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# THE GEOLOGY OF THE CARNARVON BASIN, WESTERN AUSTRALIA

## Part 1: PRE-PERMIAN STRATIGRAPHY

BY

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## PREFACE

The report on the Geology of the Carnarvon Basin is issued in three separate and relatively independent Parts. Each Part treats an individual section of the subject and is accompanied by a Summary and an appropriate list of References.

Part I deals with the Pre-Permian Stratigraphy and also includes a General Summary and other introductory information. Part II deals with the Permian Stratigraphy and Part III details the Post-Permian Stratigraphy and also contains information on Regional Structure, Palaeogeography and Economic Geology.

## GENERAL SUMMARY


The Carnarvon Basin is an epicontinental basin of Proterozoic, Palaeozoic, Mesozoic, and Tertiary sediments. On land it extends from Onslow in the north to near Geraldton in the south and eastward from the coast for about 130 miles.

Proterozoic and Lower Palaeozoic sediments crop out at the south end of the basin. Silurian dolomite has been found in bores; marine Devonian sandstone, limestone, and siltstone crop out at the north-eastern edge of the basin and are found in bores in the central coastal area. Lower Carboniferous marine limestone and greywacke overlie the Devonian in outcrop; the limestone is doubtfully recognized in coastal bores. Permian marine sediments, including marine glacial sediments, rest unconformably on Lower Carboniferous, Devonian, and Precambrian rocks. Jurassic rocks are known in outcrop only on the far northern and southern margins, but form an important part of the subsurface sequence in the northern coastal area. Cretaceous marine sediments rest unconformably on Precambrian, Permian, and Jurassic rocks, mainly in the western part of the basin. Tertiary sandstone rests unconformably on Permian and Cretaceous rocks in a belt running north-south in the centre of the basin; Tertiary limestones cover the Cretaceous rocks near the coast. Maximum known thicknesses are: Proterozoic, about 30,000 feet; Lower Palaeozoic, 10,600 feet plus possibly 10,000 feet; Devonian, 4800 feet; Lower Carboniferous, 2300 feet; Permian, 15,200 feet (Sakmarian 7200 feet, Artinskian 5500 feet, and Kungurian 2500 feet); Jurassic, 11,460 feet; Cretaceous, 2670 feet; and Tertiary, 1500 feet.

The Palaeozoic sediments were laid down on a surface of Precambrian rocks with strong relief. Minor basins sagged as sediments were laid down, and increased the original major structural relief. No evidence has been found of tangential stress in the sediments of the basin: all structures from the largest to the smallest are depositional structures affected only by large-scale down-warping.

The geological history of the basin is related to intermittent transgression and regression of the sea which may have been caused by large eustatic rises of sea level or by epeirogenic movements of the continent or its margin.

The basin is regarded as likely to contain commercial accumulations of petroleum, because of the combination of source beds in Devonian, Permian, Jurassic, and Cretaceous formations, reservoir beds in Devonian, Permian, Jurassic, and Cretaceous formations, and structural relief which has been present since deposition of the sediments.

The underground water resources of the basin are indicated: several good artesian aquifers are established.

# PRE-PERMIAN STRATIGRAPHY


## SUMMARY

Pre-Permian, mainly marine, sediments of Carboniferous, Devonian, Silurian, ?Ordovician, and Proterozoic age, rest on a crystalline basement of Precambrian (Archaean) age and are unconformably overlain by Permian, Mesozoic, and Tertiary sediments. Outcrops are confined to the north-eastern and southern margins of the Basin, but a wide subsurface distribution of pre-Permian sediments is indicated by occurrences in bores.

A regional northward plunge is suggested by the occurrence of the older sediments in the south and the younger in the north.

The several minor basins within the Carnarvon Basin apparently started to develop as downwarps at different times: Byro Basin in the Proterozoic, Gascoyne and Merlinleigh Basins (and the Coolcalalaya Basin at the north end of the Perth Basin) in the Lower Palaeozoic, and Bidgemia and Onslow Basins in the Devonian.

Marine shales and limestones provide probable source beds for petroleum, and sandstones, limestones, and dolomites have adequate porosity to form petroleum reservoirs in suitable locations. No positive indications of petroleum have been found in the pre-Permian sediments apart from a small show of gas in WAPET's Rough Range No. 1 Well, possibly in Carboniferous.

The geology of the pre-Permian is described in some detail and subsurface occurrences are discussed.

# INTRODUCTION

In 1947, an arrangement was made between the Commonwealth Government and the Government of Western Australia for the Bureau of Mineral Resources, Geology and Geophysics to carry out regional geological and geophysical surveys in the sedimentary basins of Western Australia. As a result, the regional geological survey of the Carnarvon Basin was started by a short reconnaissance in 1948, and completed in 1956 (Fig. 1).

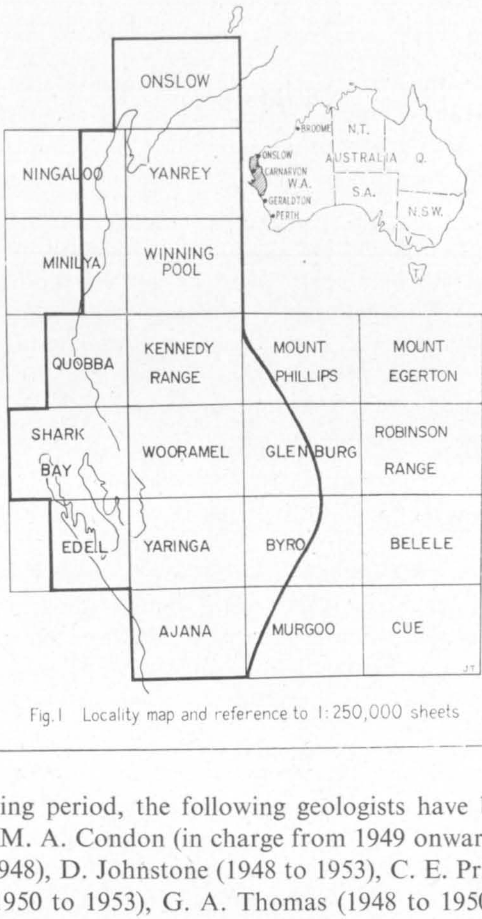



Fig. 1 Locality map and reference to 1:250,000 sheets

In the intervening period, the following geologists have been engaged in field work in the basin: M. A. Condon (in charge from 1949 onwards), C. Teichert (1948 to 1950, in charge 1948), D. Johnstone (1948 to 1953), C. E. Prichard (1949 to 1952), M. H. Johnstone (1950 to 1953), G. A. Thomas (1948 to 1950), W. J. Perry (1949, 1950, and 1956), M. C. Konecki (1954 and 1955), J. M. Dickins (1955 and 1956), T. Quinlan (1954 and 1955), S. D. Henderson (1954), D. J. Belford (1954), J. G. Best (1950), W. M. Burnett (1955), D. Moore (1955), P. E. Playford (1953), and K. G. Smith (1955). J. M. Pulley, W. J. Perry, C. R. Mercer, and R. A. McTavish were well-site geologists on the stratigraphic bores.

Palaeontological, petrological, and chemical examination of specimens collected by the field parties is continuing. The following palaeontologists have examined material collected by Bureau geologists from the Carnarvon Basin :

Irene Crespin, D. J. Belford and H. S. Edgell (foraminifera); C. Teichert (calceolispongids and goniatites); G. A. Thomas, P. J. Coleman and B. J. Glenister (brachiopods); J. M. Dickins and L. R. Cox (pelecypods); A. A. Öpik (invertebrate trails and trilobites); and Mary E. White (lycopod plants). The following petrologists have examined rock specimens: W. B. Dallwitz, A. B. Edwards and R. D. Stevens.

*The Carnarvon Basin*

The Carnarvon Basin was first named 'North West (Artesian) Basin' by Maitland (1919). Clarke (1926) used the name Carnarvon (Natural) Region, which he stated coincided with Maitland's North-West Artesian Basin. Gentilli & Fairbridge (1951) first used the term Carnarvon (or North-West) Basin for the large basin of mainly Permian sediments, underlain by Carboniferous and Devonian, and overlain by Jurassic (unimportant) and by Cretaceous sediments. Condon (1954) dropped the term North-West completely and referred only to the Carnarvon Basin.

Although the name is established, the limits of the basin have not been defined except by Condon (1956b) in a map. The Carnarvon Basin may be defined as the compound basin of sedimentation, containing Proterozoic, Palaeozoic, Mesozoic, and Tertiary sediments on a basement of Precambrian gneiss, schist, and granite, that extends from near Onslow in the north to near Geraldton in the south, and from the coast inland to the Precambrian rocks as far as 130 miles east, and seaward for an unknown distance.

In the north, the basin continues on to the continental shelf. In the south, it is continuous with the Perth Basin and the boundary between the two must be somewhat arbitrary. The only strong structural feature between the two basins is the Ajana Ridge, which separates the south-western end of the Carnarvon Basin from the north end of the Perth Basin. The south-eastern end of the Carnarvon Basin is separated from the north end of the Perth Basin by the Yallalong Ridge. Between these two ridges, at about Latitude 26° 20′ S., reconnaissance gravity indicates a saddle or sill; this, the Muggon Ridge, is regarded as the northern boundary of the Perth Basin and part of the southern boundary of the Carnarvon Basin.

The Carnarvon Basin may be subdivided (Condon, 1956b) into a number of relatively minor but still large basins separated by ridges of structurally high basement rock which crops out in a few places along these ridges (Fig. 2). The main basement ridge is the Ajana-Wandagee Ridge, which divides the Carnarvon Basin in two meridionally. The basin to the west of this ridge is called the Gascoyne Basin; this is limited at its northern end by the Bullara Ridge running south-south-west from east of Rough Range to the coast between Ningaloo and Cardabia. To the north and west of the Bullara Ridge is the Exmouth Basin, the limits of which apart from the Bullara Ridge are beyond the coastline. To the east of the Ajana-Wandagee Ridge there are a number of basins and ridges; from north to south these are: Onslow Basin, Yanrey Ridge, Merlinleigh Basin, Weedarra Ridge, Bidgemia Basin, Carrandibby Ridge, Byro Basin, Muggon Ridge, and Yallalong Ridge.

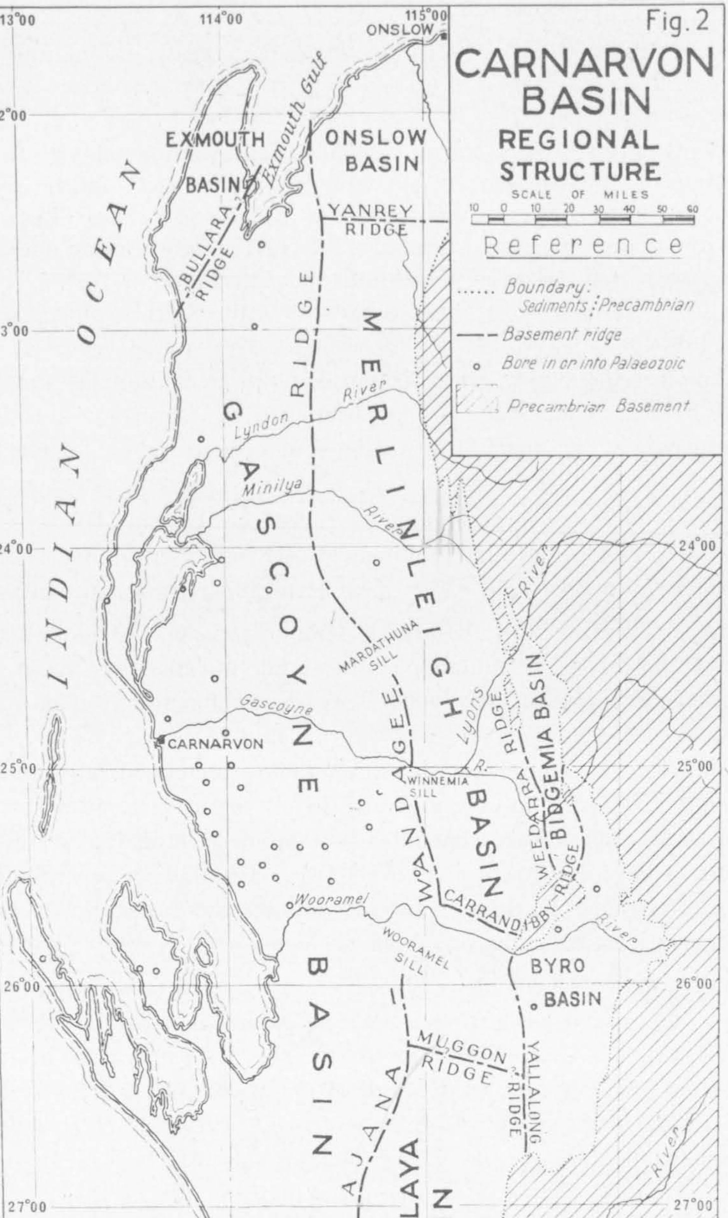


Fig. 2
CARNARVON BASIN
REGIONAL STRUCTURE
SCALE OF MILES
10 0 10 20 30 40 50 60
Reference
Boundary: Sediments : Precambrian
Basement ridge
Bore in or into Palaeozoic
Precambrian Basement
INDIAN OCEAN
ONSLOW
EXMOUTH BASIN
Exmouth Gulf
ONSLOW BASIN
BULLARA RIDGE
YANREY RIDGE
RIDGE
MERLINLEIGH BASIN
GASCOYNE BASIN
Lyndon River
Minilya River
MARDATHUNA SILL
Gascoyne
CARNARVON
WANDAGEE
WINNEMIA SILL
Lyons R.
River
WEEDARRA RIDGE
BIDGEMIA BASIN
CARRANDIBBY RIDGE
Wooramel
WOORAMEL SILL
River
BYRO BASIN
MUGGON RIDGE
YALLALONG RIDGE
AJANA
COOLCALALAYA BASIN
Murchison
River
AJANA
113°00
114°00
115°00
116°00
22°00
23°00
24°00
25°00
26°00
27°00

*Physical Conditions*

*Access.*—Most of the surface of the basin is a gently undulating plain; the only strongly dissected areas are Cape Range in the far north-west and the west side of Kennedy Range in the central part of the Basin.

A network of mail roads (shown on Plate 2) and station roads gives reasonable access to almost all the basin except the strongly dissected areas and the undeveloped area of thick scrub between the Wooramel and Murchison Rivers. They are mainly unformed dirt roads which are untrafficable for several days during and after heavy rain. The main road between Geraldton and Carnarvon is formed and sealed. The road from Carnarvon to Onslow and that from Carnarvon to Mullewa via Gascoyne Junction are formed but not sealed.

Carnarvon is the supply centre of most of the area; supplies are brought to Carnarvon by sea, road, and air, and distributed by road. Onslow supplies the far northern part of the area, Mullewa the south-eastern part, and Geraldton and Northampton the southern part.

Airfields suitable for large aircraft have been established at Carnarvon, Learmonth, Onslow, Lyndon, Mount Sandiman, Gascoyne Junction, and Hamelin Pool. Airstrips suitable only for light planes have been prepared on many of the stations.

*Climate.*—The climate of the area is semi-arid in spite of its position on the edge of the tropical zone. Rainfall averages about 10 inches per annum at Winning Pool, 9 inches at Carnarvon, 11½ inches at Gascoyne Junction, 9 inches at Onslow, and 18 inches at Geraldton. Most of the rain falls in February-March and May-June. Rainfall is very unreliable, in total amount, number of falls, and month of maximum fall. Temperatures are generally high: winter temperatures are moderate (frosts are almost unknown except inland); summer temperatures are very high; lengthy periods have daily maxima above 100°F. Humidity is generally low except during and after rain. During the summer months the humidity is very low, and evaporation rate consequently very high.

*Vegetation.*—The vegetation is generally well adapted to the semi-arid climate. Most plants have small hard aromatic leaves, phyllodes, spines or thorns, or soft fleshy watery leaves. Areas of sand support mainly spinifex (*Triodia*) in the northern part of the basin and *Acacia* scrub south of the Wooramel. Areas of outcrop or wash are covered with low scrub, mainly *Acacia*. Channels of rivers and larger creeks are lined with *Eucalyptus*.

*Development.*—Much of the basin is subdivided into pastoral leases of large size, averaging about 300,000 acres. On most of these only Merino sheep are raised. Along the lower part of the Gascoyne River, a small but important agricultural development is in progress. On the river delta, bananas and vegetables are grown under irrigation, using water obtained from the sands of the river bed and from sand aquifers in the deltaic material.

Shore-based whaling is established at Carnarvon. About 1,000 whales are taken each year and processed.

*Previous Work*

F. T. Gregory (1861) published a section eastward from Babbage Island (Carnarvon) showing a regional west dip in Palaeozoic sediments, which were shown as Devonian (?), Carboniferous (?), and Permian (?), and the overlying Cretaceous (?), which was thought to include the sandstone of the Kennedy Range.

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

A. Gibb Maitland (1898) described the junction between the (Tumblagooda) sandstone and Precambrian near Hardabut Pool on the Murchison River. He (1901) discovered the (Lyons Group) glacial sediments and recognized the possibility of obtaining artesian water in the coastal part of the basin. He was instrumental in having a deep bore drilled near Carnarvon, the Pelican Hill Bore, which struck artesian water with a flow of 520,000 gallons a day at a depth of 3011 feet (Maitland, 1903 and 1904). Maitland in 1901 made a traverse along the telegraph line between Northampton and Carnarvon and described (Maitland, 1907) the (Tumblagooda) sandstone near Mount Curious. Maitland examined the Palaeozoic sediments in the Gascoyne, Minilya, and Lyndon River valleys (1909). He described and named the Lyons Conglomerate and described limestones (of the Callytharra Formation and Moogooree Limestone) and sandstone (Kennedy Group). He described sections in the Minilya River near Wandagee, near Moogooloo Peak, and in Kialawibri Creek (Lyndon River area). In 1919 he named the 'North-West Artesian Basin' and showed the outline of the basin on a very small-scale map of Western Australia.

F. G. Clapp (1925) undertook a reconnaissance through the North-West (Carnarvon) and Desert (Canning) Basins. He added little to the knowledge of the Palaeozoic and Mesozoic stratigraphy and structure, but discovered the Cape Range Anticline in Tertiary limestone. His extremely pessimistic opinion of the oil possibilities of the basin (Clapp, 1926a and b) was based mainly on his failure to find any shales that could act as cap rocks—this in spite of the evidence of effective cap rocks in the artesian bores. The views of this experienced American oil geologist caused a complete cessation of interest in the search for oil in Western Australia for about six years, and was probably the main factor in dissuading major companies from undertaking exploration for about 15 years, when Caltex took up concessions.

In 1928, H. W. B. Talbot examined the country in the Wooramel River area (Talbot, 1929), and reported an anticlinal structure which was later named Talbot's Dome. Dr. W. G. Woolnough and F. R. Feldtmann inspected the area with Talbot, and Woolnough reported that more detailed investigation was necessary. In 1930 R. A. Hobson surveyed Talbot's Dome (Hobson, 1931). Irene Crespin (1930b, 1931) described fossils from the Wooramel River area. In 1931, Talbot, Hobson, and P. Hossfeld inspected the Wooramel area and Hossfeld (1931, unpublished) reported that more work was required.

In 1932, T. W. E. Dee and E. A. Rudd carried out semi-detailed mapping in the Wooramel River area and, in an unpublished report to Oil Search Ltd, first subdivided the Permian sequence in that area and named formations. Their names were used by Raggatt (1936) for the equivalent formations in the northern part of the Basin. Crespin (1932) described fossils collected by Dee and Rudd.

Crespin (1930a) described fossils from near the mouth of the Murchison River, collected by Mr L. Glauert.

The first really systematic geological work in the Carnarvon Basin was carried out from 1932 to 1935 by geologists of Oil Search Ltd. Condit (1935) gave a brief summary of the results. Raggatt (1936) and Condit, Raggatt, & Rudd (1936) presented the details of the stratigraphy and structure as obtained during a short reconnaissance from the Gascoyne River northwards. Raggatt was mainly responsible for the establishment of the outlines of the Permian stratigraphy and areal geology north of the Gascoyne River. The presence of Devonian and Carboniferous sediments was not recognized, although the Carboniferous (Moogooree Limestone) was examined and described. Raggatt established the presence of Cretaceous sediments in the northern part of the basin. Crespin (1934a, b, c; 1935a, b, c; 1936a, b; 1937a) described fossils collected by geologists of Oil Search Ltd.

Hobson (1936) reported the observation by Forman in 1932 of Cretaceous sediments overlying Permocarboniferous (Tumblagooda Sandstone) along the lower Murchison River. Forman examined the underground water possibilities on Woodleigh Station in 1934 (Forman, 1937). In this paper he equates the (Tumblagooda) sandstone with the Kennedy Sandstone of Raggatt (1936). He also describes the Cretaceous of the Lower Murchison and gives a list of fossils collected from that sequence.

Waterford, in about 1937, carried out a reconnaissance survey of the eastern part of the basin between Merlinleigh and Byro Plains. He added little to previous mapping, but made a good collection of fossils from the Callytharra Formation and Byro Group.

Simpson (1934), and Clarke & Teichert (1948) reported on the Cretaceous sequence of the Lower Murchison River. Clarke & Teichert did the most complete work to date, but considered the whole sequence, including the Tumblagooda Sandstone (which they named), to belong to the Cretaceous.

Raggatt & Fletcher (1937) listed the species then known from the Carnarvon Basin and examined the problem of the Carboniferous-Permian boundary in Australia and around the Indian Ocean 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 Carnarvon Basin are Lower Permian, assuming the base of the Permian to be at the base of the *Schwagerina-Uddenites* Zone. Subsequent work has confirmed this.

Conrad & Maynard (1948) made a rapid reconnaissance along the Murchison River and along the north coastal part of the basin.

In 1948, Craig (1950) surveyed the Rough Range Anticline and part of the Giralia Anticline and examined the Permian sequence along the Minilya River.

Between 1940 and 1950, Teichert carried out several reconnaissance trips in the basin and made some detailed surveys in the Wandagee area. He also did valuable palaeontological work on the calceolispongids, goniatites, and several other fossil groups. His work was mainly confined to the upper part of the Byro Group, in which he was able to correct Raggatt's sequence. He found fossils in the (Merlinleigh) sandstone and on the basis of his determination of *Aturia australis* gave a Miocene age to this formation. When the previous dating of this fossil was found to be incorrect the age was revised to Eocene, which was confirmed by later work done by Dickins and Crespin. Teichert (1940b) found marine fossils which he considered of Jurassic age.

McWhae, Parry, and Hanley of West Australian Petroleum Pty Ltd carried out reconnaissance and detailed surveys in the Merlinleigh and Byro Basins in 1952 and 1953. D. Johnstone and Playford of the same company surveyed the area between Shark Bay and the Murchison River (Johnstone, Condon, & Playford, 1958). West Australian Petroleum Company has drilled 52 bores (to December 1963) ranging in depth from 815 feet to 15,180 feet. The author has had access to some of the information obtained in these bores. Where this information is used in this Bulletin it is with the approval of the Company and is specifically acknowledged.

Gravity surveys designed to give a reconnaissance cover of the basin, with stations at about 5-mile intervals along main roads and many minor roads, were completed by geophysicists of the Bureau of Mineral Resources between 1950 and 1956 (Chamberlain, Dooley, & Vale, 1954). Seismic reflection surveys have been carried out by the Bureau of Mineral Resources at Cape Range, Giralia Anticline, and Wandagee (Chamberlain et al., op. cit.). The Bureau carried out aeromagnetic surveys of the basin in 1956, 1957, 1959, 1960, and 1961.

Many specialist investigators have done palaeontological and petrological work on specimens from the Carnarvon Basin. These are referred to specifically in the body of the report.

### *Survey Method*

*Mapping.*—Air-photographs taken by the Royal Australian Air Force in 1948, 1949, 1952, and 1953, at scales of 1 to 30,000 and 1 to 50,000, were used by the Department of Lands and Surveys of Western Australia to compile planimetric base maps by the slotted templet method, using triangulation points identified on the photographs for position control. Mainly because of inaccurate identification of triangulation points on the photographs, the absolute accuracy of the compiled maps is poor: a point on the map may be as much as half a mile out of position. These errors, where present, are distributed over quite large areas, so that the relative positions of features are more correct than this. Geological boundaries are in correct relationship to the topography as compiled within the limits of definition of the geological feature: an established boundary accurately placed is mapped relative to the topographic features: approximate or inferred boundaries, of course, are not accurate in their positions.

