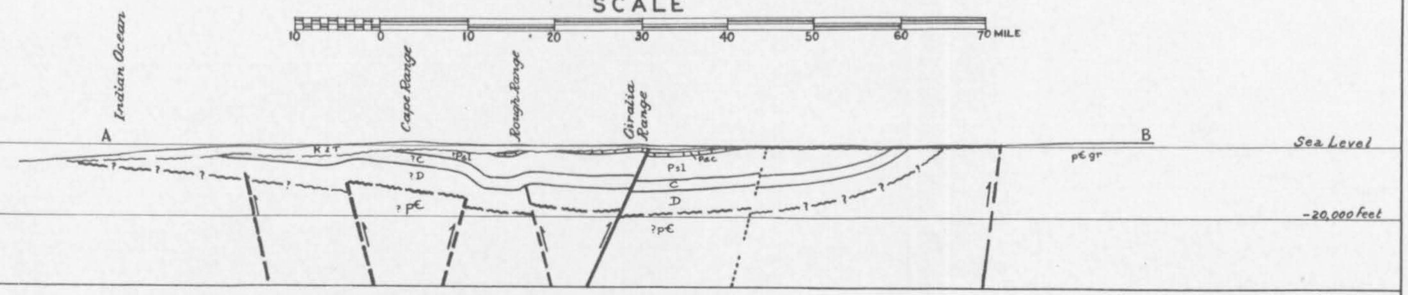
PLATE 2.

CARNARVON BASIN

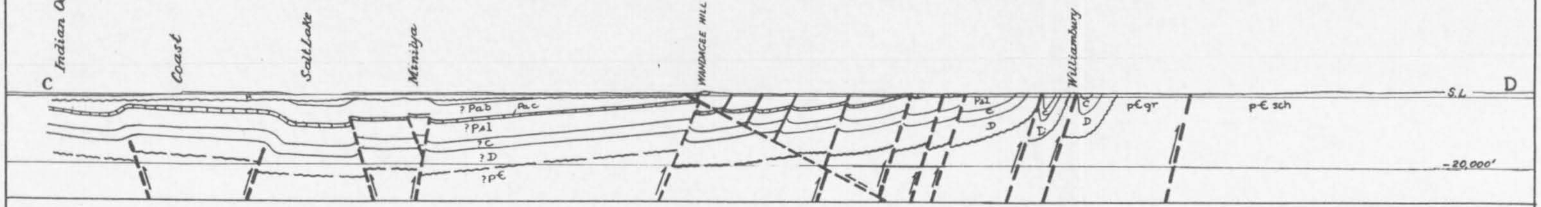
WESTERN AUSTRALIA

CROSS SECTIONS

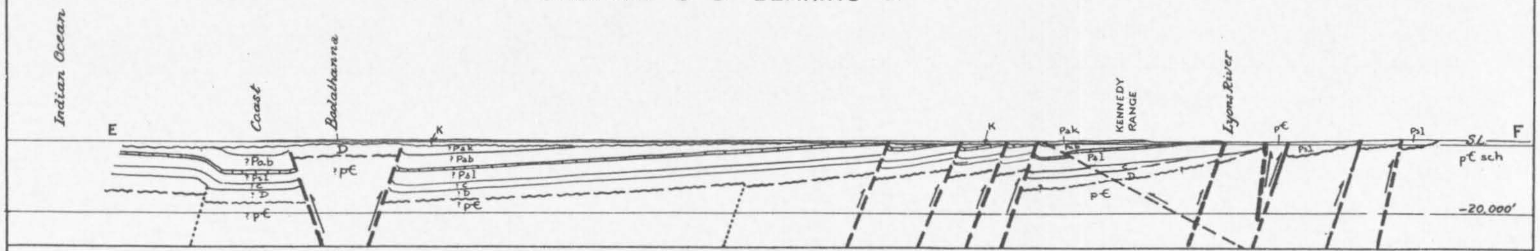
SCALE



SECTION A-B BEARING 108½°



SECTION C-D BEARING 91°



SECTION E-F BEARING 90°

WA 4-40

M.A.C.

PLATE 3.

CARNARVON BASIN

WESTERN AUSTRALIA

STRATIGRAPHIC COLUMNS