In the field, the individual photographs were used, with stereoscope, to locate outcrops, to plan access routes, and to identify observation points. The observation points were marked on the photograph and numbered on its back. The observations at the point were recorded in a field notebook.

Formation boundaries were located on the ground and identified on the photograph. Where boundaries could be followed clearly on the photograph only a few confirmatory observations were made. Where boundaries were not clear on the photograph they were either followed on the ground and located on the photograph, or located on the ground in enough places to enable the boundary to be mapped. In the office, geological boundaries were transferred to the planimetric base, at photo-scale, subdivided to one-mile sheet areas, which could be used as such or reduced to form smaller scale maps. From the one-mile sheets, the quarter-million sheets and the basin map (Pl. 1) were compiled. The 1:250,000 map sheets are being published separately.

Areas of stratigraphic or structural complexity were mapped at large scale by plane table or by chain, compass, and Abney Level.

*Stratigraphic Sections.*—Many stratigraphic sections were measured in detail to determine variations in thickness and lithology of formations. Two main methods were used: in strata dipping less than about 15°, the dip was determined as accurately as possible, preferably by surveying a bed over a large area by chain, compass, and Abney Level, by plane table, or by photo-mapping combined with a closed aneroid height survey. Using the personal height to eye-level or ranging poles five feet long, and an Abney set at the determined dip, the sequence was measured from the base upwards, and the lithology, bedding, texture, structures, and fossils were noted in their correct vertical position in the field notebook at a scale of 5 or 10 feet to 1 inch. Specimens for palaeontological or petrological examination were collected and located in the vertical sequence. In strata dipping more steeply than 15°, the section was traversed, using a plane table and tacheometric alidade, or chain, compass, and clinometer. Dips were measured by clinometer wherever possible and notes on the strata were made appropriately. A section was drawn at large scale (e.g. 40 feet to 1 inch) in the average dip direction; on this section the surface profile was drawn, all dips were plotted at observed positions, and the vertical section was developed from that.

In both methods the factor chiefly limiting the accuracy of the measurement is the determination of the dip of the bed over a large area. This is generally likely to be less accurate than the clinometer measurement of the angle of dip. With this in mind the likely error in the thickness determinations made by these methods is about 5 percent.

Where only the thickness of a formation was required, or where outcrop was not good enough for detailed measurement of the section, formation thickness was determined by obtaining as many reliable dip measurements as possible and measuring the outctop distance by chain and pace, or by scaling from the photograph. The thicknesses determined in this way have a likely error of 10 per cent, except where otherwise stated.

The author did most of the stratigraphic sectioning; sections measured by other party members are specifically acknowledged.

## PHYSIOGRAPHY

The surface of the Carnarvon Basin is a major physiographic unit characterized by low relief, open drainage pattern, and large gently undulating sand-plains (Fig. 3). This contrasts strongly with the area of Precambrian rocks to the east (Unit VI) which has moderately high relief, close dendritic drainage pattern, and mature valley topography. The surface of the basin is dominated by plains at two levels, separated in most places by a scarp ranging in height up to about 400 feet.

The lower plain is mainly a coastal plain of marine abrasion and deposition. It includes the Upper Tertiary deposits (Unit I), the wave-cut platform eroded in Cretaceous sediments (Unit II), outcrop plains in Permian sediments (Unit III), and river deltas (Unit V). The upper plain consists of remnants of the Eocene depositional coastal plain (Unit IV).

The surface of the basin slopes very gently to the west and is drained by the following main rivers: Ashburton, Yannarie, Lyndon, Mimilya, Gascoyne and its tributary Lyons, Wooramel, and Murchison, all of which have their headwaters in the Precambrian rocks to the east. The valleys of the rivers north of the Wooramel are open, but the valleys of the Lower Wooramel and Lower Murchison Rivers are entrenched in gorges; the gorge of the Lower Wooramel is about 100 feet deep and that of the Lower Murchison about 300 feet deep.

Much of the basin north of the Wooramel River is covered by sand dunes of two kinds: longitudinal dunes which run fairly straight for several miles, and braided dunes which cover large areas with an anastomosing pattern. Much of the basin south of the Wooramel is covered by sand, but dunes are rare here.

The coastline has several large features—the North-West Cape Peninsula in the north and the peninsulas and islands at the south and west sides of Shark Bay. Apart from these, the coastline is fairly regular. Along much of the coast, sea-cliffs range in height up to 800 feet. Near Point Cloates, near the south end of Salt Lake, and near the mouth of Murchison River, large coastal sand dunes have built back from the beach.

The continental shelf is narrow off Cape Range but fairly wide to north and south. Coral reefs are developed off the Cape Range coast and southward to Gnarraloo.

The main ranges in the Carnarvon Basin are the Cape Range—a young fold mountain with very youthful consequent drainage; the Giralia Range—a dip scarp in Tertiary and Cretaceous sediments on the west flank of the Giralia Anticline; the Moogooloo Range—a dip scarp and dip slope in Permian strata; the Kennedy Range—an erosion remnant of the high plain underlain by permeable and resistant Permian sandstone; the Carrandibby Range—a monadnock of Precambrian rock; and the Errabiddy Hills and Woodrarrung and Badgeradda Ranges—resistant sediments of possibly Proterozoic age.

## STRATIGRAPHY

The main features of the stratigraphy of the Carnarvon Basin are set out in Plate 1. Pre-Permian rock units are listed in Table 1.

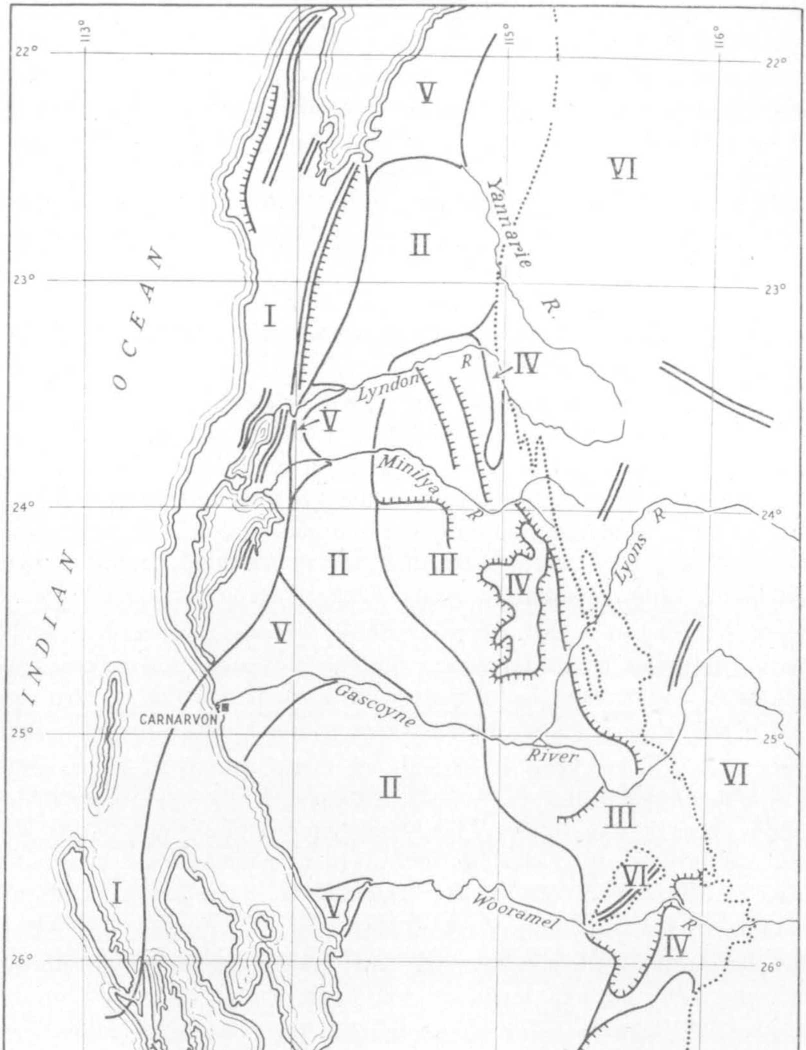



Fig.3 Physiographic subdivisions. Carnarvon Basin

At the eastern margin of the Basin, the sediments lie unconformably on Precambrian schists, gneiss, granite, and sediments, which constitute the floor of the basin. Sediments probably of Proterozoic age rest on crystalline Precambrian rocks in the south end of the basin; Devonian sediments form the base of the sedimentary sequence in the north-eastern part of the basin; Permian sediments cover the Precambrian along most of the eastern margin; and in the far north-east the Precambrian is covered by a thin veneer of Cretaceous sediments.

There are several major and many minor breaks in the pre-Permian sedimentary sequence; the major gaps are between the Lower Palaeozoic and Permian, and between Lower Carboniferous and Sakmarian. A minor break (disconformity) is known between the Devonian and Lower Carboniferous.

Terrigenous sediments of probable Proterozoic age crop out in the Badgeradda Range area at the south-eastern margin of the basin. They rest unconformably on Precambrian basement and are overlain unconformably by Permian sediments. They have not been identified in any deep bores in the basin.

Terrigenous sediments possibly of Ordovician age crop out in the Lower Murchison River area and are known in subsurface in WAPET's Wandagee No. 1 and Quail No. 1 wells. They are unconformable on Precambrian basement and are overlain unconformably by Permian, Jurassic, and Cretaceous sediments and, probably disconformably, by ?Silurian sediments.

Sediments of possible Silurian age are known only from bores: WAPET's Dirk Hartog No. 17B, Wandagee No. 1, and Quail No. 1. Carbonates are dominant; fine-grained terrigenous sediments are included. The relationships of these rocks are not well established: they are overlain by Cretaceous and Devonian sediments and overlie the ?Ordovician sediments.

Devonian sediments ranging in age from probable Givetian to probable Famennian crop out in the central eastern part of the basin and have been found in bores near Carnarvon, at WAPET's Wandagee No. 1, at WAPET's Quail No. 1, and possibly in WAPET's Rough Range No. 1. They rest unconformably on ?Silurian sediments or on Precambrian basement. Terrigenous sediments are dominant, but carbonate sediments are also included.

Lower Carboniferous sediments are known from WAPET's Rough Range No. 1 Well and from outcrop in the central eastern part of the basin, where they are unconformably overlain by Permian (Sakmarian) sediments and rest disconformably on Upper Devonian sediments; terrigenous sediments are dominant, but carbonates form an important part of the sequence.

Upper Carboniferous terrigenous and calcareous sediments are known only from the Onslow Basin, in WAPET's Minderoo No. 1 Well, where they are overlain, probably unconformably, by Cretaceous sediments.

NOMENCLATURE

*Stratigraphical.*—Stratigraphical nomenclature accords with the Australian Code (A.N.Z.A.A.S., 1956; G.S.A., 1959). New names have been approved by the State Sub-Committee on Stratigraphical Nomenclature.

*Geographical.*—Place names shown on Western Australian Department of Lands and Surveys plans have been accepted in cases of obvious inconsistency or duplication. Within the Carnarvon Basin the same name has in several cases been used, on Lands and Surveys Department plans, for different features of the same type; e.g. Binthabooka Creek, south-west of Kennedy Range flowing south into Gascoyne River, and east of Kennedy Range flowing south into Lyons River. These difficulties have all been overcome with the co-operation of the Geographical Names Committee of the Department of Lands and Surveys. In places where no Lands Department names are available, use was made of station names of bores, wells and paddocks.

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.

*Lithological.*—Names of sedimentary rocks have little meaning unless adequately defined. The following glossary sets out briefly the way in which rock names and terms are used in this Bulletin.

*Arenite:* Grainsize class name (Grabau, 1904, p. 242) for fragmental sedimentary rocks having a grainsize between 0.06 and 4.0 mm (Dapples, Krumbein, & Sloss, 1950). Sub-classes are: very coarse—2.0 to 4.0 mm; coarse—1.0 to 2.0 mm; medium—0.25 to 1.0 mm; fine—0.12 to 0.25 mm; very fine—0.06 to 0.12 mm.

*Arkose:* Arenite composed of feldspar (20 to 60 percent), quartz (20 to 75 percent), and heavy minerals of the granitic suite (2 to 4 percent), with up to 30 percent kaolinitic clay, 20 percent mica, and/or 40 percent fragments of slate, quartzite, granitic or hornfelsic rock and/or schist (Oriel, 1949).

*Bentonite:* A lutite consisting mainly of the clay minerals montmorillonite and beidellite.

*Calcarenite:* Fragmental calcium carbonate rock composed of fragments (between 0.06 and 4.0 mm) of carbonate organic tests, crystalline limestone, cleavage fragments of carbonates and/or calcareous ooliths.

*Calcilutite* (Name adapted from Grabau, 1904): Fragmental limestone of particle size less than 0.06 mm consisting mainly of carbonate.

*Claystone:* Massive lutite of grainsize 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 framework of the rock it may be considered a coquinite (Condon, 1954, p. 9).

*Greywacke:* Arenite consisting of angular and/or subrounded quartz and/or rock fragments, with or without feldspar and with a fine-grained matrix which is generally micaceous and/or chloritic (Condon, 1952). (See also *Mengwacke* and *Quartzwacke*).

*Laterite:* Mature soil profile developed by weathering, probably under humid tropical conditions, involving the removal of lime, iron, and silica from the parent rock.

*Limestone:* Dense crystalline sedimentary rock composed dominantly of calcium carbonate.

*Lutite:* Grainsize class name (Grabau, 1904) for fragmental rocks of grainsize less than 0.06 mm.

*Mengwacke:* (Fischer, 1933): Greywacke having 33 to 90 percent ' unstable ' rock or mineral fragments.

*Oilsand:* Any rock containing petroleum recoverable by drainage or other hydraulic methods.

*Oolite:* Rock consisting dominantly of ooliths.

*Oolith:* Spherical or ovoid inorganic particle smaller than 2 mm, with concentric laminated structure (Twenhofel, 1932, p. 757).

*Oolitic:* Applied to rock containing up to 50 percent ooliths.

*Quartz Sandstone:* Arenite composed predominantly (more than 75 percent) of fragments of quartz, usually subround to round.

*Quartzite:* Quartz sandstone with siliceous cement, forming a hard rock that breaks evenly through grains and cement.

*Quartzwacke* (from Fischer, 1933): Greywacke composed of quartz (50 to about 75 percent), fine-grained matrix, usually micaceous, with or without feldspar. In Condon (1954) this rock type was called quartz greywacke, but an English form of Fischer's name is preferred (Edwards, 1950).

*Radiolarite:* Siliceous organic rock consisting mainly of tests and fragments of radiolaria, with or without diatoms, foraminifera, sponge spicules, other pelagic fossils, terrigenous particles, and organic residues (adapted from Murray & Renard, 1891, p. 203). Distinguished by light colour and weight, relatively high porosity and permeability, and abrasiveness.

*Shale:* Laminated lutite of grainsize less than 0.004 mm.

*Siltstone:* Lutite of grainsize between 0.004 and 0.06 mm consisting mainly of terrigenous fragments.

*Tillite:* A genetic name for rocks deposited by ice. Some authorities restrict the term to the material of ground moraine, but here the name is used for material deposited from ice whether the ice be a valley or sheet glacier, an ice sheet, iceberg, or ice floe, and whether the material be ground moraine, lateral moraine, end moraine, or marine-glacial sediment.

*Travertine:* Dense fine-grained to medium-grained crystalline calcium carbonate deposited from solution in ground or surface waters (Fay, 1920).

*Varve:* Sediment regarded as having been deposited during one year. Distinguished by graded bedding related to seasonal deposition (sand to silt, or silt to clay) and by regular repetitions with minor fluctuations in thickness. May be up to 2 metres thick but generally thin (2 to 5 mm).

## Precambrian

Precambrian rocks crop out east of the Palaeozoic sediments of the basin, in several inliers in the eastern part of the basin, and at the south end of the basin. Four main groups of lithology appear to be represented, and these may represent rock sequences of significantly different ages: gneiss, schist, granite, and indurated sediments.

### *Granulite and Gneiss*

In the area from 40 miles north of Ajana southward past Geraldton there is an inlier of crystalline garnetiferous granulite about 20 miles wide. This is a strongly banded paragneiss, apparently steeply folded. The rock, because of its dense texture and prominent component of garnet, has a high density which results in a positive gravity anomaly of 50 milligals (Chamberlain, Dooley, & Vale, 1954). This rock is well exposed only in the valleys of the Murchison River, Hutt River, and other streams, and in the mine workings at Galena, where lead ore is mined from veins in the granulite.

It is possible that the linear trend of the relatively high gravity anomaly running north from Ajana indicates the northward extension of granulite under the sediments of the basin. The marked change in gravity gradient about 30 miles east of Ajana may indicate the junction of the granulite and the schist of lower density and of much lower grade of metamorphism.

Granulite similar to that in the Ajana inlier does not crop out anywhere in the eastern margin of the basin.

The metamorphic rocks of the Carrandibby Range and of an area east of Dairy Creek Homestead, shown on Plate 2 as schist, are banded paragneisses on a similar north-south structural trend to the Ajana gneiss. In these areas the rocks are quartz-feldspar-biotite gneiss. As they are probably close to the datum density for gravity anomaly (2·67) they show no strong gravity anomaly.

### *Schist*

The Precambrian rocks immediately to the east of the sediments of the Basin are mainly schist. Quartz schist and biotite schist are dominant, but hornblende schist, chlorite schist, and sericite schist are common in some places. The various types commonly are interlayered, probably indicating metamorphism of thin-bedded sediments. In some places, for instance the area north-east of Lyndon Homestead, the schist is interlayered with granite. Apart from the main large area of Precambrian, schists crop out also in the inliers east of Lyons River Homestead and north-west of Dairy Creek Homestead, and in tongues north-west of Williambury and north of Mount Sandiman Homestead.*

Nowhere is the relationship between the schists and the granulite of the Ajana inlier exposed. The schists may grade into the granulite, or may be faulted against, or unconformably on it. In the sections (Pl. 2) the schist is shown to lie on the

* Mount Sandiman Station is not named on the Map (Plate 2). It is the station between Merlinleigh on the west and Eudamullah on the east (see Condon, 1962b, map).

granulite, but there is no direct evidence of the relationship. There is a strong structural discordance between the gneiss east of Dairy Creek Homestead and the adjoining schist: the fold axes in the gneiss trend north-north-west, whereas those in the schist trend north of east and curve around the gneiss.

### *Granite*

Granite is of two types: one interlayered with schist, the other strongly discordant to the foliation of the schist. The granite interlayered with schist may have originated either by lit-par-lit injection or by granitization of the schist—the relationships have not been examined. The main outcrops of this type are north-east of Lyndon Homestead and east of Glenburgh Homestead. The discordant granite crops out in several small areas east of Towera. These granites are probably of two ages, the interlayered of the same age as the metamorphism of the schist and the discordant much younger.

### *Indurated Sediments*

In a belt about 30 miles long trending north-west, about 20 miles east of Lyndon Homestead, in a large area at Gifford Creek, in a belt 38 miles long trending north-westerly between Mount Phillips and Yinnietharra, and in an area around Mount Coordewandy,* indurated sediments, including quartzite, limestone, slate, and greywacke, occupy synclinal areas in the Precambrian schist. The structural relationship with the schists has not been determined, but the mapped outlines of the sediments suggest an unconformity between the schists and the sediments. These sediments are cut by quartz reefs, but, so far as is known, they are not intruded by the basic dykes that cut the schists.

### *Basic Dykes*

Throughout the area of Precambrian rocks, both gneiss and schist, there are numerous basic dykes, some more than 100 feet wide at outcrop. They trend in two main directions—one nearly north, the other east-north-east. A radioactive age determination on galena ground in one dyke intruding the granulite of the Ajana inlier gave an age of 500 million years (Prider, 1954); so the dykes are possibly of Cambrian rather than Precambrian age. As they also intrude the sediments of the Badgeradda Group (Perry & Dickins, 1960), they follow the beginning of the development of the Carnarvon Basin.

## PROTEROZOIC

In the south end of the Carnarvon Basin and the north end of the Perth Basin two separate sequences of sediments older than Permian rest unconformably on crystalline Precambrian rocks: the Badgeradda Group and the Tumblagooda Sandstone. The relationship between the two is not observed in outcrop; but the Badgeradda Group almost certainly is the older, as it is intruded by basic dykes

* Mount Coordewandy is not shown on Plate 2. It is 13 miles east-south-east of Coordewandy Homestead (see Condon, 1962b, map).

and sills, whereas the Tumblagooda Sandstone rests unconformably on similar dykes, and the Tumblagooda Sandstone has many invertebrate trails and burrows, whereas the Badgeradda Group apparently has none.

Underlying the Badgeradda Group and cropping out to the west and south of its outcrop area is a steeply folded, regionally metamorphosed sequence of phyllite, slate, and altered quartzwacke that was mapped (Perry & Dickins, 1960, pl. 1) as Precambrian schist. M. C. Konecki (personal communication) suggested that this sequence might be separate from the crystalline Precambrian rocks and from the Badgeradda Group, and it is here named Yarramulla Beds. Perry & Dickins (1960) gave the name Nilling Beds to a sequence of sandstone locally unconformable beneath the Badgeradda Group and in isolated outcrops to the south-east of the Badgeradda Syncline. The Nilling Beds may be part of the Yarramulla Beds, equivalent of part of them, or quite separate from them. Outcrops would appear to be insufficient to reveal the relationship.

### *Yarramulla Beds*

The Yarramulla Beds are the regionally metamorphosed sediments, mainly phyllite, with some slate and altered quartzwacke, cropping out to the west and south of the Badgeradda Group. The sediments are strongly folded and details of their relationships with the Badgeradda Group and with the crystalline Precambrian rocks have not been observed. The dominant trends in the beds are parallel to the base of the Badgeradda Group: this is perhaps particularly significant north of Butchers Track (which runs out to the coast), where the trends of both the Badgeradda Group and the Yarramulla Beds swing from north to north-north-east. No attempt has been made to measure the thickness of this sequence; it may be as much as 17,000 feet thick if there are no fold or fault repetitions.

The name is taken from Yarramulla Paddock, which extends north-west from Wail Outcamp, Yallalong Station, about 25 miles north of the homestead; the most extensive outcrop area of the beds is found in Yarramulla Paddock.

The rather meagre evidence available suggests that the Yarramulla Beds are in sequence with the Badgeradda Group and perhaps are a structionally incompetent formation between the competent Badgeradda Group and the crystalline basement. Like the Badgeradda Group, the Yarramulla Beds are intruded by basic rocks, which crop out roughly parallel to the structural trend of the Yarramulla Beds; they may be either dykes or sills.

### *Badgeradda Group*

The Badgeradda Group (named Badgeradda Beds by Konecki, Dickins, & Quinlan, 1958, p. 10; defined by Perry & Dickins, 1960, p. 9) rests, possibly conformably, on the Yarramulla Beds, and unconformably on the Precambrian schist and gneiss. It is overlain unconformably by Permian Lyons Group. The Nilling Beds are excluded from the Badgeradda Group by Perry & Dickins. The local unconformities between the Nilling Beds and the Bililly Formation (Perry & Dickins, fig. 1) relate mainly to the relief of the crystalline basement floor. The lower part of the Bililly Formation is similarly truncated above the Precambrian ridge north-east from Deep Bore. As the Nilling Beds (as here interpreted) and the Badgeradda Group are probably part of a continuous sedimentary sequence and as the Nilling Beds include rocks of similar lithology to those of the Badgeradda Group, they should be included in it.

In the Badgeradda Syncline the downward sequence of the Badgeradda Group is:

Yarrawolya Formation
Coomberarie Formation
Woodrarrung Sandstone
Bililly Formation
Nilling Beds

The Errabiddy Sandstone and the underlying quartzwacke and siltstone cannot be identified with any of these formations but are included in the Group (Fig. 4).

*Nilling Beds*

The Nilling Beds are described by Perry & Dickins (1960, p. 6) as consisting 'predominantly of sandstone and quartz greywacke.' Actually there is no evidence of the predominant lithology of the full sequence of the Nilling Beds in the area of their outcrop as mapped by Perry & Dickins (1960, pl. 1), since only a small part of the likely sequence is exposed there. I consider that the Nilling Beds are probably included in the outcrop mapped by Perry & Dickins as upper Bililly Formation in the area 1½ miles south-east of Bililly claypan. The section is 4025 feet thick, whereas the greatest thickness of the whole of the Bililly Formation elsewhere is 1200 feet. The upper part of the sequence consists of a lower unit of coarse quartz sandstone and an upper unit of fine-grained quartz sandstone, together having a thickness of 925 feet. These sandstone units certainly can be identified with the Bililly Formation as defined by Perry & Dickins. Below the sandstone units I recorded 3100 feet of red siltstone and fine-grained quartzwacke. I consider that the quartzwacke of this unit is the finer-grained lateral variant of the coarse-grained quartzwacke of the Nilling Beds as described by Perry & Dickins, and that the areas of no outcrop between the outcrops of Nilling Beds mapped by them are underlain by the siltstones revealed in this unit. If this is so the Nilling Beds consist dominantly of siltstone, but include quartzwacke as beds and members. I have adopted this view in the map (Fig. 4) and in the stratigraphic columns (Fig. 5).

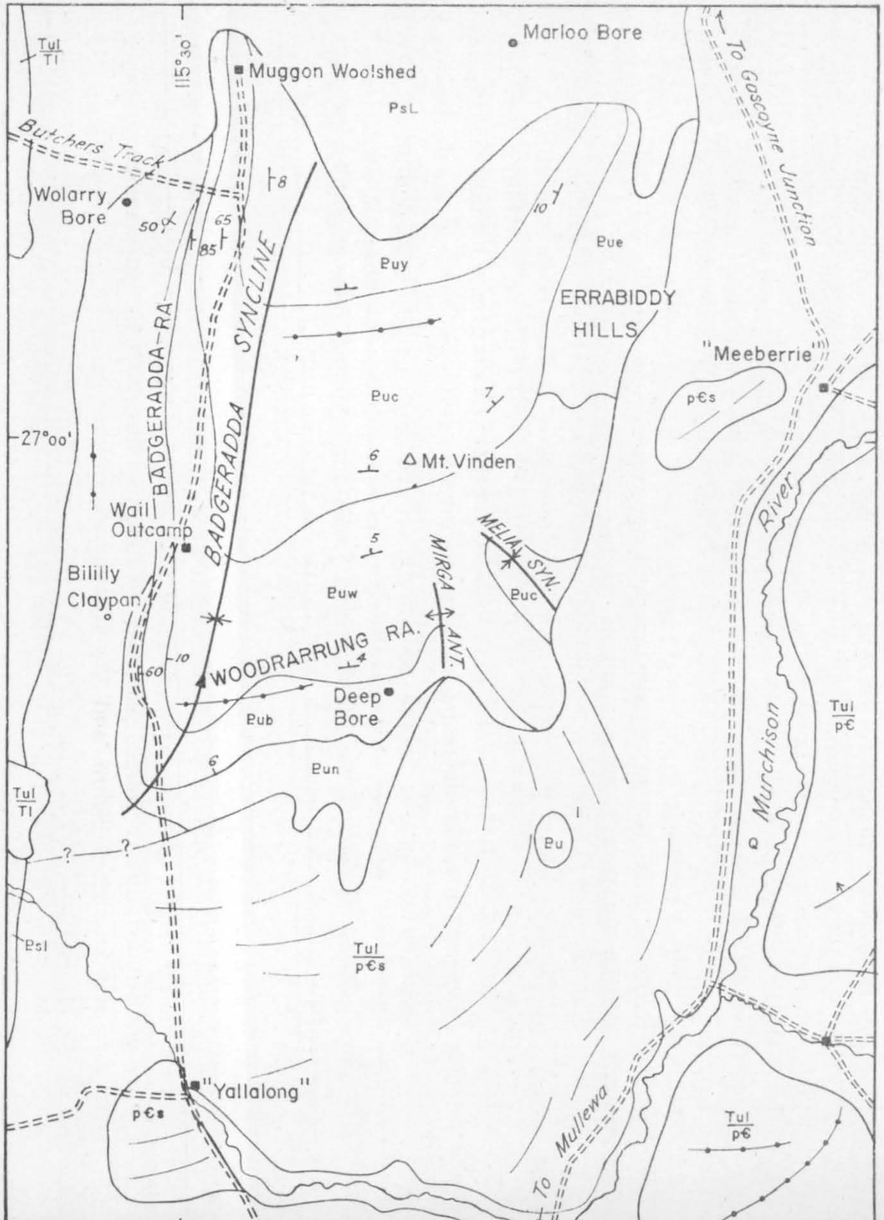
It seems likely that the Nilling Beds are equivalent to the upper part of the Yarramulla Beds: the upper part of both sequences is about the same stratigraphic distance below the base of the Woodrarrung Sandstone and they include similar types of rock (somewhat metamorphosed in the Yarramulla Beds).

*Bililly Formation*

The Bililly Formation (Perry & Dickins, 1960, p. 9) consists of a lower member of medium to coarse-grained quartz sandstone and an upper member of fine-grained silty sandstone and interbedded micaceous siltstone totalling 1200 feet in thickness at the southern end of the Badgeradda Syncline.

Fig. 4

# OUTCROP of the BADGERADDA GROUP




10 0 10 20 MILES

## Reference

| | | | |
|---|---|---|---|
| Q | Undifferentiated, Quaternary | | |
| Tul | Laterite, Tertiary | | |
| Tl | Lower Tertiary | | |
| PsL | Lyons Group, Permian | | |
| Ꝑuy | Yarrawolya Formation | Badgeradda Group | Proterozoic |
| Ꝑuc | Coomberarie Formation | Badgeradda Group | Proterozoic |
| Ꝑue | Errabiddy Sandstone | Badgeradda Group | Proterozoic |
| Ꝑuw | Woodrarrung Sandstone | Badgeradda Group | Proterozoic |
| Ꝑub | Bililly Formation | Badgeradda Group | Proterozoic |
| Ꝑun | Nilling Beds | Badgeradda Group | Proterozoic |
| Ꝑua | Yarramulla Beds | Badgeradda Group | Proterozoic |
| Ꝑu | Undifferentiated | | Proterozoic |
| p€s | Schist, Precambrian | | |

—•—•— Dyke

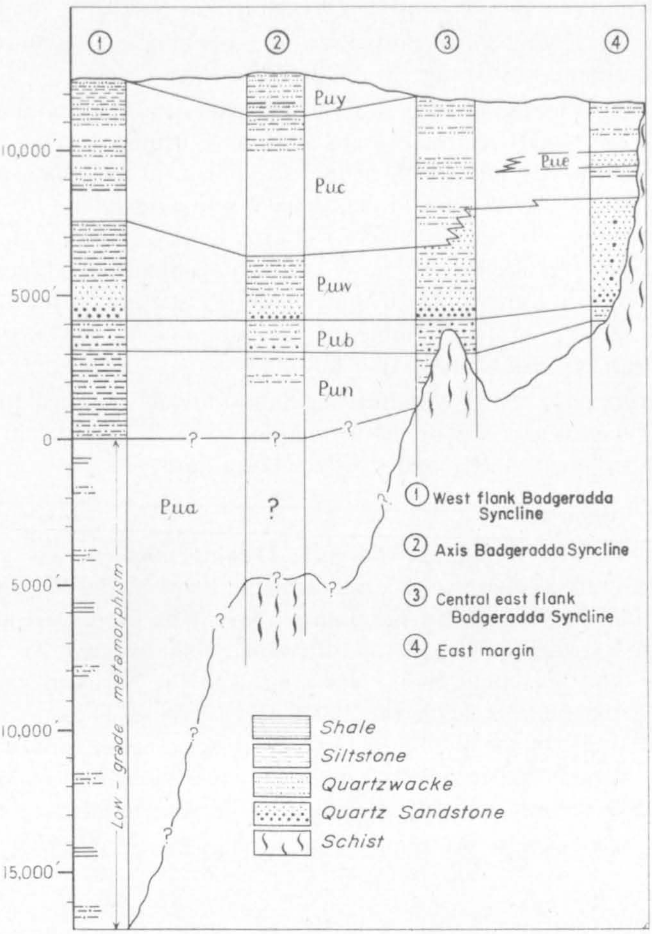


Fig. 5 Stratigraphical columns, Badgeradda Group
(See Fig. 4 for formations)

The Bililly Formation is known to crop out only around the south end of Badgeradda Syncline, from Yarramulla Paddock (north of Wail Outcamp) to Deep Bore. The area one to two miles south-east of Bililly Claypan mapped by Perry & Dickins (1960, pl. 1) as Bililly Formation is dominantly siltstone and therefore certainly does not belong in the Bililly Formation. On the west flank of the syncline the thickness of the Bililly Formation is nearly constant (about 950 feet), but on the south-eastern flank it varies. North-east of Deep Bore the Bililly Formation is apparently overlapped by the Woodrarrung Sandstone.

*Woodrarrung Sandstone*

The Woodrarrung Sandstone (Perry & Dickins, 1960) consists of a lower member of medium-grained to coarse-grained sandstone and an upper member of fine-grained to medium-grained kaolinitic sandstone. It is conformable between the Bililly Formation below and the Coomberarie Formation above. East of

Mount Vinden the upper part of the Woodrarrung Sandstone appears to grade laterally into the Coomberarie Formation and possibly is the equivalent of, and perhaps is continuous with, the Errabiddy Sandstone.

The Woodrarrung Sandstone is about 3350 feet thick 2½ miles east-south-east of Wolarry Bore; 3000 feet thick south of Wail Outcamp; about 2150 feet thick near the axis of the Badgeradda Syncline; about 2500 feet thick north of Deep Bore; and about 3700 feet thick in the Melia Syncline (including the lateral equivalent of the lower part of the Coomberarie Formation). In terms of the definitions of the formation, the section of the Woodrarrung Sandstone (Perry & Dickins, 1960, Appendix p. iv) appears to include Bililly Formation in the lower 594 feet, and the 'type section' of the Coomberarie Formation (*Ibid.*, p. v) includes 1940 feet of the Woodrarrung Sandstone at the bottom.

The quartz grains of the Woodrarrung Sandstone are rounded and well sorted; cross-bedding is characteristic of the formation. The Woodrarrung was deposited in shallow water on a quietly and slowly sinking floor.

*Coomberarie Formation*

The Coomberarie Formation (Perry & Dickins, 1960, p. 13) consists of siltstone and fine-grained quartzwacke, conformable between the Woodrarrung Sandstone below and the Yarrawolya Formation above. Its lower part grades laterally into the Woodrarrung Sandstone and Errabiddy Sandstone. The Coomberarie Formation is 4985 feet thick in its type section in the northern part of the west flank of the Badgeradda Syncline (not 6925 feet (Perry & Dickins, 1960, App., v) as this includes part of the Woodrarrung Sandstone); about 5000 feet thick west and north of Mount Vinden; 5000 feet thick 5 miles north-east of Mount Vinden; and about 3500 feet thick in the Errabiddy Hills area (including the Errabiddy Sandstone).

*Errabiddy Sandstone*

The Errabiddy Sandstone (Perry & Dickins, 1960, 13) was named as a separate formation because of doubts about its identification with any other formation of the Badgeradda Group.

Although its lithology is similar to that of the Woodrarrung Sandstone it is not demonstrably continuous with the formation. Structural trends suggest that the Errabiddy Sandstone is equivalent to part of the Coomberarie Formation, and the underlying quartzwacke and siltstone support this.

*Yarrawolya Formation*

The Yarrawolya Formation (Perry & Dickins, 1960, p. 15) is the uppermost formation (in outcrop) of the Badgeradda Group. It consists of laminated siltstone and fine-grained quartzwacke conformably overlying the Coomberarie Formation. Although the Permian Lyons Group has not been observed in contact with the Yarrawolya Formation the regional distribution of the two sequences strongly suggests that the Lyons Group is unconformable on the Yarrawolya. As the Yarrawolya Formation is probably truncated by an unconformity no complete thickness is known; the thickness in the syncline is about 1435 feet.

*Structure*.—The Badgeradda Group is folded into a large north-plunging syncline with steeply dipping to overturned west flank and gently dipping east flank; in the eastern part of the outcrop of the group the north-plunging Mirga Anticline and Melia Syncline appear to be related to topographic relief of the surface of crystalline rocks (gneiss and granite) that form the floor of the basin. The outcrop trend changes sharply along a line between Marloo and Deep Bores. This may reflect a hinge-line between a shelf area to the east and a basin area to the west.

The joint diagram (Perry & Dickins, 1960, fig. 4) clearly indicates two shear-joint systems with obtuse bisectrices at about 17° and 330°.

Two stress episodes are indicated, one directed north-south, perhaps related to downwarping during sedimentation; the other, directed north-west, probably produced the overturned west limb. Neither of these is related to an east-west tension direction; this suggests that the tension jointing with which the basic dykes are associated was produced by a separate stress episode perhaps related to uplift.

The large positive gravity anomaly (17 milligals) near the axis of the Badgeradda Syncline (B.M.R. Geophysical Branch map No. G98–37, unpublished) must be related to a large mass, in the basement, of very dense rock; this may or may not form a basement ridge. The sharp change east of the axis from very steep dip to very gentle dip suggests a subsurface buttress below the axis.

The structure of the west limb of the Badgeradda Syncline resulted from upthrusting of a western block, including Precambrian crystalline rocks. It is possible that the plane of this thrust provided the weak zone along which later subsidence formed the Coolcalalaya Basin. Sediments equivalent to the Badgeradda Group would have been removed by erosion from the upthrust block: there may be no such sediments in the Coolcalalaya Basin, the subsidence of which must have started much later than the thrusting on the west side of the Badgeradda Syncline. The outcropping Badgeradda Group is considered, at present, to occupy the southern end of the Byro Basin and possibly to continue into the deeper part of that Basin, near Wooramel River. The sediments of Mount Coordewandy may be equivalent to the Badgeradda Group. The upthrust basement west of the Badgeradda Syncline may be represented at the north end of the Byro Basin by the crystalline metamorphic rocks of the Carrandibby Range (Condon, 1962b, map).

On the basis of the tectonic history it seems unlikely that there is any equivalent of the Badgeradda Group between the outcrop of the Yarramulla Beds and the west side of the Ajana Ridge.

*Age*.—The basic dykes intruding the Badgeradda Group appear related by lithology and trend to those of the Ajana area dated as 500 million years old (i.e., Cambrian) (Prider, 1954, p. 73); they are younger than the main thrust-faulting of the basement and Badgeradda Group. The thrust-faulting is not related to any obvious pre-existing structure in the sediments. Thus a major compression causing large-scale reverse faulting followed the deposition of 30,000 feet of sediments (Badgeradda Group and Yarramulla Beds), all before 500 million years ago. The sediments are evidently Precambrian, therefore, and as they rest unconformably on crystalline metamorphic Precambrian rocks they are probably upper rather than lower Precambrian, i.e. Proterozoic; but no finer approximation can be made.

*Palaeogeography.*—The Badgeradda Group was deposited on a floor of Precambrian crystalline rocks (gneiss and granite) with fairly strong topographic relief. The supply of sediment was from the east and south-east. During sedimentation the floor subsided. In the eastern part of the basin water remained shallow, and the sediments deposited were mainly clean sands. West of a hinge-line between Deep Bore and the west side of Errabiddy Hills subsidence was generally faster and more irregular. After an initial deep subsidence the Yarramulla Beds were laid down and the basin filled by sedimentation, so that the Woodrarrung Sandstone was deposited in shallow water. The basin then subsided to moderate depth and the finer-grained sediments of the upper part of the exposed sequence were deposited. It is likely that sedimentation finished with a regressive sandstone, but this is not seen in outcrop.

*Economic Geology.*—The sandstones of the sequence are good aquifers that have been developed at only a few bores and to shallow depth.

*Problems.*—The subsurface distribution of the Yarramulla Beds and Badgeradda Group is quite unknown. The sequence is quite unprospective for oil, but it would be hard to distinguish in geophysical data: it would produce a negative gravity anomaly similar to the prospective sediments, it would have low magnetic intensity, and would give normal sedimentary seismic reflections and probably moderate velocities. It would be desirable and may be necessary to establish its subsurface extent by running a seismic traverse northward from the outcrop area.

The location and nature of the western thrust-fault and its prolongation would indicate the likely westward limit of these sediments. There may be equivalent sediments to the west of the Ajana-Wandagee Ridge, but this could only be inferred from the total sequence established by seismic survey and comparison of velocities with those of the Badgeradda Group in a similar structural position (in the deeper part of the Byro Basin).

In the Cape Range area, conformable reflections underneath Permian sediments indicate a thickness of at least 18,000 feet of pre-Permian sediments. As there are not likely to be much more than 7000 feet of Devonian and Carboniferous sediments, the Badgeradda Group or Tumblagooda Sandstone, or both, may well be represented there.

## Lower Palaeozoic

### *Tumblagooda Sandstone*

The Tumblagooda Sandstone was named by Clarke & Teichert (1948), who described the formation in some detail, but gave no formal definition or type section apart from the reference to Tumblagooda Hill 'where a typical (part) section is exposed.' The Tumblagooda Sandstone is defined as the formation of quartz sandstone with minor siltstone and conglomerate which, in the type locality on the lower Murchison River, rests unconformably on Precambrian gneiss and is overlain unconformably by Cretaceous sandstone of the Birdrong Formation.

The name is taken from Tumblagooda Hill (Lat. 27° 40½′ S., Long. 114° 09½′ E.) on the west side of the Murchison River near its mouth. The type locality (Fig. 6)

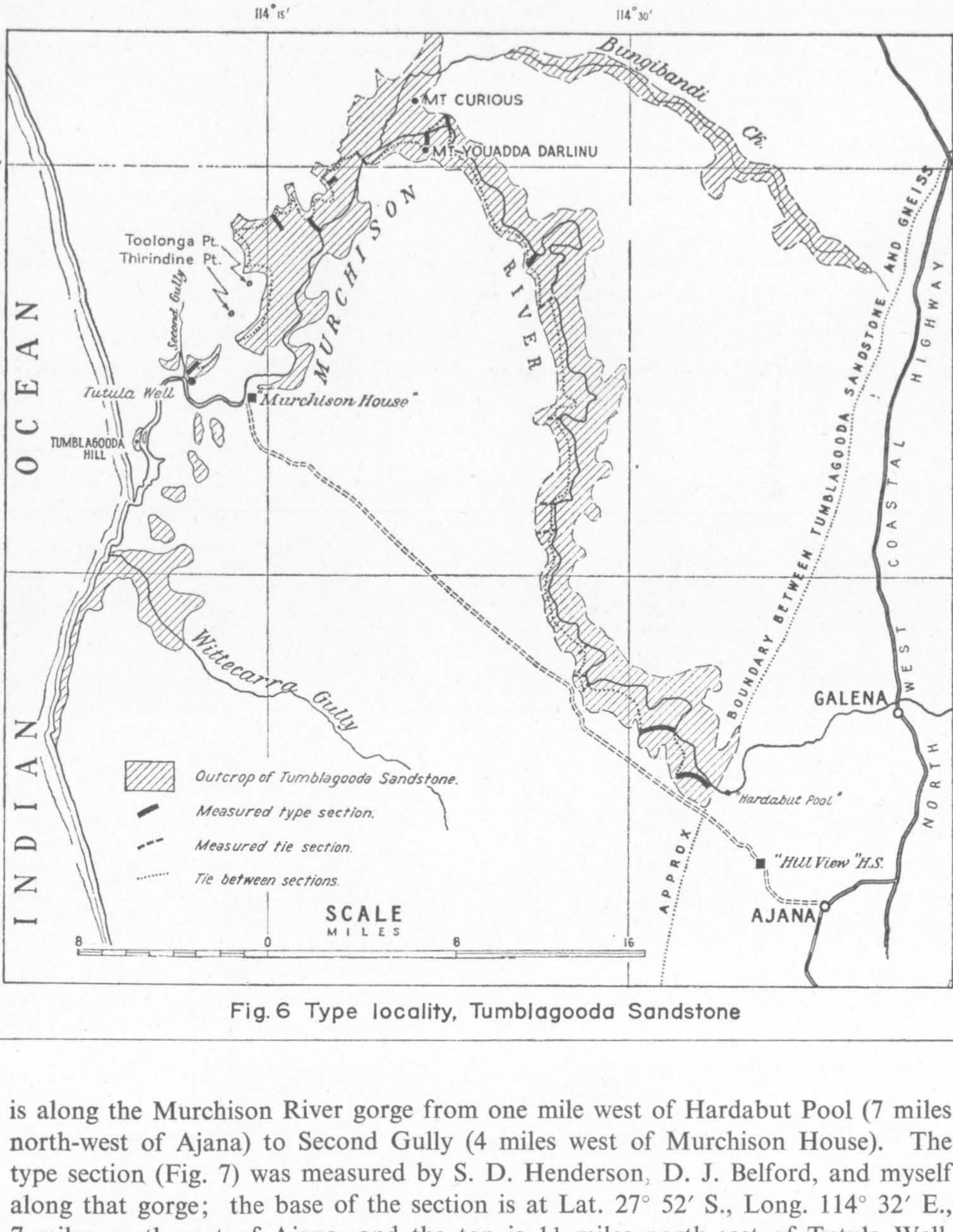



Fig. 6 Type locality, Tumblagooda Sandstone

is along the Murchison River gorge from one mile west of Hardabut Pool (7 miles north-west of Ajana) to Second Gully (4 miles west of Murchison House). The type section (Fig. 7) was measured by S. D. Henderson, D. J. Belford, and myself along that gorge; the base of the section is at Lat. 27° 52′ S., Long. 114° 32′ E., 7 miles north-west of Ajana, and the top is 1½ miles north-east of Tutula Well, at Lat. 27° 36½′ S., Long. 114° 8½′ E.

The contact between the Tumblagooda Sandstone and the Precambrian gneiss in the Murchison River was regarded as a fault by Maitland (1898, p. 15), Clarke & Teichert (1948), and Johnstone & Playford (1955). Close examination of the vicinity of the contact reveals that the contact is not exposed; the nearest approach

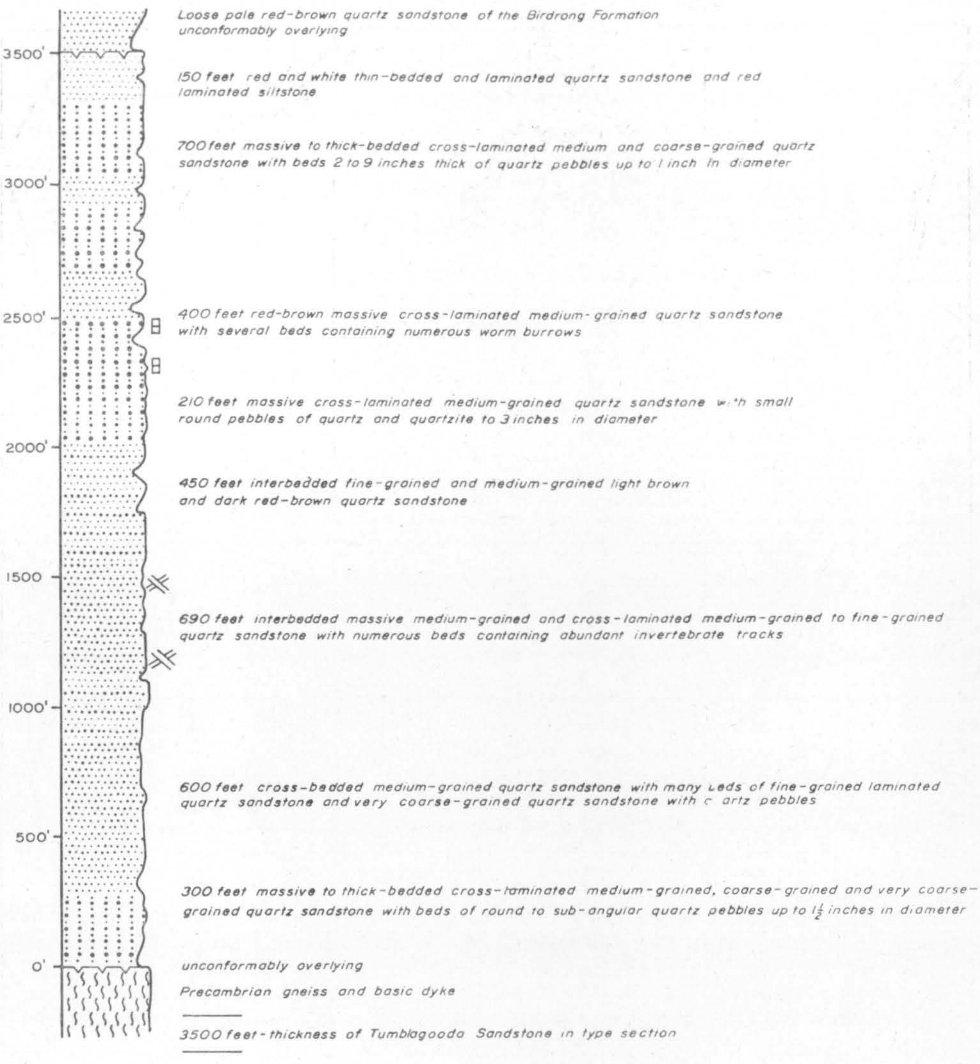



Fig. 7. Type section, Tumblagooda Sandstone

of sandstone to Precambrian gneiss or dyke rock is about 10 feet, on the left (south) bank of the river; the sandstone forms an east-facing scarp running back from the river for 2½ miles north and 1 mile south; there are isolated small outliers of Tumblagooda Sandstone resting unconformably on the Precambrian gneiss east of the main contact south and north of the river; in detail the contact is irregular—it is not the outcrop of a plane surface; several small folds, in the Tumblagooda Sandstone near the contact, trend into it and are there coincident with small salients and re-entrants of the contact—these folds are obviously developed over hills and valleys of the old surface of the Precambrian. Some of these relationships are shown on the map of the contact (Fig. 8).

The contact on the east side of the Precambrian gneiss (at Yandi) is much steeper but is not well exposed. The trace is irregular; beds strike into it; sandstone is brecciated and slightly silicified near it. There has obviously been some movement of the sandstone along the contact, but the irregular trace suggests that the contact is a steep unconformity along which the sandstone has moved, either by faulting or compaction sliding. Prider (1958) regards the Yandi contact as an unconformity.


Fig. 8-Contact between Tumblagooda Sandstone and Precambrian Gneiss

Clarke & Teichert (1948) regarded the Tumblagooda Sandstone as being conformable with the overlying 'Butte Sandstone' (Birdrong Formation) and of the same age (Cretaceous). In fact there is an angular unconformity of about 2°, in the area between Toolonga Point and Thirindine Point, and the base of the Birdrong Formation rests on obviously different parts of the Tumblagooda Sandstone throughout their contact area.

The contact between the Tumblagooda Sandstone and the Lyons Group is not generally exposed. The Tumblagooda Sandstone dips at about 12° eastward at its easternmost outcrop, and the Lyons Group, which crops out to the east of the Tumblagooda Sandstone, also dips eastward but at about 5°. On this basis it is assumed that there is an angular unconformity between the Lyons Group and the Tumblagooda Sandstone. At only one place, about 10 miles north-east of Yandi Homestead and about 2000 yards east of the Murchison River, soft tillitic claystone of the Lyons Group directly overlies indurated Tumblagooda Sandstone dipping 13° east (Perry & Dickins, 1959). The contact cannot be seen and no dip can be measured in the Lyons Group, but the disposition of the outliers of Lyons Group indicates that the surface of unconformity is nearly horizontal, although irregular in detail.

As both bottom and top of the exposed sequence are unconformities, the full sequence of the Tumblagooda Sandstone is not known.

*Lithology*.—The Tumblagooda Sandstone consists predominantly of quartz sandstone ranging in grainsize from very coarse to fine. Medium-grained sandstone is dominant. The colour both at the surface and in bores is orange, red-brown, cream, and purplish.

The quartz is commonly clear, the grains are subrounded to subangular. Crystal overgrowth is seen in some specimens. Quartz makes up 75 to 90 percent of the rock. Most specimens contain a little cloudy feldspar (1 to 3 percent), some of which is probably microcline. Some specimens contain up to 3 percent of biotite. A silty matrix is present in some specimens, consisting of quartz, feldspar, mica silt, and undetermined clay minerals. Calcite cement or ferruginous cement is present in a few specimens. Ferruginous staining of quartz grains and a fine dust of opaque mineral, possibly hematite, are common.

Red siltstone is common as partings between sandstone beds in the lower part of the sequence and as beds up to about 3 feet thick in the upper part. The siltstone has not been examined petrographically.

*Thickness*.—The Tumblagooda Sandstone is bounded over and below by unconformities. The only two thicknesses measured are the type thickness of 3500 feet and the sequence along the Murchison River near Yandi Homestead, where a thickness of 5600 feet was measured (Perry & Dickins, 1959), and an additional 15,000 feet is indicated by poorly outcropping Tumblagooda Sandstone over a width normal to strike of 13½ miles and by a dip, measured in several places over this width, of 12°. Parts of the sequence may be repeated in this belt, but the reconnaissance gravity survey shows a decrease of about 50 milligals in gravity, from the western contact to the eastern edge of outcrop of the Tumblagooda Sandstone; this indicates that the estimated total thickness of Tumblagooda Sandstone

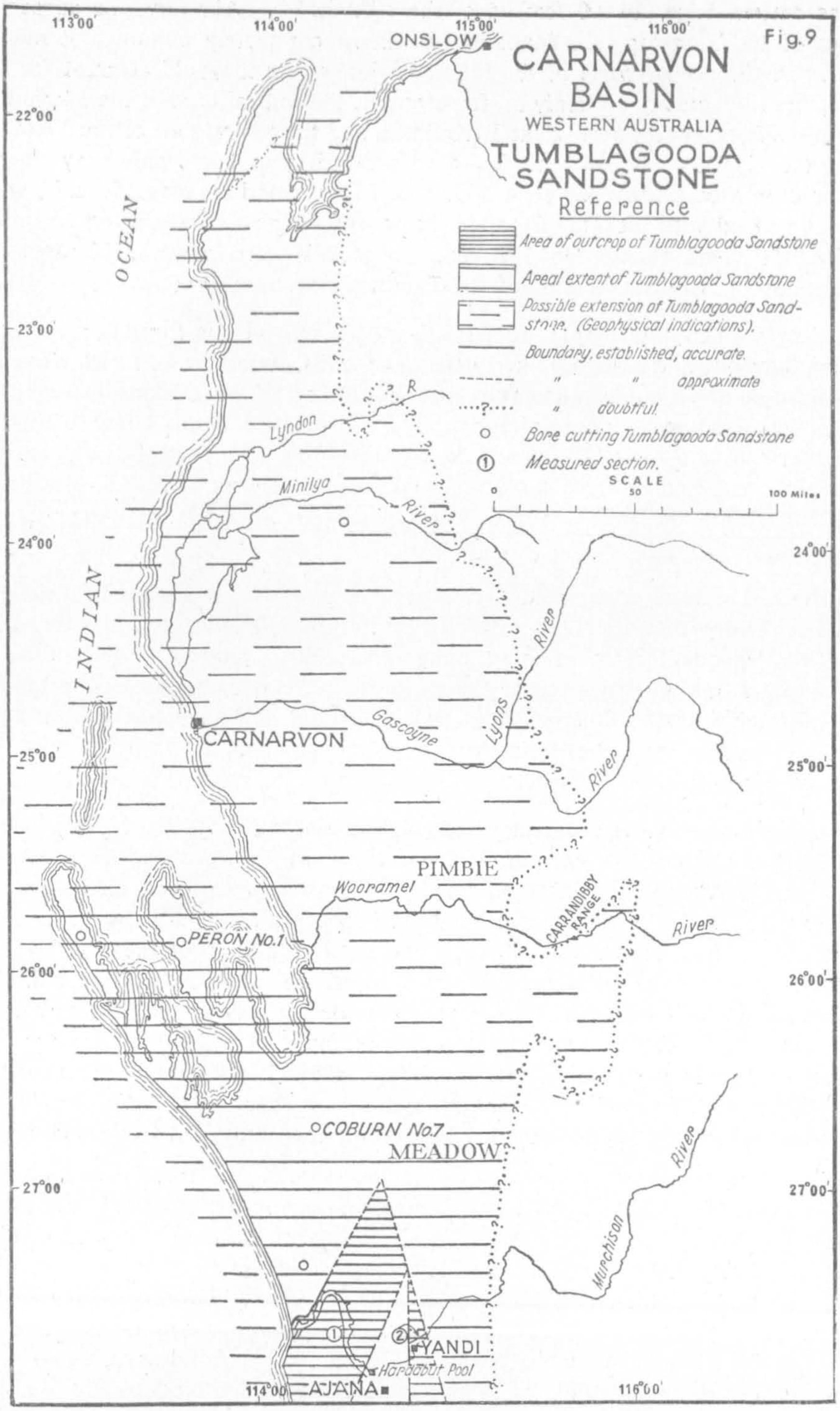


Fig. 9
CARNARVON BASIN
WESTERN AUSTRALIA
TUMBLAGOODA SANDSTONE
Reference
Area of outcrop of Tumblagooda Sandstone
Areal extent of Tumblagooda Sandstone
Possible extension of Tumblagooda Sandstone. (Geophysical indications).
Boundary, established, accurate.
" " approximate
" doubtful
Bore cutting Tumblagooda Sandstone
Measured section.
SCALE
0
50
100 Miles
113°00'
114°00'
115°00'
116°00'
22°00'
23°00'
24°00'
25°00'
26°00'
27°00'
ONSLOW
INDIAN OCEAN
Lyndon R
Minilya River
Lyons River
Gascoyne
CARNARVON
River
PIMBIE
Wooramel
CARRANDIBBY RANGE
River
PERON No.1
COBURN No.7
MEADOW
Murchison River
YANDI
Hardabut Pool
AJANA

at the eastern edge (20,600 feet) is of the right order. Although the subsurface extent of the Tumblagooda Sandstone is almost completely unknown it may be present in the deeper parts of the minor basins, where it would account for part of the negative gravity anomaly in, for example, the central part of the Merlinleigh Basin, the Byro Pallins area of the Byro Basin, and the central part of the Gascoyne Basin (see Fig. 9). It has been found with certainty in bores only very close to the outcrop area. McWhae et al. (1958, p. 17) reported a sandstone unit, which they correlated with the Tumblagooda, below the Silurian Dirk Hartog Limestone in WAPET's Dirk Hartog No. 17B bore. No fossils were found in the sandstone, which may or may not be part of the Tumblagooda Sandstone.

*Fossils.*—The only organic remains found to date in this formation are intertwined burrows, and trails (Öpik, 1950). The trails, found by P. E. Playford and J. MacIntyre of West Australian Petroleum Pty Ltd and J. M. Dickins of the Bureau of Mineral Resources, consist of a sinuous flat depression about 1 inch wide with, on either side and directly opposed, marks consisting of a hollow and ridge of a shape that is repeated from mark to mark. Öpik reports having found similar tracks in Cambrian and Lower Ordovician sediments of Central Australia and Tasmania.

*Age.*—The poor fossil record gives only a doubtful indication of Cambrian or Lower Ordovician age (Öpik, op. cit.). From its relationships with other rocks the Tumblagooda Sandstone is certainly older than Cretaceous, older than the Sakmarian Lyons Group, probably younger than the Badgeradda Group (as it is unconformable on the dolerite dykes which intrude the Badgeradda Group), and certainly younger than the gneiss (and dolerite) of Ajana. For the present it is tentatively regarded as Ordovician.

*Correlation.*—It has been suggested (McWhae et al., 1958, pp. 17, 31) that the Tumblagooda Sandstone extends, beneath the Cretaceous, from the Murchison River to the vicinity of Carnarvon. This opinion has been based on information (driller's logs and a few bore cores) obtained from water bores between the Murchison River and Carnarvon. In my opinion the lithology of the Tumblagooda Sandstone cannot be recognized in bores north of Meadow Homestead. The sediments north of this, which have been regarded as having the lithology of the Tumblagooda Sandstone, are quartz greywacke, much of which is of coarser mean grainsize than is common in the Tumblagooda Sandstone. They are more like the Nannyarra Greywacke in lithology and, where they underlie the fossiliferous sediments equivalent to the Gneudna Formation, are equivalent to the Nannyarra.

In the area between Meadow and Pimbie, there is probably an unconformity between the Nannyarra Greywacke and the underlying Tumblagooda Sandstone. In many places in the deeper parts of the Carnarvon Basin the Nannyarra Greywacke probably rests with little angular unconformity on the Dirk Hartog Limestone or the Tumblagooda Sandstone. The only neighbouring formations of similar lithology and approximately similar stratigraphic position are the Enokurra Grit and the Bindoo Hill Beds (Johnson, De La Hunty, & Gleeson, 1954) in the Irwin Basin, 30 miles south of Ajana Homestead. The Bindoo Hill Beds are immediately to the east of the Precambrian of the Northampton block, which continues to the Murchison River at Ajana; it is likely that they are the southern extension of the Tumblagooda Sandstone that crops out at Yandi.

Ordovician sediments are known in the Bonaparte Gulf Basin, in the eastern Fitzroy Basin, and, subsurface, in the western Canning Basin. The Tumblagooda Sandstone may be the equivalent in the Carnarvon Basin of those sediments; it is quite likely that the Ordovician Sea transgressed the Carnarvon Basin, as well as the northern basins.

*Structure.*—Regionally the outcropping Tumblagooda Sandstone forms a large breached anticline plunging northward and southward. In the gorge of the Murchison River, the anticline is asymmetrical, with gentle west dips and steep eastward dips. The Tumblagooda Sandstone is probably continuous across the crest of the anticline from 40 to about 80 miles north of Ajana, but is obscured by a cover of superficial deposits.

The Tumblagooda Sandstone is strongly jointed; in the western outcrop area the main joint direction is 110° to 120° and the minor direction 030° to 040°; in the eastern outcrop area the two main joint directions are 80° to 110° and 350° to 010°. The joints generally appear to be approximately normal to the bedding.

There are small anticlines and synclines near the contact of the western outcrop with the Precambrian gneiss; I interpret these as being developed by deposition over hills and valleys in the surface of the Precambrian gneiss. In the gently dipping western sequence there are several undulations producing terrace structure at the surface; these terraces may develop downward into anticlines. In the eastern sequence, undulations are evident in arcuate strike trends, but there are no fold structures. Several breaks in sequence are probably normal faults, but none of these have been found exposed.

The regional anticline is regarded as being formed mainly by deposition over a pre-existing ridge on the surface of the gneiss. The regional structural relief has been increased by downwarping of the Coolcalalaya Basin during deposition of the Tumblagooda Sandstone and possibly also by some downwarping of the western area.

The directions of jointing are not consistent with the development of a compressional anticlinal fold in the sediments over the Ajana Ridge, nor do they indicate stress in the same direction on either side of the ridge. As they are roughly parallel to dip and strike directions in the sediments it is more likely that they are the effect of tensional forces (such as may be produced by downwarping or compaction).

*Palaeogeography.*—As even the present extent of the Tumblagooda Sandstone is not known, little can be indicated of its original extent.

A small sample of observed directions of cross-bedding, supported by general observation, indicates that the cross-bedding dips in the same direction as the bedding (west-north-west) on the west side of the Ajana Precambrian gneiss and that the foresetting is in this direction (that is, the dip of the foresets is in the same general direction as, but at angles greater than, the dip of the beds). On the east side of the Precambrian gneiss, the beds dip eastward at angles from 45° to 12° and the foresets dip in the same direction at steeper angles. As the foresetting is away from the Precambrian on both sides the sediment must have moved away from the present area of the Precambrian, and therefore that area was probably higher than the areas of deposition on either side. The Ajana Ridge probably supplied some sediment to the lower part of the formation, particularly to those parts overlapped by the outcropping sequence, but certainly was not the main source of the sediment. The presence of microcline and biotite suggests that the sediment was derived from elsewhere than the metamorphic rocks of the Northampton block and almost certainly came from the main Precambrian mass of Western Australia. The Ajana Ridge was probably a submarine ridge, at some distance from the shoreline, where wave and current action was effective in cleaning the sediment and rounding the quartz grains. This is confirmed by the appearance of a significant proportion of siltstone beds only high in the sequence and far away from the Ajana Ridge. It seems likely that the western sequence was deposited at the dips at present displayed but that the western sequence was tilted from an originally gentle east dip to the present steeper dips during sedimentation: the foresets with actual dips up to 54° indicate that these lower beds must have been tilted at least 10° and probably 25°, since the maximum foreset dip determined experimentally is 45° and the common observed natural maximum is about 30°; however, since the present dip of the higher beds is only 12° the tilting of the lower beds must have occurred mainly during deposition of the formation and was probably produced by a downwarping of the Coolcalalaya Basin during deposition of the Tumblagooda Sandstone. This downwarping of the basement and overlying beds produced some movement of the Tumblagooda Sandstone at the unconformity. In the Murchison River area the Ajana Ridge probably was not covered by a great thickness of Tumblagooda Sandstone: strong wave and current action on the ridge would prevent sedimentation in that area.

The lithology of the Tumblagooda Sandstone probably continues only along either side of the Ajana-Wandagee Ridge and on its crest for a short distance north—to where the ridge at the time of deposition of the Tumblagooda Sandstone was submerged sufficiently deeply to be beyond strong wave and current action. Beyond this, the Tumblagooda Sandstone may be expected to change into sediments of different lithology, possibly quartzwacke and siltstone. From gravity indications of the shape of the Ajana-Wandagee Ridge, and assuming that it has not been changed significantly since the Tumblagooda Sandstone was deposited, the formation probably extends only as far north as Meadow Station; its stratigraphic equivalents may occupy large parts of the Carnarvon Basin north of this.

The very great volume of coarse sediment indicated by the outcropping sequence of the Tumblagooda Sandstone requires an actively eroding hinterland. This implies uplift of the hinterland at the time of the marine transgression; the downwarping of the Coolcalalaya Basin (and possibly of the minor basins within the Carnarvon Basin) may have been associated with the crustal instability thus indicated.

As it seems likely that the Tumblagooda may change into a more shaly marine facies in the deeper parts of the basin, oil may have migrated laterally; the Tumblagooda is therefore quite prospective for oil in any closed trap, particularly on the basement ridges where the structure was probably in existence during sedimentation.

### SILURIAN

No rocks of Silurian age are known in outcrop in the Carnarvon Basin, but several bores have cut Silurian sediments.

The first record of Silurian rocks in the Carnarvon Basin (and indeed in Western Australia) was from WAPET's Dirk Hartog No. 17B bore. McWhae et al. (1958, p. 31) proposed the name ' Dirk Hartog Limestone ' for the sequence of dolomite with minor limestone, siltstone, and anhydrite between 2183 feet and 4608 feet depth. Apart from the undesirability of establishing formal stratigraphic units on the basis of a single subsurface intersection, the use of ' Limestone ' for a dominantly dolomitic rock is unsatisfactory.

Dolomitic sediments of Silurian age have been penetrated in WAPET's Wandagee No. 1 bore (1308 to 2660 feet depth). These have been identified as ' Dirk Hartog Limestone ' (Pudovskis, 1962), but may or may not be co-extensive with the dolomite in the Dirk Hartog bore.

A formation of sandstone, with minor shale, claystone, and siltstone, was penetrated beneath the Gneudna equivalent in WAPET's Wandagee No. 1 bore from 912 to 1308 feet depth. Conodonts from this interval have been identified by McTavish (1962) as belonging to genera some of which have ranges that are not known to overlap; if the identifications are correct the generic ranges must be revised, but first the age of the unit must be established. Although the available evidence merely indicates a possible age between Lower Ordovician and Upper Devonian Pudovskis (1962) referred it, tentatively, to the Nannyarra Greywacke. Because it is dolomitic in parts, this unit is more likely to be conformable with the underlying ' Dirk Hartog Limestone ' and disconformable beneath the Gneudna equivalent.

In WAPET's Marrilla No. 1 bore, 75 feet of vuggy dolomite, medium and coarse-grained sandstone, chocolate siltstone, and blue shale is thought (Johnstone et al., 1963) to represent beds of ' Dirk Hartog Limestone.' The few microfossils are regarded by Edgell (1963) as probably indicating Silurian age, but the evidence is very weak and the sequence may be Devonian.

At present the faunas available cannot be related to those in other Australian Silurian sequences and are not sufficiently diagnostic to allow certain correlation with overseas sequences. It appears desirable to establish the Australian microfossil sequence in stratigraphically established outcrop sequences before attempting to correlate these subsurface occurrences.

Unsatisfactory age determinations can prevent any firm conclusions being drawn about the regional distribution, structure, and palaeogeography of the parts of the total pre-Devonian sequence of the Carnarvon Basin likely to be affected.

The ' Dirk Hartog Limestone ' is likely to form a good reservoir for oil in suitable traps; it has not been drilled in an established closed structural or stratigraphic trap. Its extent eastward and southward from Dirk Hartog Island may possibly be indicated by detailed gravity survey; unconformity traps may be present at its eastern edge, either by lateral variation into a shaly equivalent of the Tumblagooda Sandstone or by truncation and cover by the Jurassic Woodleigh Beds.

Because it is present at Dirk Hartog Island and at Wandagee it is likely that it occurs in subsurface over a large part of the Gascoyne Basin; it may or may not be present in the eastern basins. It is within easy reach of the surface along the Wandagee Ridge and probably also along the continental shelf between Dirk Hartog and Cape Range.

### DEVONIAN

The Nannyarra Greywacke, Gneudna Formation, Munabia Sandstone, and Willaraddie Formation are the outcropping formations regarded as Devonian, although fossils diagnostic of Devonian age have been found only in the Gneudna Formation.

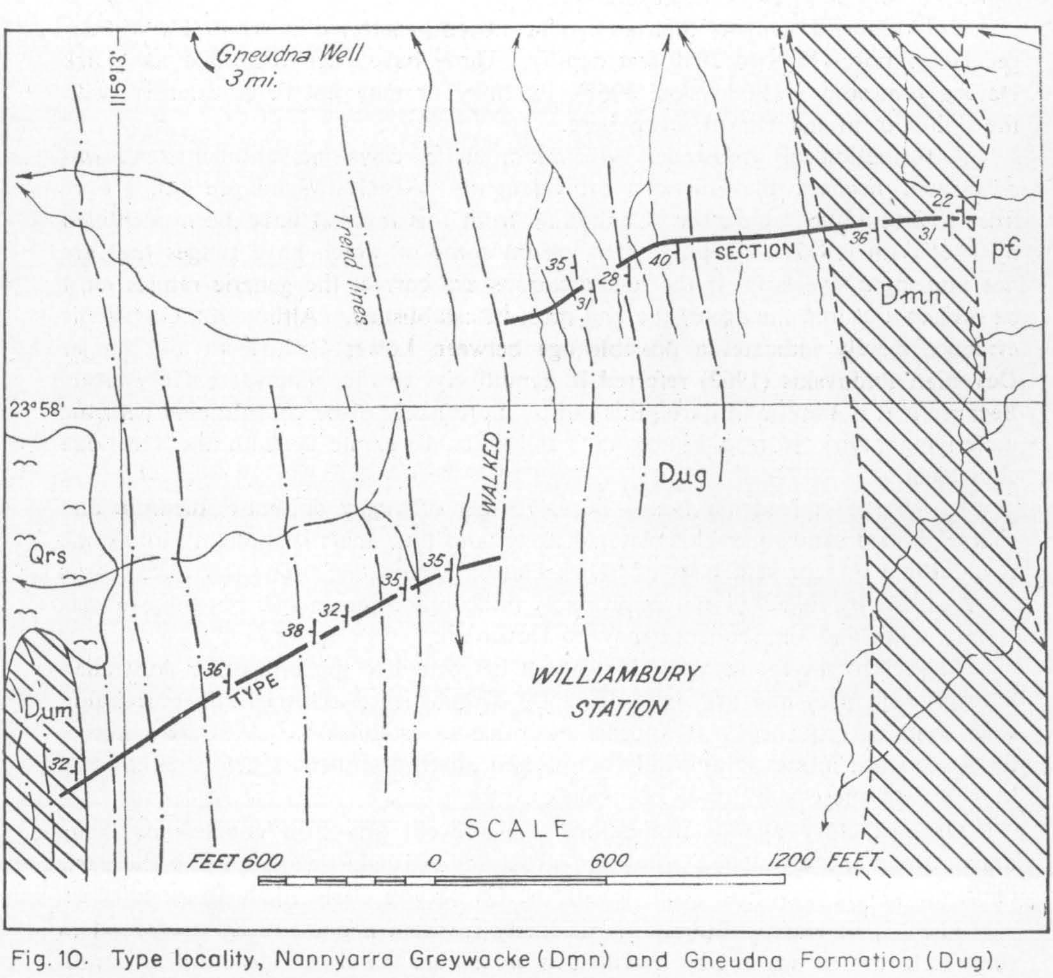



Fig. 10. Type locality, Nannyarra Greywacke (Dmn) and Gneudna Formation (Dug).
Dum — Munabia Sandstone; Qrs — Sand pЄ — Precambrian schist and granite

### *Nannyarra Greywacke*

The Nannyarra Greywacke (Condon, 1954a) is the oldest of the outcropping Devonian formations. It consists of greywacke, quartzwacke, and siltstone, and rests unconformably on a maturely dissected surface of Precambrian schist and granite; it has a transitional, conformable contact with the overlying Gneudna Formation.

The name (pronounced nan′-e-a′-r$\underline{a}$) is taken from Nannyarra Paddock on Moogooree Station; the north-west corner of this paddock is 4¾ miles south-south-east of Moogooree Homestead. The type section of the formation, at the south end of Gneudna Paddock, Williambury, at Lat. 23° 58′ S., Long. 115° 14′ E. (Fig. 10), was measured by G. A. Thomas, C. E. Prichard, and myself. Figure 11 shows the type section. The thickness of the type section is 193 feet.

The upper boundary of the Nannyarra Greywacke is placed at the change of lithology from quartzwacke to calcilutite or calcareous siltstone. This boundary is rarely well exposed, but can be located for mapping purposes by reference to the lowermost hard limestone bed of the Gneudna Formation, which in the type section is 72 feet above the base of the Gneudna Formation. In 1954, I placed this 72 feet of ' calcareous siltstone ' in the Nannyarra Greywacke, but subsequent work showed that where outcrop was good enough to show the lowermost hard limestone bed the transition from greywacke to calcilutite could also be mapped. This is the better boundary, as it is the main change in lithology from arenaceous to calcareous and would be more easily picked in bores, in both cuttings and electric logs.

The lower boundary of the formation is the unconformity with the Precambrian crystalline rocks. Because of the relief of the surface of the Precambrian rocks, the unconformity may be at any part of the formation.

*Lithology.*—The basal beds of the Nannyarra Greywacke are rather arkosic in appearance, particularly where they overlie granitic rock, but contain too little feldspar to be classified as such (Edwards, 1952). They consist of 40 to 60 percent of angular to subangular grains of quartz ranging in size from about 50 mm to 0.5 mm; 5 to 20 percent of angular to subround fragments of quartzite, schist, and granite, ranging in size from about 75 mm to 10 mm; 5 to 10 percent feldspar (mainly microcline and orthoclase); 3 to about 5 percent mica (mainly biotite, some muscovite, sericite, and chlorite) and up to 25 percent fine-grained matrix.

The larger part of the formation consists of medium-grained greywacke made up of 50 to 60 percent angular to subround quartz from 2 mm to 0.1 mm; 5 to 10 percent feldspar; about 3 percent mica (mainly biotite); few grains of quartzite; and up to 35 percent of fine-grained matrix.

The upper beds consist of thin-bedded to laminated medium-grained and fine-grained quartzwacke consisting of 60 to 70 percent subangular to subround quartz; about 5 percent feldspar; about 3 percent biotite and a little white mica (possibly leached biotite); and about 30 percent of pale fine-grained matrix.

*Distribution.*—The Nannyarra Greywacke crops out along the eastern margin of the Carnarvon Basin from five miles south-west of Lyndon Homestead to one mile north of Mount Sandiman Homestead; and along the north-eastern margin

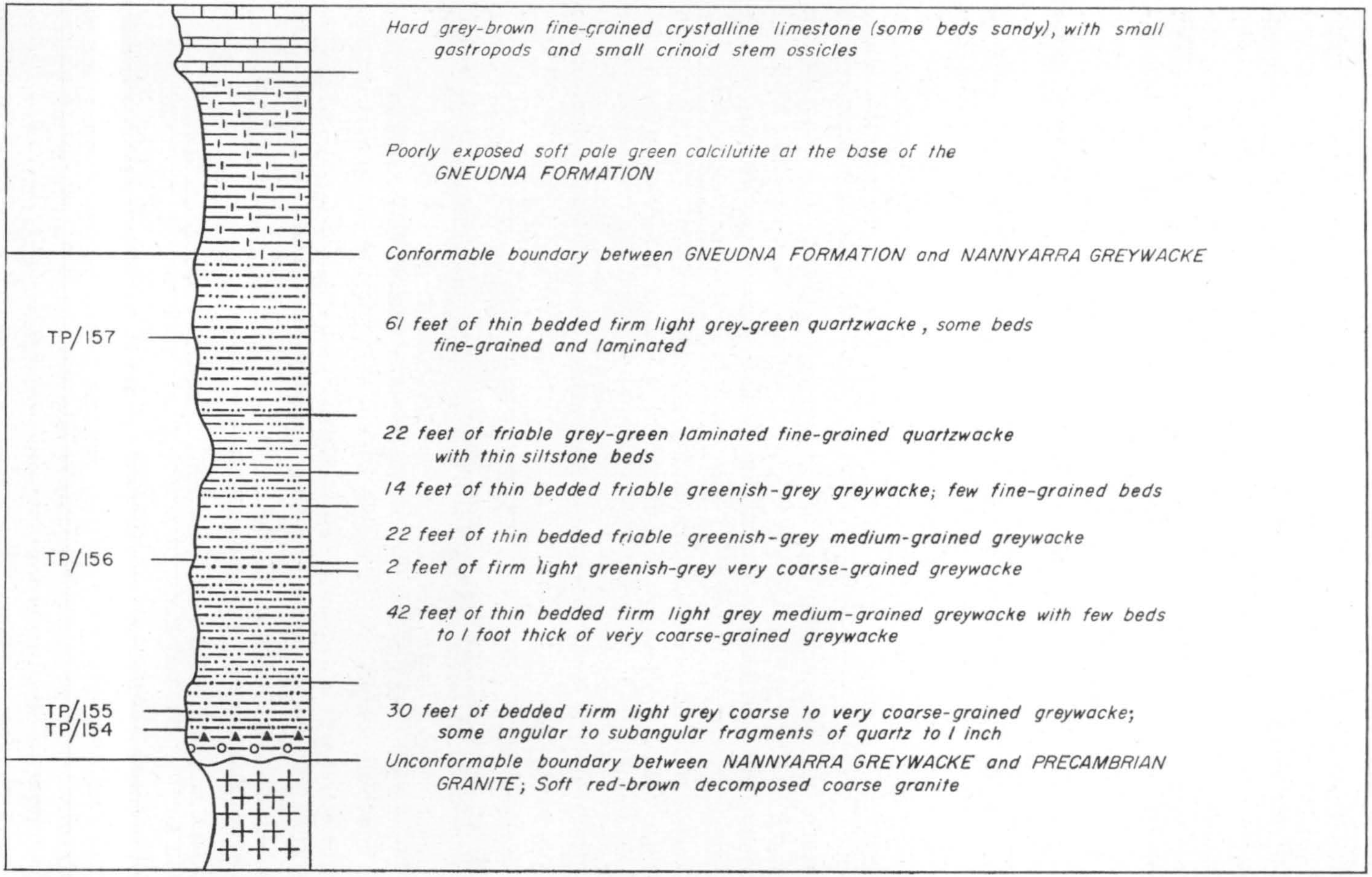
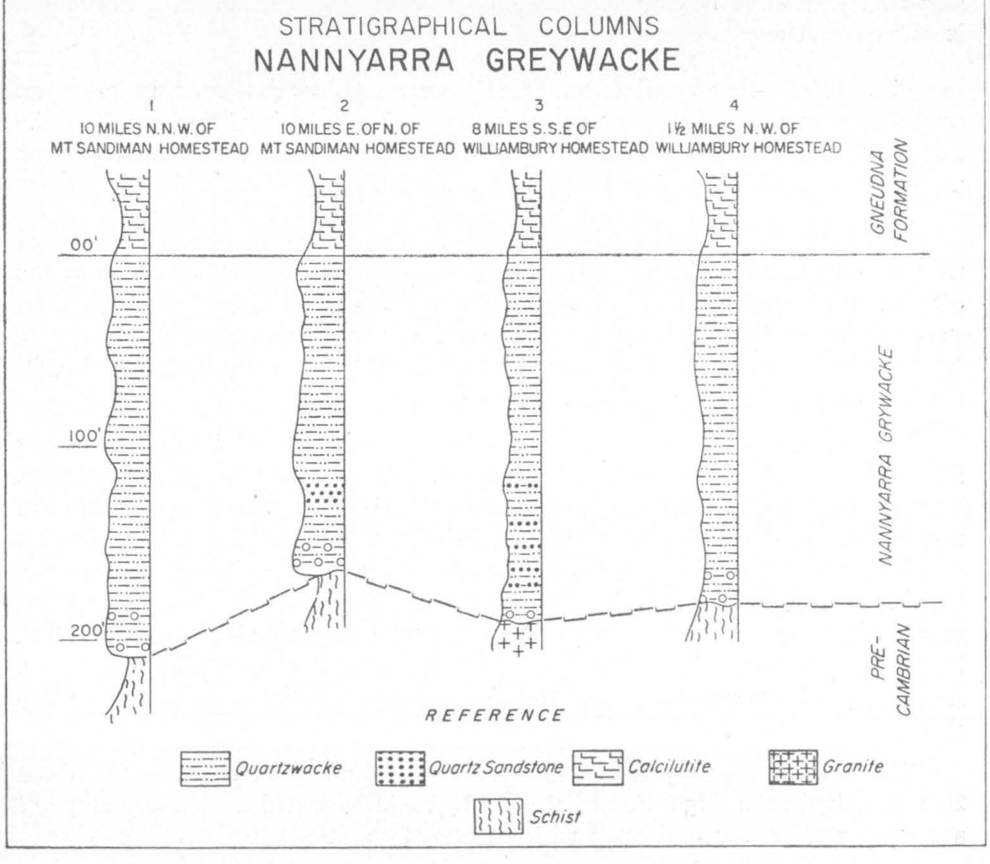



Fig. 11 - Type section, Nannyarra Greywacke

of the Bidgemia Basin for about 1½ miles on each side of the Moogooree/Mount Sandiman boundary fence. It is not exposed in the Devonian outliers east of Moogooree Homestead or in most of the outcrops of Devonian west of Williambury Homestead. There is a small outcrop 1¼ miles south-south-west of Williambury and other small outcrops occur in the area 8 miles west-south-west of Lyndon. Arenaceous sediments possibly equivalent to the Nannyarra Greywacke are reported from the Pelican Hill Bore at 2307 to 3011 feet depth, from Brickhouse Bore No. 1 from 1917 to 2147 feet, from WAPET's Wandagee No. 1 Bore (912 to 1308 feet) and from WAPET's Quail No. 1 Bore (10,110 to 10,513 feet). McWhae et al. (1958, p. 44) considered this sequence in the Pelican Hill Bore to be Tumblagooda Sandstone, but the lithology (quartzwacke, not quartz sandstone) is closer to Nannyarra than Tumblagooda.

*Thickness.*—The strong relief of the surface of the Precambrian rocks on which the Nannyarra Greywacke rests results in great and rapid variation in the thickness of the formation. Very few sections were measured because of this. One mile north of Mount Sandiman Homestead, the Nannyarra Greywacke pinches out and

Fig. 12



the Gneudna Formation rests directly on the Precambrian schist. The maximum measured thickness in outcrop is about 200 feet, 10 miles north-north-west of Mount Sandiman Homestead (column 1, fig. 12). Some outcrops which have been stated (Thomas & Prichard, 1953) to contain thicknesses up to 400 feet, such as the outcrop 2½ miles east of Woodcock's Bore, Mount Sandiman (Condon, 1962a), include large foresets resting on a gently sloping surface of the Precambrian. If these foresets are regarded as dips, even greater thicknesses than 400 feet would be measured. In the south-east corner of Moogooree and the adjoining corner of Mount Sandiman outlying outcrops of the coarse basal greywacke form hills completely surrounded by outcropping schist; the greywacke beds 'dip' at 20 to 28° westward. These beds are in fact large foresets.

In the area about 8 miles north of Mount Sandiman Homestead the thickness of the Nannyarra, estimated from dip and outcrop width, is about 500 feet.

*Fossils.*—No fossils have been found in the Nannyarra Greywacke.

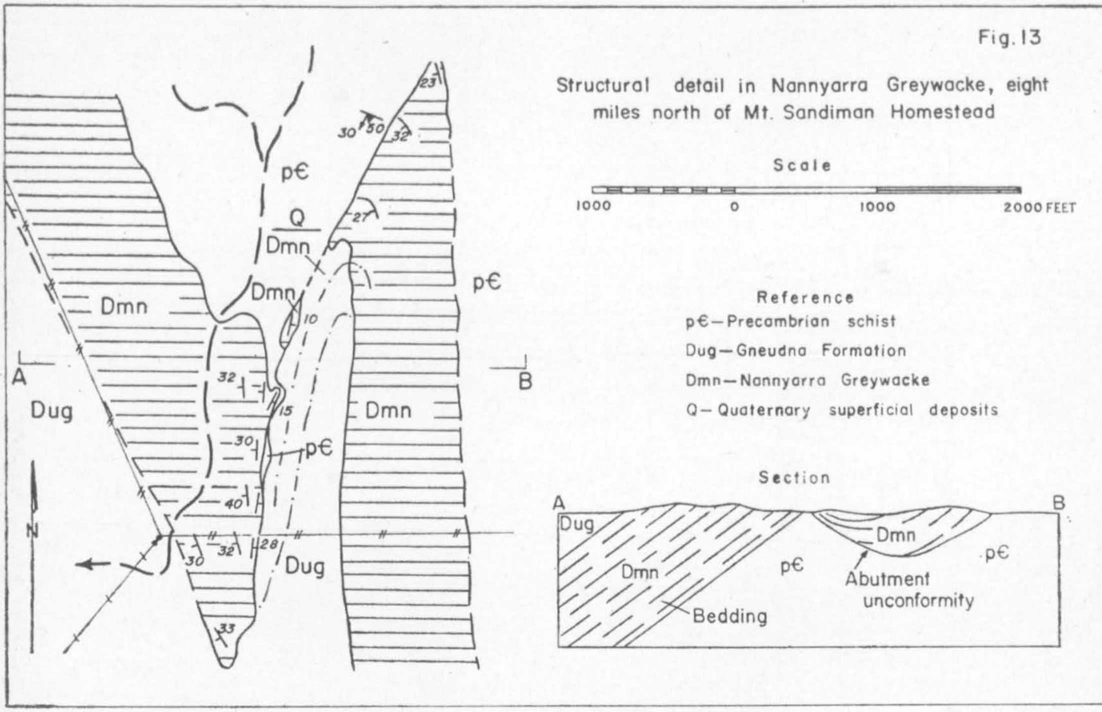
*Age.*—The Nannyarra Greywacke is overlain conformably by the Gneudna Formation, the fossils in the upper part of which indicate a Frasnian age. As the corals (Hill, 1954) have Givetian affinities also, it is likely that the lower part of the Gneudna Formation is Givetian and that the conformable Nannyarra Formation is also of that age.

*Correlation.*—It is possible that the Nannyarra Greywacke is of the same age as the lower part of the Pillara Formation of the Fitzroy Basin of Western Australia and that the transgression resulting in the deposition of these two formations took place at about the same time in the two basins.

*Structure.*—In its area of outcrop the Nannyarra Greywacke dips south of west at between 30° and 40°; it appears to continue into the synclines 5 miles and 11 miles south-west of Lyndon Homestead. There is some indication of anticlinal structure where the Nannyarra Greywacke crops out 1¼ miles south-south-west of Williambury Homestead at the south end of the ridge of Precambrian schist immediately west of the homestead.

Along the outcrop from the northern boundary of Mount Sandiman to near Mount Sandiman Homestead there are several offsets of the trend of the outcrop. These were at first thought to be caused by faulting, but careful examination of several and mapping of one showed that the offsets were produced by deposition over and around asymmetrical ridges and valleys in the surface of the Precambrian (Fig. 13). This ridge and valley surface has a relief of about 500 feet and has scarps facing east and south-east and more gentle slopes facing westward. The Nannyarra Greywacke is deposited parallel to the gentler slope and abuts the scarp slope with minor run-up. There is some compaction sliding against the scarp slope.

The present geometry suggests that the maximum westward tilting is about 20°: at this tilt the ridge of schist (Fig. 13) would have had a westward slope of about 10° and an eastward scarp with a slope of about 50°.




*Palaeogeography.*—Large-scale cross-bedding indicates that at the time of deposition of the Nannyarra Greywacke, its outcrop area was in a deltaic environment. The material forming the sediments was derived from nearby Precambrian rocks: this may indicate that some of the sediments of the formation were eroded and deposited by marine action during a transgression. It is unlikely that the hinterland was strongly elevated at this stage, as the thin transgressive Nannyarra Greywacke is followed by the Gneudna Formation, in which calcareous material, including marine fossils, is dominant and terrigenous material subordinate. The absence of Nannyarra Greywacke from the base of the Devonian sediments in the outliers east of Moogooree suggest that the shoreline did not reach there during deposition of the Nannyarra Greywacke. The shape of the unconformity between the Nannyarra Greywacke and the Precambrian rocks shows that the Middle Devonian surface of the Precambrian rocks in the area between Williambury and Mount Sandiman was generally of mature relief, but in places there were ridges and valleys of moderate relief.

*Gneudna Formation*

The Gneudna Formation (named Teichert, 1949a, defined Condon, 1954a, p. 13) consists of calcarenite, quartzwacke, calcilutite, and calcarenous siltstone, generally very fossiliferous, resting conformably above the Nannyarra Greywacke and beneath the Munabia Sandstone and in part grading laterally into the Munabia Sandstone.

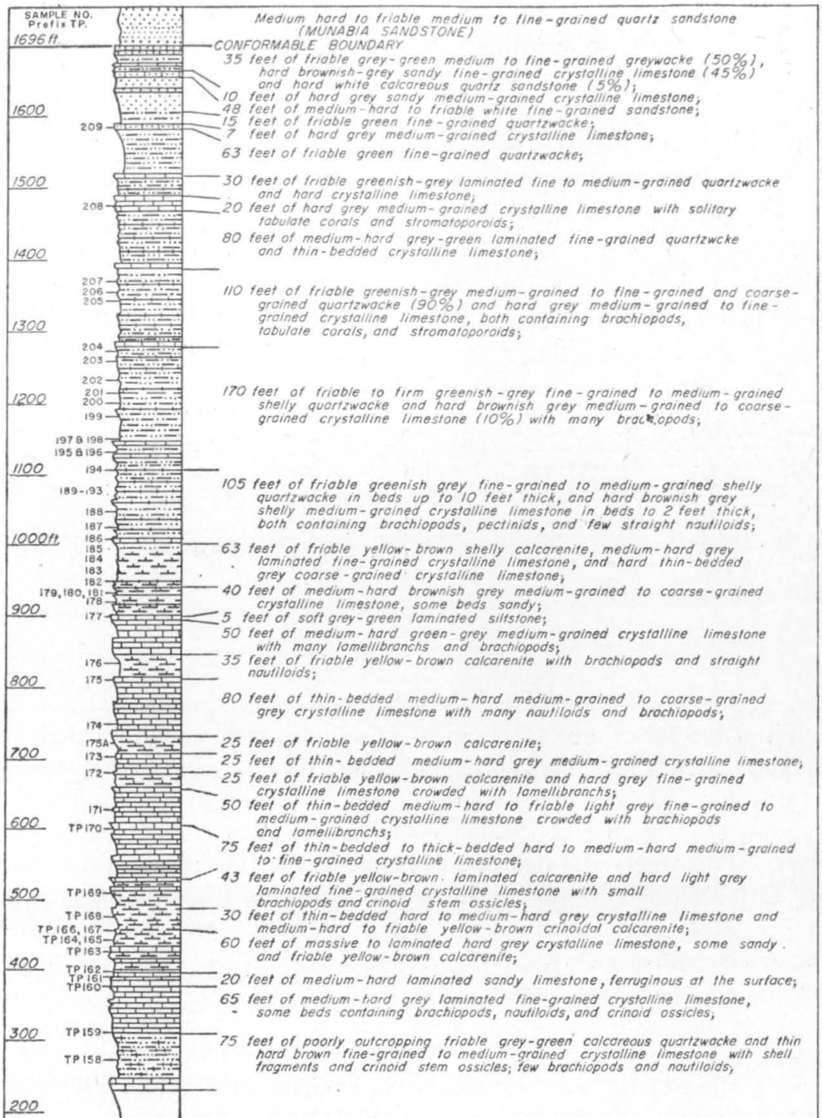



Fig. 14 – Type section, Gneudna Formation

The name (pronounced nūd'-na̲) is taken from Gneudna Paddock, which is immediately south-east of Williambury 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 (Fig. 10). Details of the type section, measured by G. A. Thomas, C. E. Prichard, and myself, are shown in Figure 14; the thickness is 1696 feet.

The lower boundary of the formation is taken at the change from dominantly arenaceous to dominantly calcareous sediments. The upper boundary is at the top of the uppermost hard limestone bed overlain by friable quartz sandstone; this boundary is transitional and there are many beds of quartz sandstone in the top 100 feet of the Gneudna Formation.

The Gneudna Formation forms plains with low parallel ridges of limestone which appear on air-photographs as parallel narrow dark lines on a light ground. Vegetation is sparse acacia scrub and small herbaceous plants.

The Gneudna Formation crops out in a continuous belt about half a mile wide from five miles south-west of Lyndon Homestead to two miles north of Mount Sandiman Homestead; in a belt of discontinuous outcrop from immediately north of the Lyndon River about 25 miles north-west of Lyndon Homestead, southward for about 37 miles to the area 4½ miles south of west of Williambury Homestead; in a belt 11½ miles long from 10 miles north-north-west to 1½ miles south-south-west of Williambury; in an outlier 6½ miles long and up to 1 mile wide on Precambrian schist, 9½ miles east of Moogooree; in a small outlier 1 mile farther south; in a small area around Howells Bore, 14 miles south-east of Moogooree Homestead; in a narrow belt trending south-south-east for 9 miles from the area 12 miles north of Mount Sandiman Homestead; and in a small outcrop 2 miles south-east of the southern end of this belt. The outcrops extend over a total length of 70 miles and a maximum width of 10 miles (Fig. 15). A subsurface equivalent of the Gneudna Formation has been found in the Pelican Hill Bore 10 miles north of Carnarvon from 1406 to 2307 feet depth, where fossiliferous limestone and calcareous shale contain brachiopods, pelecypods, and ostracods of the same species as those found in the Gneudna Formation, or species diagnostic of Upper Devonian age (Fig. 16). Although Glenister has identified fragments similar to *Cyrtospirifer* from WAPET's Rough Range No. 1 Bore, between 10,700 feet and 14,607 feet (McWhae, et al., 1958), it is unlikely that the bore had entered the equivalent of the Gneudna Formation; the formations drilled below the Lyons Group can be compared lithologically with outcropping formations and on this basis it would appear that at total depth this bore was in a formation approximately equivalent to the Munabia Sandstone.

McWhae et al. (1958, p. 44) consider that calcareous sediments entered beneath the Mesozoic in WAPET's Cape Cuvier and Grierson Bores are equivalent to the Pelican Hill Bore Upper Devonian, although fossil confirmation is lacking; I have seen the cores and, on the basis of lithology, agree that the Cuvier Bore entered a formation similar to the Gneudna Formation equivalent in Pelican Hill Bore, but would suggest that the dolomite entered in Grierson Bores is different. WAPET's

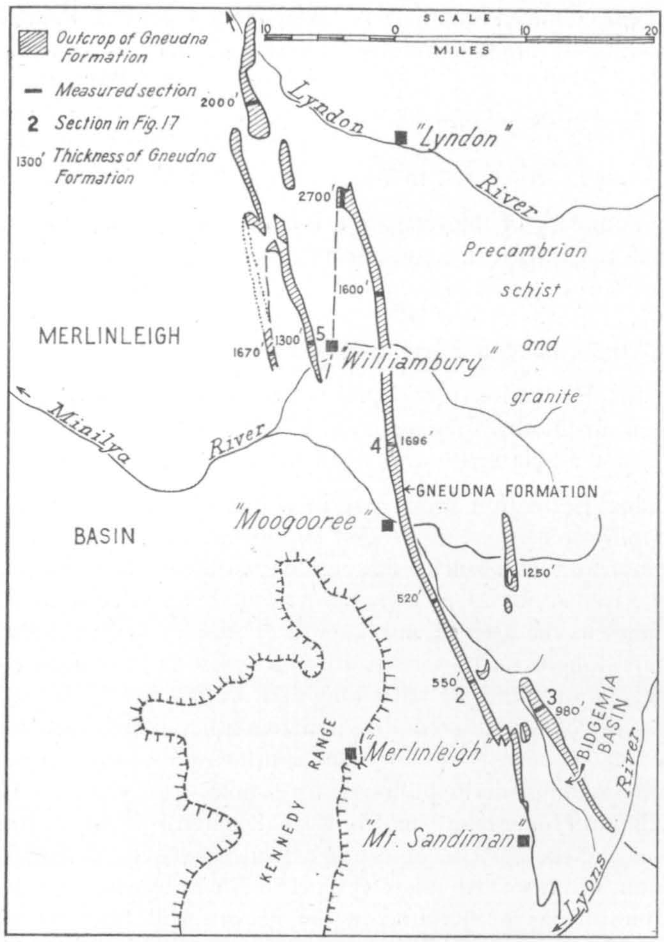



Fig.15 Outcrop of Gneudna Formation showing thicknesses. Numbers 2 to 5 are locations of stratigraphical columns shown in Fig. 17.

Wandagee No. 1 Bore penetrated sediments equivalent to the Gneudna Formation (limestone, dolomite, siltstone, and shale) between 591 and 912 feet (Pudovskis, 1962).

*Lithology.*—The main rock-types in the Gneudna Formation are calcarenite (45 percent), quartzwacke (30 percent), calcilutite (10 percent), quartz sandstone (3 percent), and siltstone (1 percent).

There are four main types of calcarenite. The dominant rock is thin-bedded to laminated, friable to medium-hard, medium-grained, coarse-grained, and fine-grained; it consists of cleavage fragments of calcite, fragments of shells and crinoid stems, and scattered fossils. The most commonly outcropping rock is laminated hard medium-grained and fine-grained calcarenite which is very similar in composition to the above rock but has an interstitial cement of calcite. This interstitial calcite is very fine-grained and cloudy and was probably a lime mud deposited

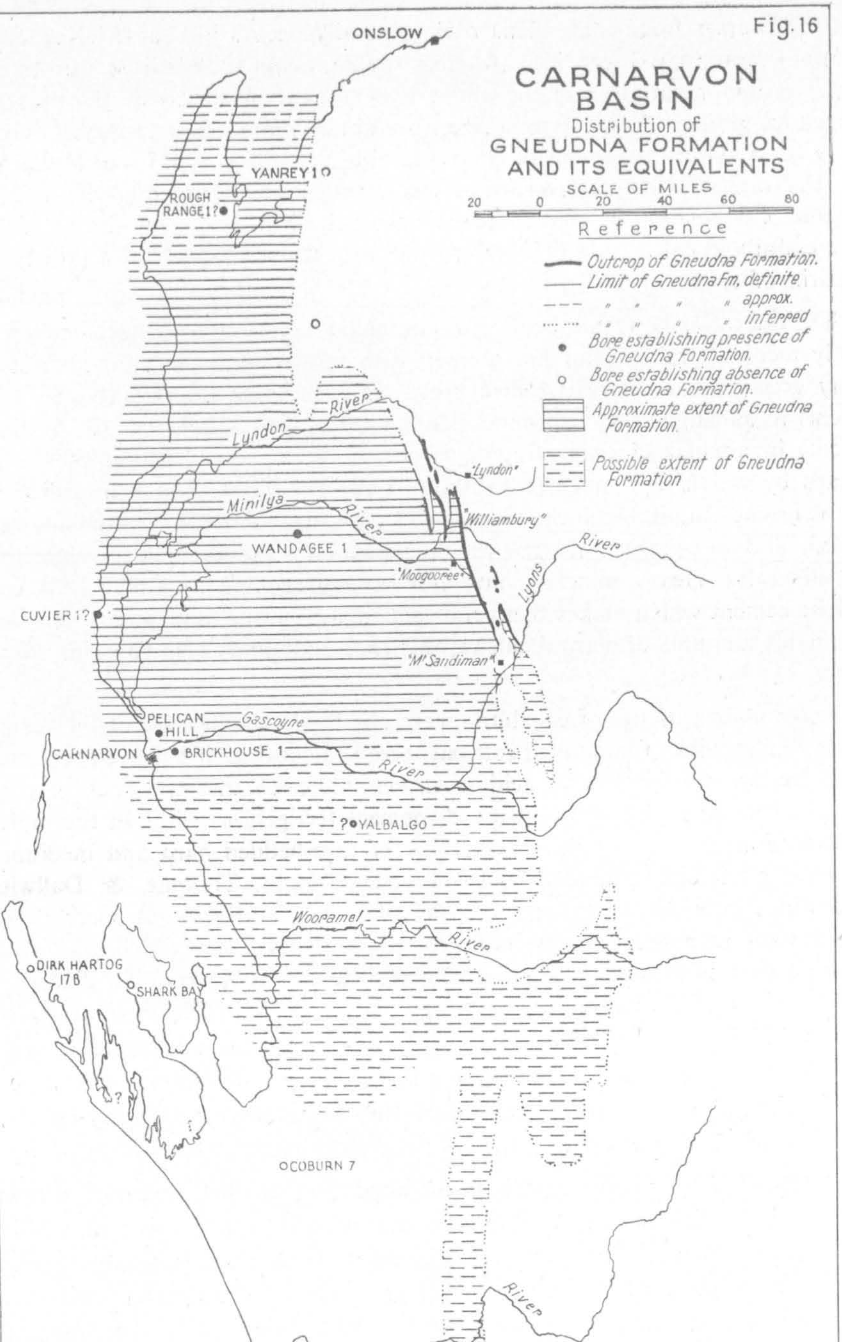


Fig. 16
CARNARVON
BASIN
Distribution of
GNEUDNA FORMATION
AND ITS EQUIVALENTS
SCALE OF MILES
20 0 20 40 60 80
Reference
Outcrop of Gneudna Formation.
Limit of Gneudna Fm, definite
" " " " approx.
" " " " inferred
Bore establishing presence of Gneudna Formation.
Bore establishing absence of Gneudna Formation.
Approximate extent of Gneudna Formation.
Possible extent of Gneudna Formation
ONSLOW
YANREY 1
ROUGH RANGE 1?
Lyndon River
"Lyndon"
Minilya River
"Williambury"
WANDAGEE 1
Lyons River
"Moogooree"
CUVIER 1?
"Mt Sandiman"
PELICAN HILL
Gascoyne River
CARNARVON
BRICKHOUSE 1
?YALBALGO
Wooramel River
DIRK HARTOG 17B
SHARK BAY
?
COBURN 7
Murchison River

with the coarser fragments. This rock generally occurs in sets (McKee & Weir, 1953) not more than 3 feet thick, whereas the dominant rock is in sets up to 50 feet thick. A minor variation of the above two types is produced by the presence of terrigenous grains; these range in size from about 4 mm down to clay; they commonly form about 20 percent of the rock, although there appears to be an almost complete range from quartzwacke to calcarenite. The terrigenous material is of the same composition as that in the quartzwacke beds. A very minor rock-type is the coquinoid calcarenite in which fossils form the framework of a thin bed with a matrix of calcarenite.

The quartzwacke is thin-bedded to laminated in sets up to 20 feet thick, friable, mainly medium-grained and fine-grained with few beds coarse-grained, and commonly grey-green or dark greenish grey. It consists of quartz (about 50 to 60 percent) in subangular to subround clear or milky grains, feldspar (0 to about 10 percent) in angular cleavage fragments commonly opaque because of alteration, perhaps by weathering, mica (1 to about 5 percent biotite and white mica which may be leached biotite), chlorite (2 to 10 per cent, apart from that in the fine-grained matrix), and fine-grained matrix which appears to include quartz, chlorite, and clay minerals. Heavy minerals have not been determined. A few beds contain a calcite cement which makes them resistant to weathering, and several sets contain appreciable amounts of detrital calcite; this rock commonly also contains abundant fossils.

Three main varieties of calcilutite were observed: at the base of the formation is a set 72 feet thick of laminated soft pale green calcilutite; it has not been analysed quantitatively, but qualitative acid treatment indicates that the rock is predominantly calcareous, with about 10 to 20 percent terrigenous silt. In the middle of the formation are sets up to 30 feet thick of thin-bedded hard and medium-hard calcilutite containing abundant calcispheres. Crespin, Thomas, & Dallwitz (in preparation) consider that these are definitely organic and not merely ooliths. They are set in a very fine-grained groundmass of calcite, which was probably deposited as a lime mud. The calcispheres are 0.4 to 0.5 mm in diameter and consist mainly of chalcedonic silica, apparently replacing calcite or aragonite, of which residual particles are present. In the upper part of the formation are thin beds of hard oolitic calcilutite. The ooliths, ranging in diameter from 0.5 to about 1.0 mm, have concentric structure; they are set in an extremely fine-grained groundmass probably of calcite; the ooliths constitute about 60 percent of the rock.

Quartz sandstone is found only in the upper part of the formation; it is laminated to thin-bedded, mainly friable, and fine-grained, and consists of subangular and subround quartz grains of even size, many with quartz crystal overgrowths, a very small amount of chlorite and very little matrix of quartz silt and clay. A few beds have a clear calcite cement. Most of the sandstone is interstratified with sandy calcarenite, but a few beds are intercalated with quartzwacke that shows no indication of removal during sedimentation of matrix or other non-resistant fragments; the presence of chlorite in the sandstone and the shape of the quartz grains suggest that the sandstone was derived from quartzwacke sediment before deposition by removal of the matrix, feldspar, and mica by wave and current action. It indicates the change of conditions which resulted in the deposition of the Munabia Sandstone.

A very little siltstone is present in the formation, as sets ranging from 3 to 6 feet thick of laminated soft siltstone. This rock has not been examined in detail.

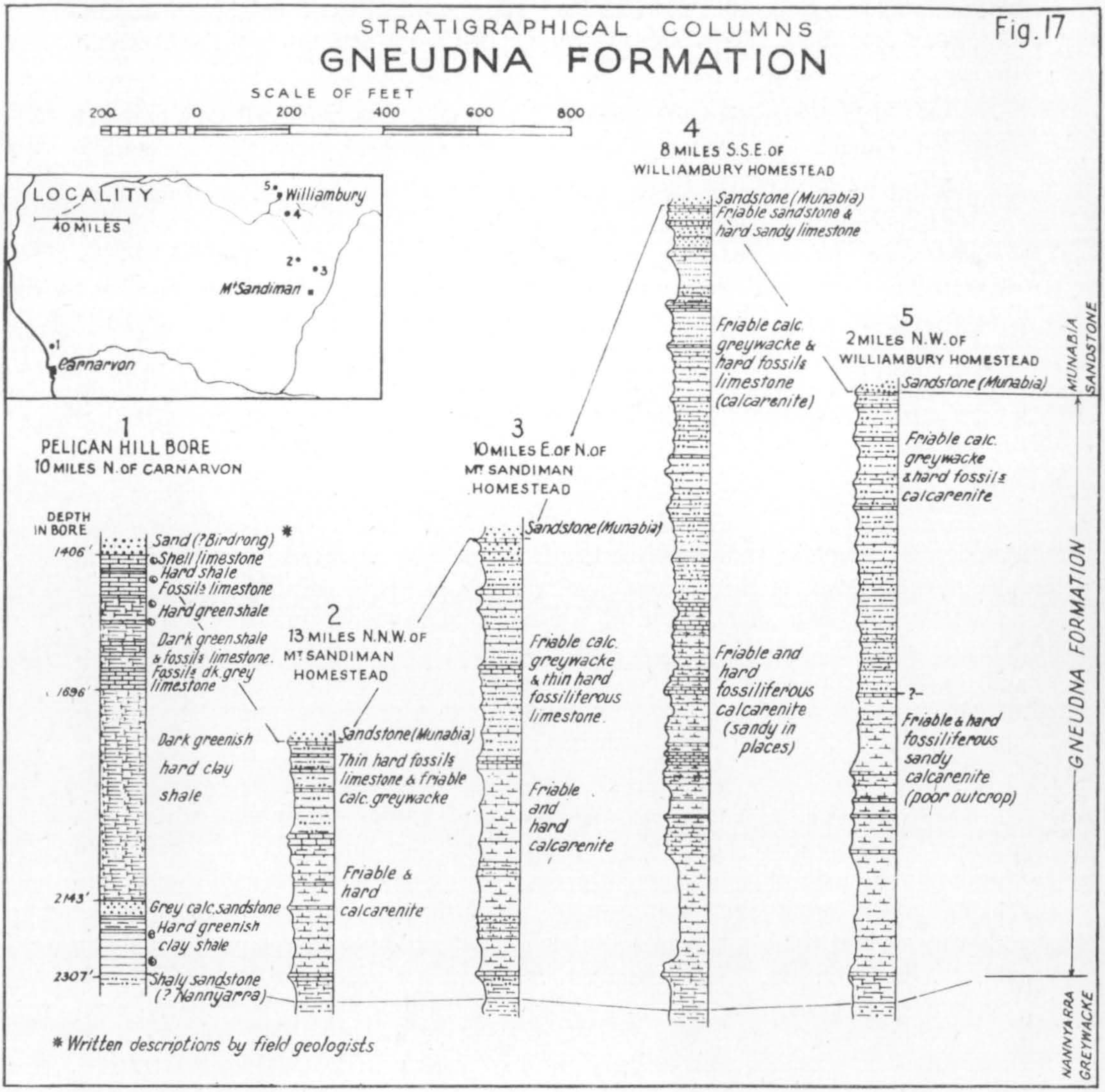
The lithology indicates a moderately deep marine environment of contemporaneous calcareous and terrigenous deposition. An abundant organic population supplied some of the calcareous material in the form of tests, some of which disintegrated to form calcarenite and lime mud. Some of the lime mud may have been produced by the life processes of micro-organisms. The terrigenous material apparently came from rocks like those cropping out immediately to the east—crystalline schists and granite. The appearance of quartz sandstone derived from the quartzwacke sediment in the uppermost part of the formation indicates that the sea shallowed, allowing waves and currents to remove the fine matrix, mica, and easily broken feldspar from the sediments.

Throughout the outcrop area there are no significant changes in lithology although the abundance of fossils varies from place to place. In the Pelican Hill Bore the equivalent of the Gneudna Formation consists of fossiliferous dark hard calcarenite and dark shale, some of which also is fossiliferous. The calcarenite indicates a depth of water not markedly different from that in the outcrop area, and the shale, though it could have been laid down in deeper water, may rather indicate distance from the source of supply of the terrigenous material, so that only the very fine-grained mud reached the area.

*Thickness.*—The Gneudna Formation generally crops out very poorly. Even in areas where the hard beds crop out fairly well, the outcrop consists mainly of blocks of limestone obviously not in place, making measurement of dip quite unreliable. As a result reliable measurements of thickness are very few, and the following statement must be read with this in mind; all but the type section and section 3, Figure 17, are figures computed from the best dip information available and from distances scaled from air-photographs. The thickness at outcrop ranges from 520 feet to 2700 feet; the greatest thicknesses, and thicknesses greater than those in the immediately surrounding area, are found in the axial regions of synclines. The thickness variation along the long outcrop belt indicates a westward divergence of about 400 feet per mile; in the area between the Lyndon and Minilya Rivers no regional divergence can be estimated, although a local divergence of about 500 feet per mile into the individual synclines is indicated.

The greater thicknesses in the synclines may have resulted from accumulation in original valleys in the basement or by bulking of the relatively incompetent sediments of the Gneudna Formation during folding.

*Fossils.*—The Gneudna Formation is very fossiliferous. In most outcrops, original test material is present. There is a rough abundance-zoning in the fossils: in the lower part brachiopods are dominant; in ascending order crinoid stems,




pelecypods, nautiloids, brachiopods, and corals and stromatoporoids are dominant. Palaeontological work is still continuing on the faunas, but the following species have been determined:

Corals (Hill, 1954):

*Disphyllum virgatum* (Hinde) var. *variabile* Hill
*Hexagonaria gneudnensis* Hill
*Thamnopora* cf. *polyforata* (Schlotheim)
*Alveolites caudatus* Hill

Brachiopods:

Coleman (1951):

*Atrypa aspera prideri* Coleman

Glenister (1956):

*Austrospirifer variabilis* Glenister
*Cyrtospirifer minilyaensis* Glenister
*C. australis* Glenister
*C. gneudnaensis* Glenister
*C. brevicardinis* Glenister

Veevers (1959):

*Productella accidua* Veevers
*Camarotoechia puteana* Veevers
cf. *Ladjia saltica* Veevers
Spiriferidae gen. et sp. ind.

*Age.*—Hill (1954) states that the association of the four genera of corals is characteristic of the Givetian and Frasnian. Glenister (1956) states that *Cyrtospirifer* is restricted to the Frasnian, but Veevers (1959) points out that it is known from the Famennian also. Although the fossil evidence is not very clear it is likely that the Gneudna Formation is Frasnian in age. Fossils from the lower part have not been determined, so that at present it is not possible to give a precise age to the lowermost part of the formation; the absence of *Cyrtospirifer* may be an indication that the lowermost part of the formation is Givetian.

*Correlation.*—The Gneudna Formation may be correlated with the formation of limestone and shale containing *Cyrtospirifer* in the Pelican Hill Bore between 1406 feet and 2307 feet (Thomas & Dickins, 1954). This formation directly underlies the Lower Cretaceous Birdrong Formation and the cores show dips of about 8°. Although McWhae et al. (1958) consider that strata equivalent to the Gneudna Formation may be present in Rough Range Bore No. 1 ' between 10,700 feet and 14,607 feet ' I should compare the lithology of the formation in this interval with the outcropping formations above the Gneudna Formation. Cape Cuvier Bore No. 1 cut dolomite, limestone, siltstone, and conglomerate immediately below the Mesozoic. Although no fossils were found, the lithology suggests that it may be of the same formation as that in the Pelican Hill Bore and therefore equivalent to the Gneudna Formation.

In the Fitzroy Basin, the upper part of the Pillara Limestone, the Sadler Formation, the Mount Pierre Group, the Oscar Formation, and the Geikie Formation (Guppy, Lindner, Rattigan, & Casey, 1958) are Frasnian and therefore to be correlated with the Gneudna Formation (Veevers, 1959). Other marine Frasnian sediments that may be correlated tentatively with the Gneudna Formation include the Star Beds, Hodgkinson Beds, and Thomson Clastics of Queensland.

*Structure.*—The main belt of outcrop of the Gneudna Formation dips westward at 30° to 45°. North of the latitude of Williambury, the Gneudna Formation is folded into large synclines with east flank dips of 25° to 40°, southward plunges between 10° and 30°, and narrow steep west flanks. The Formation is folded into a south-plunging anticline $1\frac{1}{2}$ miles south-south-west of Williambury. West of Lyndon several small synclines contain only Gneudna Formation and Nannyarra Greywacke. Outliers in synclines east of Moogooree and north of Mount Sandiman consist mainly of Gneudna Formation with some Munabia Sandstone. In a south-plunging syncline 30 miles north of Mount Sandiman, the Gneudna Formation dips 30° west.

In much of the outcrop area the beds are irregularly contorted and faulted in a manner that suggests slump structures; some of these are on a scale sufficiently large to be visible on the air-photographs (e.g., in the outlier $8\frac{1}{2}$ miles south of west of Lyndon).

In the area five miles south-west of Lyndon, the west flank of a narrow syncline is seen to be faulted against Precambrian silicified quartz breccia. A fault zone within the sediments dips 65° east-south-east. The fault appears to continue north into the Precambrian, alongside the silicified quartz breccia, which is a sealed pre-Devonian and probably Precambrian fault.

*Palaeogeography.*—The Gneudna Formation was deposited in shallow sea water containing abundant lime; terrigenous sediments were introduced intermittently. The sea floor had a bathymetric relief of several hundred feet at least and its slopes were sufficient to cause slumping of the lime-mud sediments. The shoreline was probably not far to the east of the present outcrop area and was strongly indented with gulfs and peninsulas trending mainly north. Near Carnarvon (Pelican Hill Bore), the fossils of the Gneudna equivalent indicate shallow water, but the sediments indicate that the shoreline was far away: this area was probably a submarine bank. Another was probably present in the area of the Wandagee Ridge from about the Lyndon River to the Gascoyne River; stromatoporoid-coral reefs may have developed on parts of it.

*Economic Geology.*—Brackish ground-water suitable for stock is drawn from the outcrop of the Gneudna Formation, but it cannot be regarded as a good source of ground-water. The fact that useful quantities of water are produced indicates moderate porosity and permeability in the formation at outcrop.

The subsurface equivalent of the Gneudna (as seen in Pelican Hill Bore) is of oil source-bed type. The formation equivalent has been drilled in structurally high locations (at Wandagee No. 1 and Quail No. 1), but structural closure has not been established at these places. The Gneudna is a main target for oil exploration, since it is likely to include both source beds and reservoirs in its equivalents. Prospective areas for exploration for closed structures include the Wandagee Ridge between Lyndon and Gascoyne Rivers, the southward extension of basement ridges from Williambury, and possibly the coastal area between Carnarvon and Rough Range. Stratigraphic traps, including unconformities, may be found in the outcrop area (Lyndon to Mount Sandiman), on the steep eastern flank of the Wandagee Ridge between Lyndon and Gascoyne Rivers and, perhaps, on the western flank of the ridge north of Marrilla.

*Problems.*—The limits of the extent of the Gneudna and its equivalents are not yet established even approximately: seismic surveys combined with drilling are required to indicate this, as well as facies variations that may lead to stratigraphic prospects. Such work will also help to establish the structure and thickness variations of the unit.

The shaly parts of the Gneudna equivalents should be examined to determine their worth as oil source-beds.

### *Munabia Sandstone*

The Munabia Sandstone was named by Teichert (1949a) and defined and described by Condon (1954a). As a result of additional field work it is apparent that the definition needs to be revised somewhat, as follows: the Munabia Sandstone is the formation of quartz sandstone resting conformably on and in part varying laterally into the Gneudna Formation and overlain conformably by the Willaraddie Formation, disconformably by the Moogooree Limestone, or unconformably by the Lyons Group.

The name (pronounced mū-na̲-bi′-a̲) is taken from Munabia Paddock, Williambury Station, which is immediately north-east of the homestead. The formation crops out in a north-south belt crossing the paddock. The type section, in Gneudna Paddock, five miles south-east of Williambury Homestead and one mile north-east of Gneudna Well, at Lat. 23° 55′ S., Long. 115° 12′ E. (Fig. 18), was measured by G. A. Thomas and C. E. Prichard; it is shown in Figure 19.

The Gneudna Formation grades into the Munabia Sandstone and the boundary is taken at the top of the uppermost hard limestone bed. In the type locality there is much quartz sandstone in the uppermost part of the Gneudna Formation, and in the area west of Howells Bore, Moogooree Station (Lat. 24° 13′ S., Long. 115° 19′ E.), these limestones are not developed and the lowermost part of the Munabia Sandstone is a lateral variant of the uppermost part of the Gneudna Formation farther north. The upper boundary of the Munabia Sandstone is taken at the main change of lithology from quartz sandstone to pebbly quartzwacke. In the area between 4 and 9½ miles south-south-east of Moogooree Homestead, the Moogooree Limestone rests directly, disconformably, on the Munabia Sandstone: from 10 to 19 miles south-south-east of Moogooree and from 3½ miles slightly south of east to 5½ miles south-east of Howell's Bore the Austin Greywacke rests unconformably on the Munabia Sandstone.

*Distribution.*—The Munabia Sandstone crops out in a continuous belt except for alluvial cover from 6 miles south-south-west of Lyndon Homestead to 7 miles slightly west of north of Mount Sandiman Homestead; in a belt 11 miles long from 9 miles north-north-west to 3 miles south-west of Williambury Homestead; in a belt 3½ miles long 5½ miles west of Williambury; in an outlier 10 miles slightly south of east of Moogooree; in a belt running 3 miles south-east from 3½ miles east of Howell's Bore, Moogooree Station; and in an outlier 7½ miles north of Mount Sandiman Homestead (Fig. 20).

*Lithology.*—The Munabia Sandstone consists dominantly of quartz sandstone ranging from clear quartz sandstone (90 percent quartz, 5 percent feldspar, 2 percent chert fragments and 3 percent clay matrix) to silty quartz sandstone (80 percent

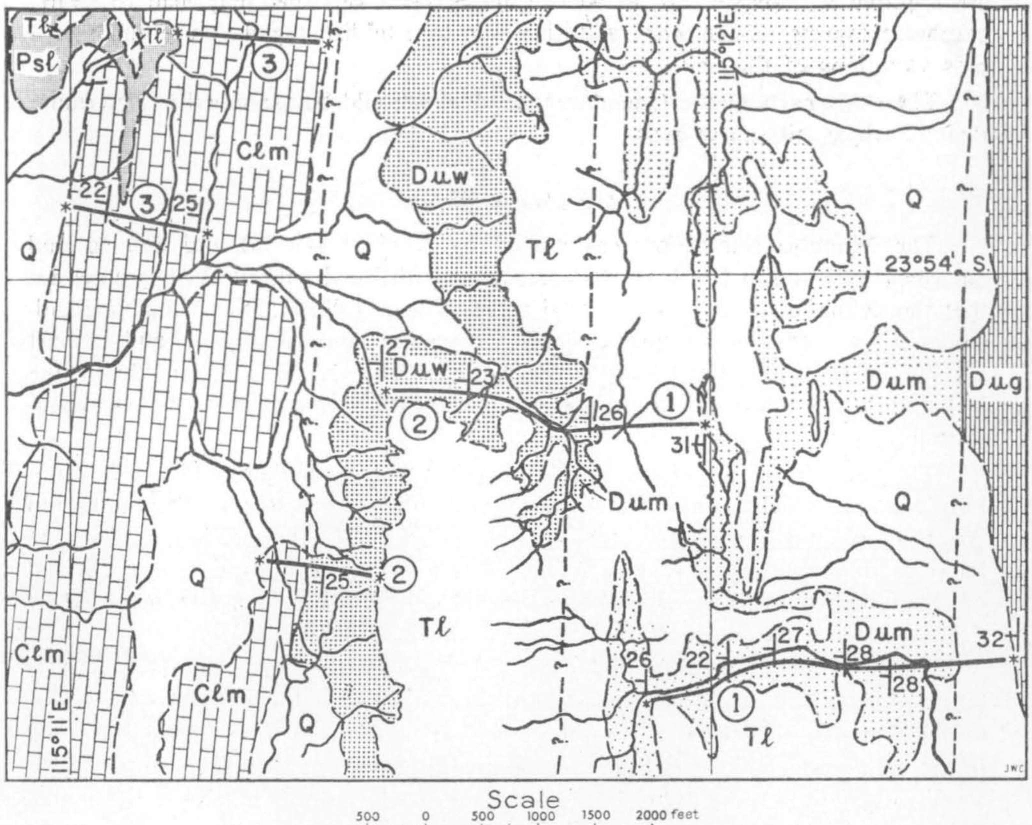



Fig. 18. Type localities

| | | | |
|---|---|---|---|
| 1: Dᴜm : Munabia Sandstone | | Psℓ : Lyons Group | |
| 2: Dᴜw : Willaraddie Formation | | Tℓ : Tertiary | |
| 3: Cℓm : Moogooree Limestone | | Q : Quaternary | |
| Dᴜg : Gneudna Formation | | | |

quartz, 15 percent clay matrix, 5 percent feldspar, chert, and white mica). The quartz is commonly overgrown and the resulting crystal faces give a sparkle to the surface of the rock. Mica is common in some beds but almost absent in others; it is concentrated along bedding planes. The grainsize ranges from fine to very coarse; within the individual beds sorting is good and porosity moderate to high (10 to about 20 percent). Permeability is estimated to be moderately high (about 50 to 100 millidarcies), although no tests have been made. Cross-bedding is common, with sets ranging from small (6 inches) to very large (about 100 feet).

In the upper part of the formation there is a member of siltstone, quartzwacke, and limestone.

*Thickness.*—In the main outcrop belt the Munabia Sandstone ranges from 4450 feet thick to absent (Fig. 21); in the area north of Lat. 24° 06′ S., where the formation rests conformably between the Gneudna Formation and the Willaraddie Formation, the thickness ranges from 1300 to 1820 feet; south of that latitude

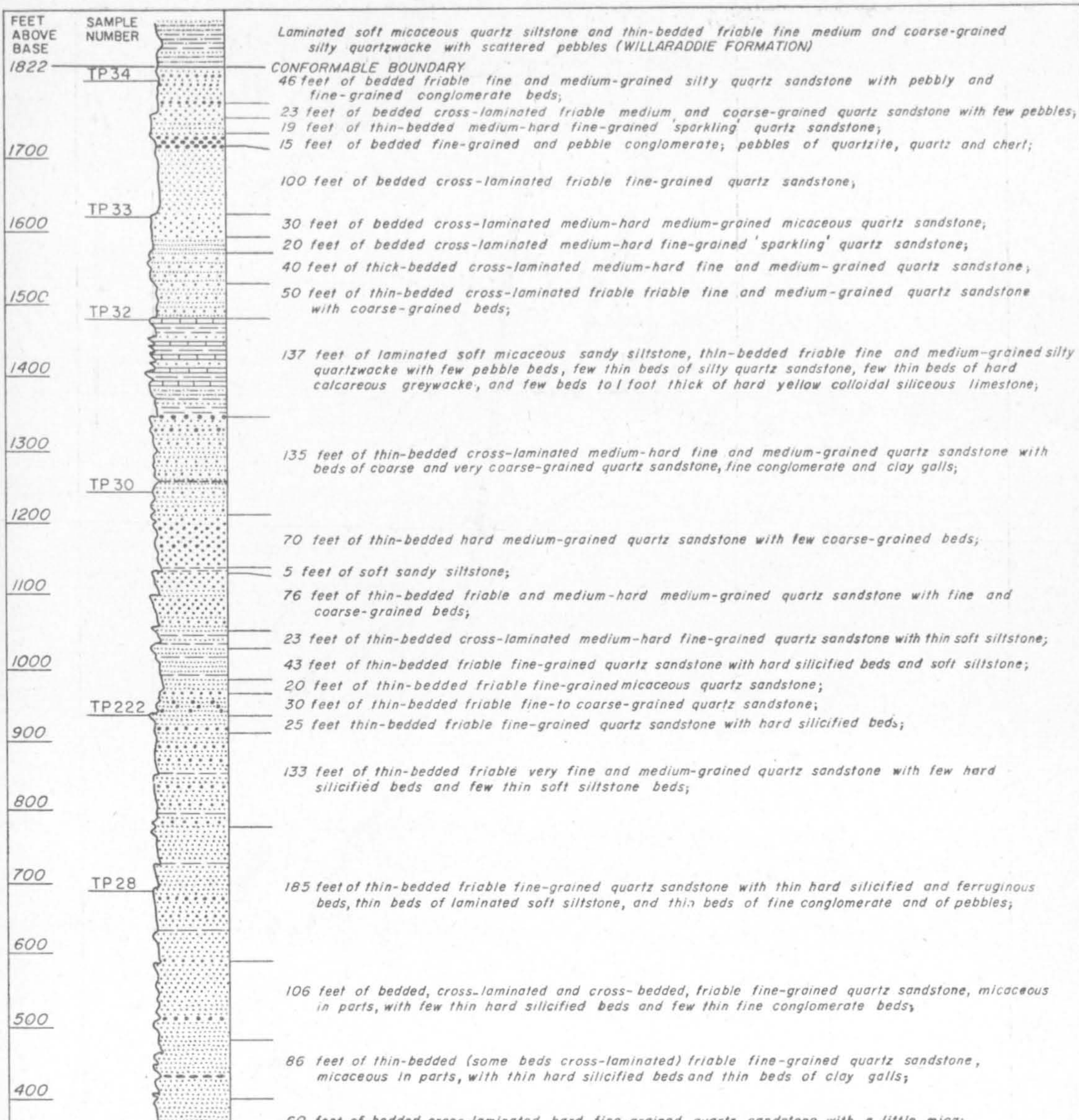



Fig.19 Type section, Munabia Sandstone

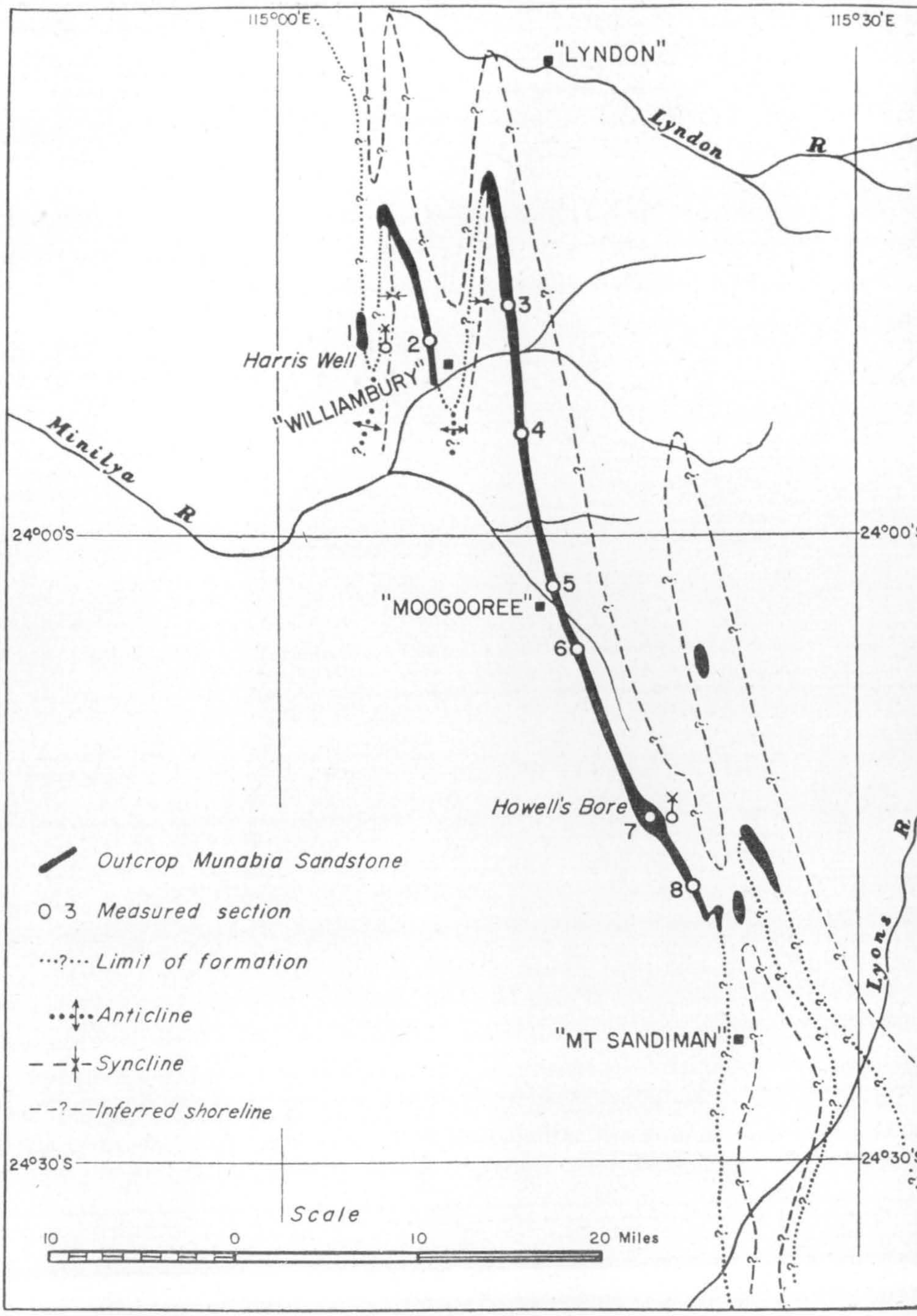



Fig 20 Munabia Sandstone: distribution of outcrops, inferred shoreline, (location of sections shown in Fig 21)

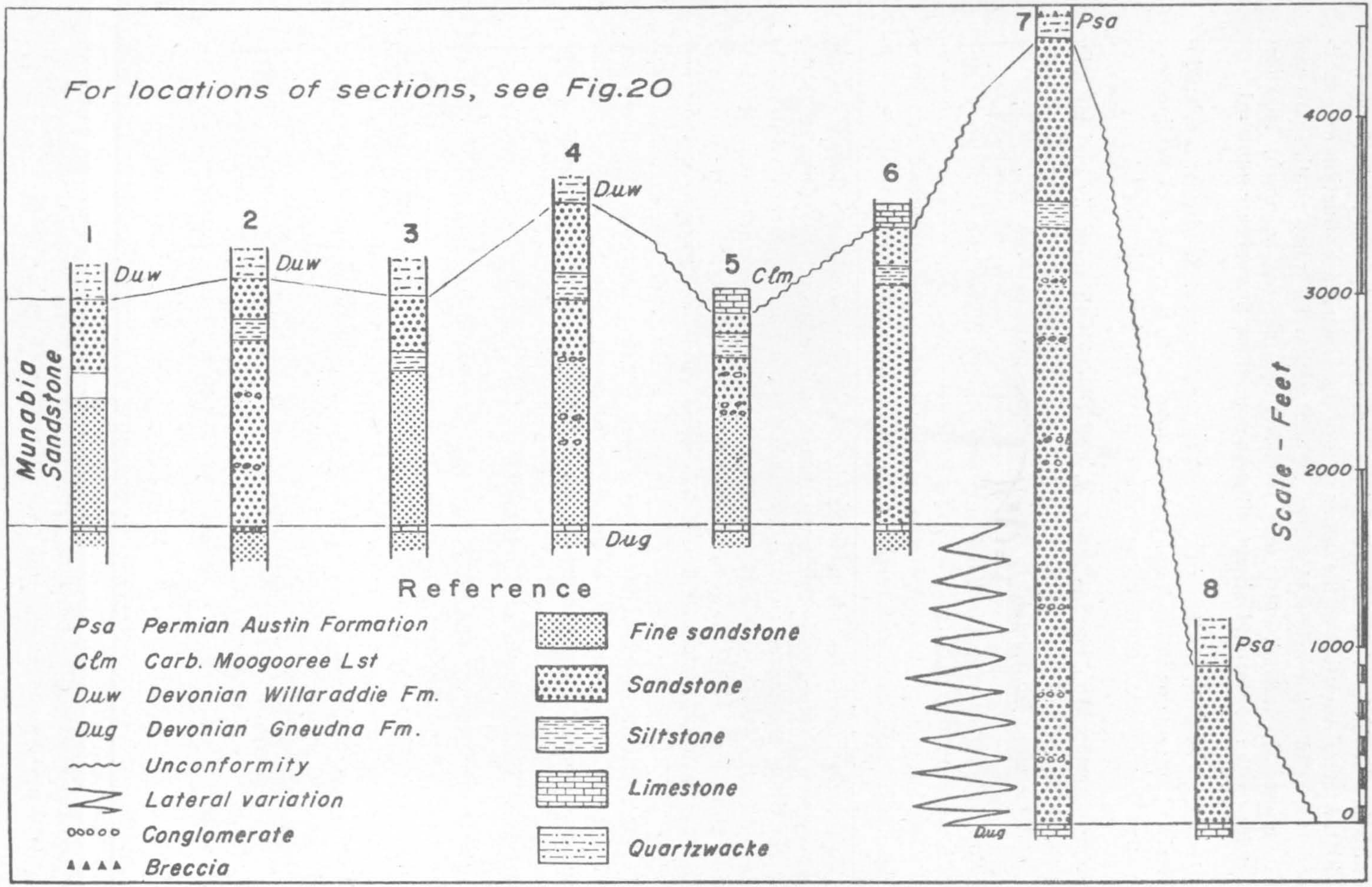



Fig. 21 Stratigraphical columns, Munabia Sandstone

the variation in thickness is controlled by the erosion of the top of the formation and by the lateral variation of the upper part of the Gneudna Formation into sandstone: the thickness reaches 4450 feet in one section 12 miles south-south-east of Moogooree Homestead, but is only 1600 feet one mile to the north, 2400 feet two miles to the south, and absent altogether another five miles southward.

*Fossils.*—The only fossils so far found in the Munabia Sandstone are lepidodendroid plant remains in the basal beds 7½ miles north-north-west of Williambury Homestead; they are poorly preserved and have not been identified.

*Age.*—As the Munabia Sandstone is gradational both vertically and laterally with the upper part of the Gneudna Formation it must be very nearly of the same age, and therefore is probably Frasnian or Famennian, or both.

*Structure.*—The Munabia Sandstone everywhere follows the structure of the Gneudna Formation, commonly with slightly lower dips. Only synclinal structures are known in outcrop, although it may be anticlinal over the subsurface extensions of the north-south basement ridges in the Williambury area.

*Palaeogeography.*—The Munabia Sandstone was deposited in shallow sea water on a very slowly subsiding bottom; the terrigenous sediment was subjected to the action of waves and currents and a clean quartz sandstone was deposited in cross-laminated beds. As there is little variation in lithology and thickness in the formation above each of the basement ridges near Williambury, the present outcrop areas must have had similar depths of water and similar distances from shore and therefore the basement ridges probably existed at that time (see Fig. 20). It is likely that the formation changes within a short distance down-dip to a much less clean lithology, either quartzwacke or siltstone or both. The thin siltstone member in the upper part of the formation suggests a temporary deepening of the sea; the change of lithology into the Willaraddie Formation most probably indicates deeper water and a more rapidly subsiding floor.

*Economic Geology.*—The Munabia Sandstone would be a very good groundwater aquifer, but as its high permeability probably does not extend very far down dip it is not likely to be a good artesian aquifer. The Harris Well, 4 miles west of Williambury, may perhaps be dug in the Munabia Sandstone. The change of width and type of channel of the large streams, including the Minilya River and its South Branch, indicates recharging of this aquifer.

Any areas, such as parts of the Wandagee Ridge, that were close to sea level at the time of deposition of the Munabia Sandstone may have similar clean sandstone which would form a favourable reservoir rock for petroleum.

*Problems.*—The Munabia Sandstone is a good reservoir bed both for water and petroleum, but its subsurface distribution is quite unknown and can only be established by drilling. As it contains plant remains at outcrop, the formation may contain a microflora of value in identifying it and its equivalents in bores. Suitable material may be available from WAPET's Quail No. 1 Bore.

*Willaraddie Formation*

The Willaraddie Formation (Condon, 1954a) consists of quartzwacke, siltstone, quartz sandstone, and conglomerate; it rests conformably on the Munabia Sandstone and is overlain disconformably by the Moogooree Limestone. The name is taken from Willaraddie Creek, which flows south-westward through Munabia

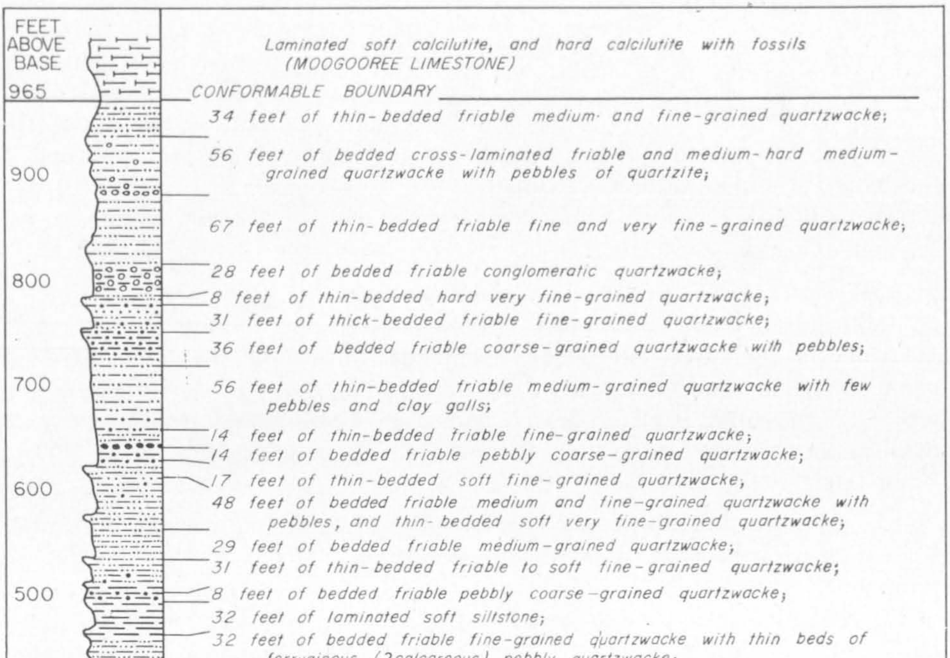



Fig. 22 Type section, Willaraddie Formation

Paddock, Williambury Station, and joins the Minilya River three miles eastward of Williambury Homestead. The formation crops out immediately west of the mouth of the creek. The type locality and type section (Fig. 18) is in Gneudna Paddock, four miles south-east of Williambury Homestead. The type section starts near the head of a west-flowing watercourse a mile and a half north-west of Gneudna Well (Condon, 1954b) (continuing from the top of the Munabia Sandstone type section) and continues along the south side of the valley for 1600 feet; as the top of the formation is not exposed along this line the traverse is transferred 1600 feet south, along a west-facing strike scarp, and the section continues westward along the south side of a drainage divide and small butte to the base of the Moogooree Limestone in a small south-draining gully on the south-west side of the butte. The type section, measured by G. A. Thomas and C. E. Prichard, is shown in Figure 22. I have made some modifications to their lithological descriptions (Condon, 1954a, p. 19).

*Boundaries.*—The base of the Willaraddie Formation is placed at the change in lithology from quartz sandstone to pebbly quartzwacke; there are beds of quartz sandstone in the lower part of the Willaraddie Formation, but no quartzwacke in the Munabia Sandstone (apart from thin beds in the siltstone member). The top of the formation is placed at the sharp change in lithology from quartzwacke to calcilutite. In the type locality, the uppermost part of the Willaraddie is ferruginous and leached. This may represent a Pre-Carboniferous weathered surface.

To the north and west of the type locality the relationships of the Willaraddie Formation with the underlying Munabia Sandstone and the overlying Moogooree Limestone remain constant. About two miles south of the type locality, the top of the formation is missing and, southward, more and more of the formation is absent; the whole formation is missing four miles south-south-east of Moogooree Homestead. The boundary with the Moogooree Limestone south of the type locality is very irregular and is probably an erosion surface with a relief of about 400 feet.

*Lithology.*—The formation consists of four main rock types—pebbly quartzwacke (about 40 percent), quartzwacke (about 20 percent), quartz sandstone (about 30 percent), and siltstone (about 10 percent).

The pebbles of the pebbly quartzwacke are round to subangular, mainly ovoid, and up to about 4 inches long, and consist of black chert, light grey chert, milky quartz, quartzite, and jasper. The quartzwacke and the matrix of the pebbly quartzwacke are uneven (mostly medium grainsize ranging from about 1 mm downwards), consisting of subangular milky and clear quartz, quartzite, quartz schist, quartz-mica schist, red jasper, black and grey chert, phyllite, muscovite and bleached biotite, little or no feldspar, and few heavy minerals (blue tourmaline and leucoxene), in a silt-clay matrix containing much angular quartz. The proportions of the constituents are very variable, but the silt-clay matrix fills all interstices and forms about 20 to 40 percent of the quartzwacke. The rocks, except where indurated by surface silicification, are quite friable.

The quartz sandstone is mainly cleaned-up quartzwacke; it consists of poorly sorted subangular grains of quartz and chert (50 to 70 percent), feldspar (0 to 10 percent), white mica (muscovite and bleached biotite) about 2 percent, and quartzite, phyllite, and mica schist (10 to about 25 percent), with a matrix, amounting to about 10 to 15 percent, of quartz silt, clay, and sericite.

The siltstone beds consist of silt-size angular quartz, feldspar, and little mica with clay and a large proportion (up to about 40 percent) of sand-size angular grains of quartz and mica, and a little chert, quartzite, and blue tourmaline.

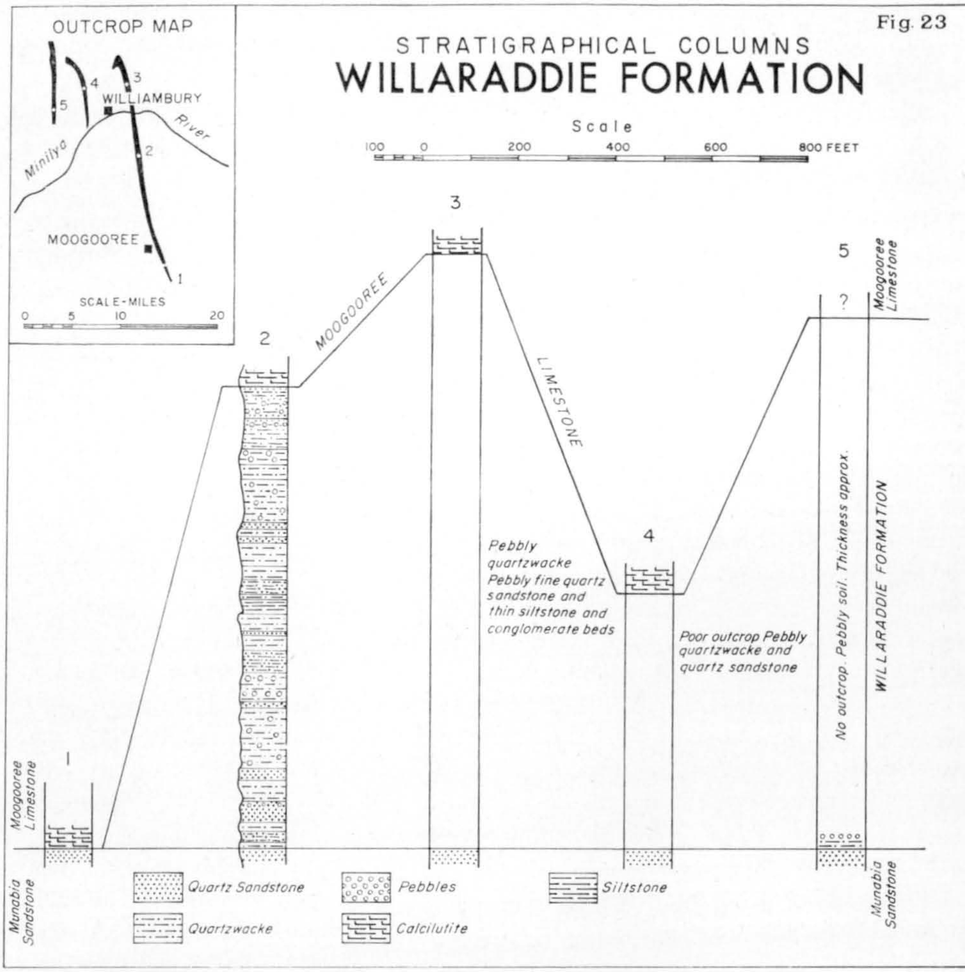
*Distribution and Thickness.*—The outcrop of the Willaraddie Formation is generally parallel to and west of the outcrop of the Munabia Sandstone, but does not extend as far south. The main outcrop belt, 27 miles long and up to 1½ miles wide, runs from 10 miles north by east of Williambury to 4 miles south-south-east of Moogooree; along this belt the thickness ranges mainly between about 950 feet (at the type locality) and about 1300 feet, with a fairly even northward divergence of about 50 feet per mile; at the north end of this belt, in the syncline, exposures are poor, but the few dips available indicate a very marked increase in thickness into the syncline: along the axis of the syncline the thickness is not less than 3000 feet and may be as much as 4000 feet. South of the type locality the outcrop narrows rapidly to pinch out 4 miles south-south-east of Moogooree.

The second main outcrop belt, 8 miles long and half a mile wide, runs from 7 miles north-west to 2½ miles south-west of Williambury. Exposure is very poor along this belt, which is recognized mainly by typical pebbles strewn over the surface between the outcrops of Moogooree Limestone and Munabia Sandstone. Only in the synclinal area are exposures good enough for dip readings; thicknesses based mainly on dips measured in the adjoining formations vary from about 1000 feet at the south end to about 500 feet in the middle part, about 850 feet towards the north end and about 1500 feet in the syncline.

The western area of outcrop is mainly covered by a thin layer of sand; however, the boundaries with the adjoining formations can be established at the south end and followed on air-photographs as trends showing through the sand. The indications are that at the south end the Willaraddie Formation is about 1000 feet ($\pm$ 200 feet) and that it thickens appreciably northward (at least the outcrop width increases from 1700 feet at the main Middalya-Williambury road to 5500 feet 4 miles north); farther north the outcrop width narrows gradually to 4500 feet at the north end of outcrop, where the Cretaceous Birdrong Formation laps over the Willaraddie Formation. This western outcrop belt is about 10 miles long.

The subsurface extent of the Willaraddie Formation and its equivalents is almost completely unknown. McWhae et al. (1958, p. 44) place the sediments between 10,700 and 14,607 feet in Rough Range No. 1 in the Devonian; the lithology and the stated possible range of the poorly preserved spiriferids (Ibid., p. 51) suggest that the sediments from 9740 to 13,540 feet are Carboniferous and the sediments from 13,540 to 14,607 feet (in descending order 300 feet of fine-grained quartzwacke, 370 feet of dark calcareous shale, and 397 feet of fine-grained quartzwacke) are the equivalent of the Willaraddie Formation.

South of the Minilya River, the main outcrop belt consists of a succession of long mesas capped by laterized Willaraddie Formation; exposures are found only in the lower slopes of the mesa scarps; north of the Minilya River this belt consists




of isolated buttes of laterized Willaraddie Formation with an undulating surface of poorly exposed sediments between. The middle outcrop belt is mainly a pebble-strewn plain with no exposures in minor watercourses. In the western outcrop belt the surface is mainly a sand plain with pebbles.

*Fossils.*—Fossils have been found in only one place in this formation: poorly preserved bryozoa and brachiopods were found about 100 feet above the base, $3\frac{1}{4}$ miles east-south-east of Williambury Homestead.

*Age.*—The poorly preserved fossils do not help in determining the age of the Willaraddie Formation; its age can be determined only by reference to the Frasnian Gneudna Formation about 1900 feet stratigraphically below it and the Lower Carboniferous Moogooree Limestone immediately above. As there is an erosional unconformity between the Willaraddie Formation and Moogooree Limestone, the Willaraddie Formation almost certainly belongs in the Devonian rather than the

Carboniferous. About 3000 feet of clastic sediment separate the established Frasnian from the top of the Willaraddie Formation, so it is most likely to be of Famennian age.

*Correlation.*—The Willaraddie Formation may be the same age as the lowermost sediments in Rough Range No. 1, although those sediments are much finer-grained and could not be referred to the same formation.

In the Fitzroy Basin, the Fairfield Formation and Bugle Gap Limestone (Guppy et al., 1958) are probably of about the same age as the Willaraddie Formation. In the Bonaparte Gulf Basin, the Burt Range Limestone may be of about the same age.

In eastern Australia, the Dotswood Beds, Hodgkinson ' Series,' Star ' Series,' and part of the Drummond ' Series ' of Queensland, the Barraba Group, Lambie Beds, and Mulga Downs Formation of New South Wales, and the Taggerty Beds of Victoria are of about the same age as the Willaraddie Formation.

*Structure.*—The Willaraddie Formation everywhere overlies the Munabia Sandstone and follows it structurally, generally with slightly lower dips. Regionally the outcropping Willaraddie Formation forms two south-plunging synclines and two west-dipping homoclines (one of which is the southward continuation of the east limb of the eastern syncline).

The very great thickening of the formation in the synclines is regarded as indicating that they are topographic basins or valleys during the deposition of the Willaraddie Formation. The excess thickness (between 2000 and 3000 feet in one syncline) indicates the minimum relief of the bottom of the formation at the end of the deposition of the formation. This relief may have been original, but as this would require bottom slopes of about 15° it is more likely to be partly original and partly structural, produced by downwarping during sedimentation.

The west flank of each of the synclines is in contact with Precambrian schist; the contact is not exposed. In the Willaraddie Formation near the contact dips are variable in direction and amount; this has been interpreted (Thomas & Prichard, 1953) as caused by fault movement, but the appearance of trends on air-photographs suggests slump folding rather than faulting: this would be consistent with a steep abutment unconformity between the Willaraddie Formation and the Precambrian schist.

Although both Munabia Sandstone and Moogooree Limestone are exposed on the anticlinal nose 3½ miles south-south-west of Williambury, there is no sign of the presence of Willaraddie Formation there. This also would be consistent with original topographic relief if the sea were very shallow over the ridge now occupied by the anticlinal nose, so that the sediments were cleaned up into the lithology of the Munabia Sandstone, removed by waves and currents, or not deposited.

*Palaeogeography.*—The sediments of the Willaraddie Formation show little evidence of the action of waves and currents: this may indicate that they were deposited in deep water or built up rapidly on a shallow bottom subsiding equally rapidly so that there was little time for the sediments to be sorted. The generally poor exposure has not provided data to indicate which is more likely.

The poor consolidation of the sediments indicates that the formation has not been subjected to large stresses either by superimposed load of sediments or by tangential, tectonic stress. This also confirms that much of the structural relief was original or pene-contemporaneous with sedimentation, and indicates that the coastline continued to be strongly indented, but was probably located farther inland than during deposition of the Munabia Sandstone, resulting in slightly deeper water over the present outcrop area.

The nature of the sediments indicates rapid erosion of a terrain mainly occupied by sedimentary rocks (sandstones, chert, quartzite) with some metamorphic rocks (phyllite and quartz-mica schist). The main difference between the provenances of the Munabia Sandstone and the Willaraddie Formation may have been higher elevation and relief during deposition of Willaraddie Formation, or merely higher rainfall and resulting stronger dissection, or perhaps a combination of both.

After the Willaraddie Formation had been laid down, the sea regressed slightly and exposed it to erosion; in one place six miles south-south-east of Moogooree, a valley was cut completely through the Willaraddie Formation and well into the Munabia Sandstone. A slight tilting of the sediments with an upward component to the south must have accompanied the regression, as the erosion of the Willaraddie is progressively greater southwards.

*Economic Geology.*—The Willaraddie Formation is an aquiclude above the Munabia Sandstone or possibly a cap rock to the Munabia Sandstone if it occurs in a structurally favourable position for oil accumulation.

It would provide good road-building material, particularly for the base course, and would be easily excavated.

### CARBONIFEROUS

The outcropping Carboniferous formations in the Carnarvon Basin comprise Moogooree Limestone, Williambury Formation, and Yindagindy Formation. They form a conformable sequence between unconformities. The Carboniferous sediments are known only from the northern half of the Carnarvon Basin (Fig. 24), but regional structure suggests that they probably extend south of the Wooramel River in the Gascoyne Basin, perhaps across the Wooramel Sill into the Byro Basin and Coolcalalaya Basin and from there into the Perth Basin (although there is no record of Carboniferous there yet).

No Upper Carboniferous sediments are known in outcrop. The Harris Sandstone has been described, on the basis of plant fossils and microfossils, as possibly Upper Carboniferous, but it is clearly part of the Permian sequence; it is a lateral variant of the marine sequence. The only sediments likely to be Upper Carboniferous are those found in WAPET's Minderoo No. 1 Well between 1270 feet and total depth (2000 feet) (Johnstone et al., 1963).

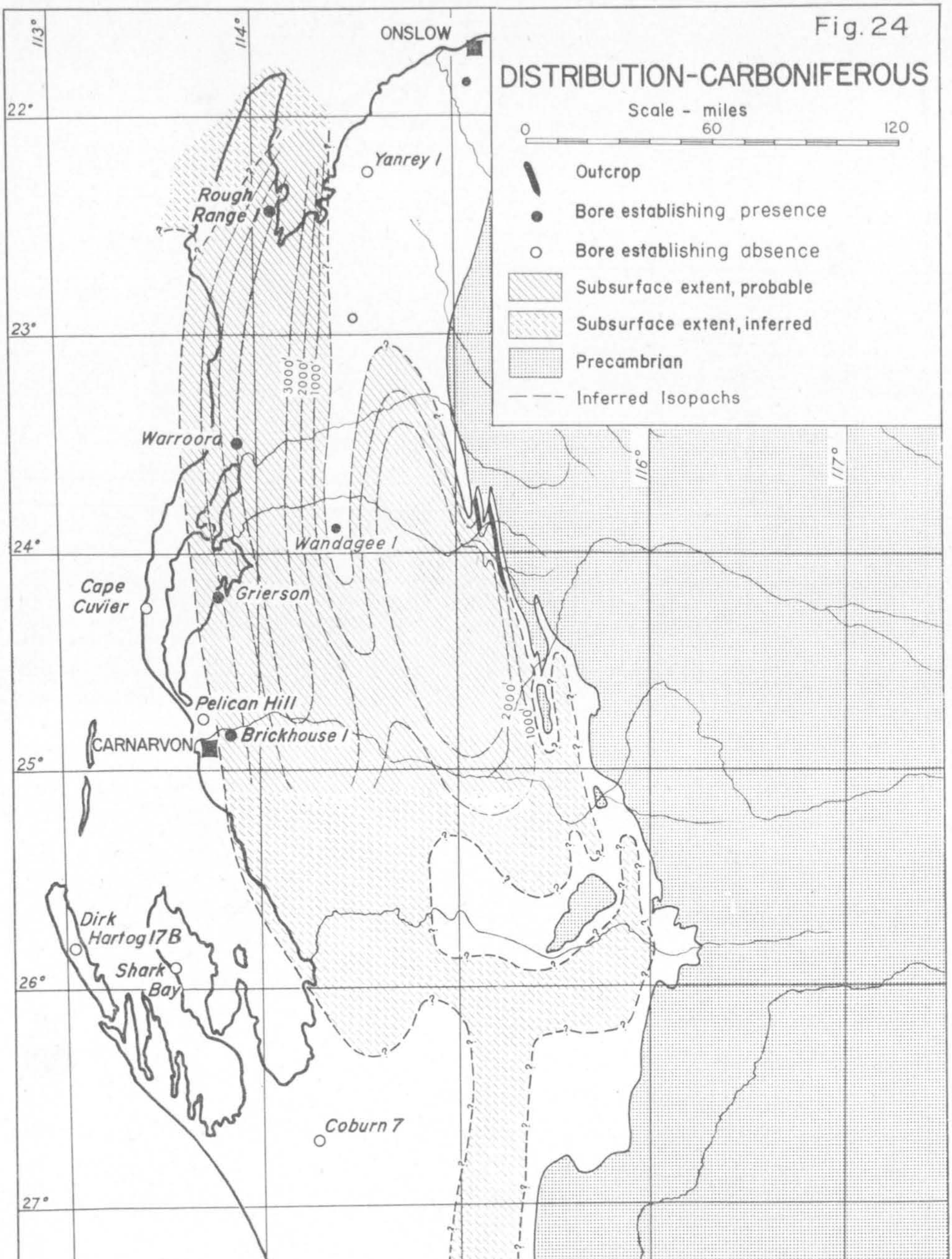


Fig. 24
DISTRIBUTION-CARBONIFEROUS
Scale - miles
0
60
120
Outcrop
Bore establishing presence
Bore establishing absence
Subsurface extent, probable
Subsurface extent, inferred
Precambrian
Inferred Isopachs
ONSLOW
Yanrey I
Rough Range I
Warroora
Wandagee I
Cape Cuvier
Grierson
Pelican Hill
CARNARVON
Brickhouse I
Dirk Hartog 17B
Shark Bay
Coburn 7
3000'
2000'
1000'
113°
114°
116°
117°
22°
23°
24°
25°
26°
27°
28°
Bureau of Mineral Resources, Geology & Geophysics
April 1961
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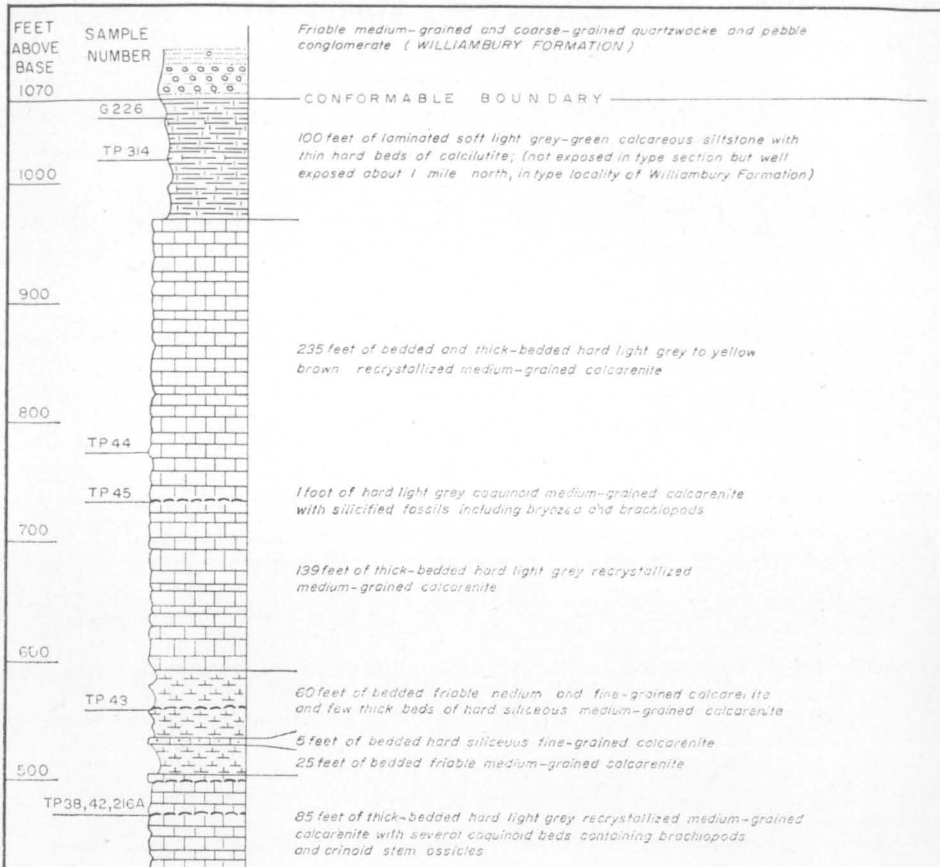



Fig. 25.—Type section, Moogooree Limestone

*Moogooree Limestone*

The Moogooree Limestone (Teichert, 1949a) was defined by Condon (1954a). Additional work requires the revision of that definition thus: the Moogooree Limestone is the formation, consisting largely of *recrystallized calcarenite* with *coquinoid* beds containing Lower Carboniferous marine fossils, resting *disconformably or unconformably* on Willaraddie Formation *or Munabia Sandstone* and overlain conformably by Williambury Formation *or unconformably by formations of the Lyons Group*. (Revision italicized.)

The name (pronounced moog′-ōō-ree) is taken from Moogooree Station. The formation crops out in a ridge to the east of the creek that flows north past Moogooree Homestead. The type section (Fig. 25) was measured by G. A. Thomas in Gneudna Paddock, Williambury Station, 3½ miles south-east of the homestead and 2½ miles north-west of Gneudna Well, at Lat. 23° 53¼′ S., Long. 115° 11¼′ E. (Fig. 18.)

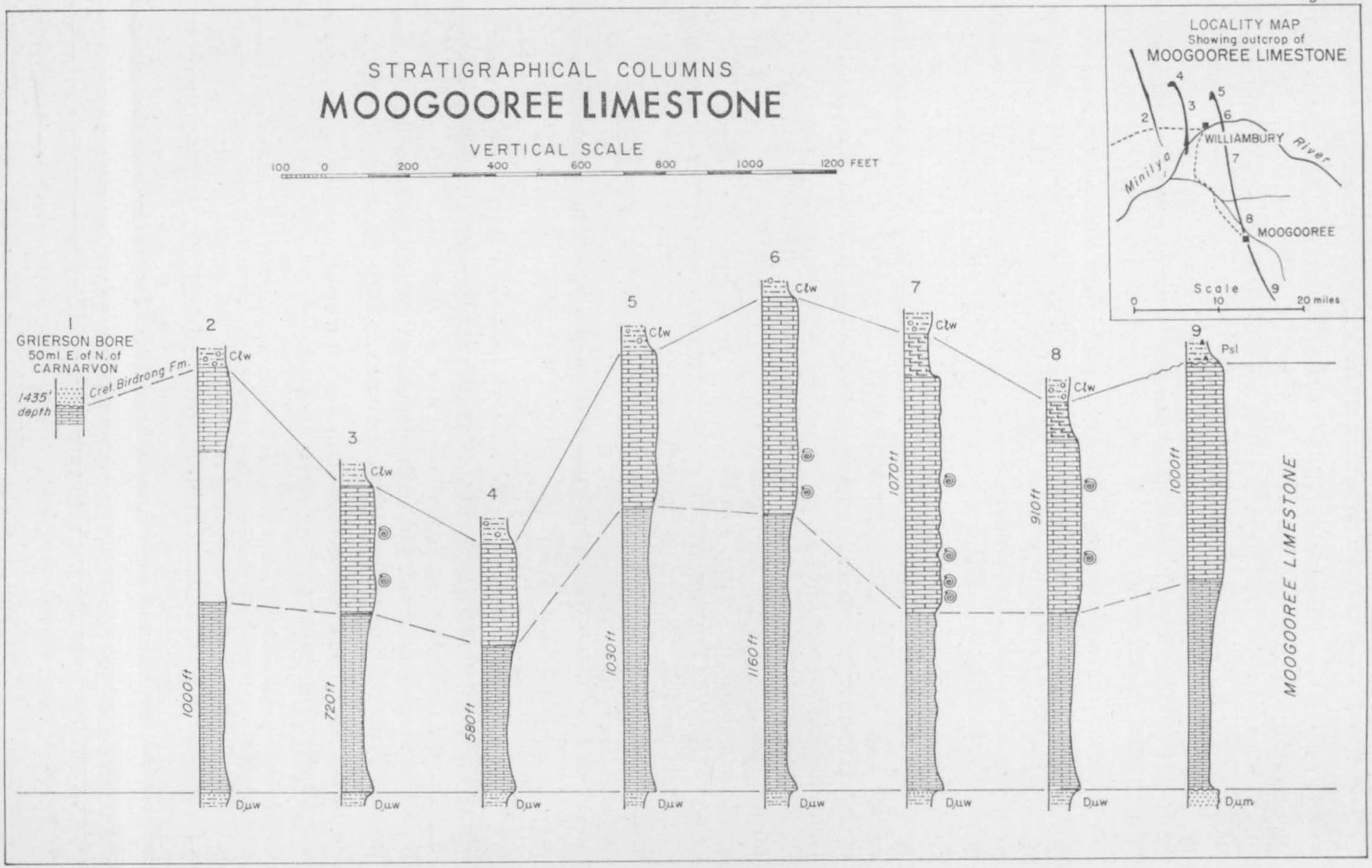
The base of the formation, which is not exposed in the type section, but is exposed west of the Willaraddie type section (at Lat. 23° 54′ 34″ S., Long. 115° 11′ 20″ E.) (Figs. 18 and 26), is taken at the change from the arenaceous to the dominantly calcareous lithology. The top also is not exposed in the type section, but is exposed at the east end of the type section of the Williambury Formation (Fig. 26, column 7). The top of the formation is revised to include all the calcareous sediments and is thus to be placed at the change from calcareous to arenaceous lithology. The type section has been re-examined and the computation of thicknesses checked; as a result the details of the type section (as shown in Condon, 1954, pp. 22, 23) have been revised.

*Lithology.*—The predominant rock type of the Moogooree Limestone is calcarenite; in the lower part of the formation it is mainly friable, but in the upper part it is predominantly recrystallized, siliceous, and hard, and contains beds of dolomite. The lower part contains about 35 percent of beds of terrigenous sediments—fine-grained to medium-grained quartzwacke commonly with a proportion of fragmental carbonate, and calcareous siltstone. The upper part contains about 25 percent friable calcarenite and, in the uppermost 100 feet, soft calcilutite. Fossils occur as beds of coquinite and scattered sparsely through the calcarenite.

In the lower part the bedding is thin to laminated; in the upper part it is generally thick (6 inches to 2 feet) and undulate.

*Distribution and Thickness.*—The Moogooree Limestone generally crops out to the west of and roughly parallel to the Devonian formations. In the main outcrop belt, running for 28 miles from 4½ miles north by east of Williambury to 9½ miles south-south-east of Moogooree, only the upper part of the formation is generally exposed, and forms a rounded ridge; the lower part forms a plain in which exposures are rare. Thickness ranges between 820 and 1260 feet along most of this belt; at the south end the formation pinches out by erosion below the Permian; at the north end, in the syncline, the lower boundary is very poorly exposed but the thickness is about 1400 feet. In the middle belt, running for

Fig. 26


STRATIGRAPHICAL COLUMNS
MOOGOOREE LIMESTONE
VERTICAL SCALE
100 0 200 400 600 800 1000 1200 FEET
LOCALITY MAP
Showing outcrop of
MOOGOOREE LIMESTONE
WILLIAMBURY
MOOGOOREE
Minilya
River
Scale
0 10 20 miles
1
GRIERSON BORE
50 ml. E. of N. of
CARNARVON
1435' depth
Cret. Birdrong Fm.
Clw
Dµw
Dµm
Psl
1000 ft
720 ft
580 ft
1030 ft
1160 ft
1070 ft
910 ft
1000 ft
MOOGOOREE LIMESTONE

$9\frac{1}{2}$ miles from $6\frac{1}{2}$ miles north-west to $3\frac{1}{2}$ miles south-west of Williambury, the formation is generally poorly exposed in a low ridge. The thickness increases generally from about 500 feet in the syncline to about 820 feet near the Minilya River. The western belt is very poorly exposed and dips can be measured in only a few places; the boundaries can be placed quite accurately in a few places and extended by means of trends showing through the sand in air-photographs. The belt is about 12 miles long; the outcrop width increases slowly northward. Two miles north of the Middalya-Williambury road, where dips were measured, the thickness is about 1000 feet.

Few subsurface indications of the Moogooree Limestone and its equivalents are known. In Rough Range Bore No. 1 the dark grey limestone, argillaceous limestone, and calcilutite between 12,280 and 13,540 feet may be equivalent to the Moogooree Limestone. McWhae et al. (1958) include this in the Devonian but state that the fossil evidence does not preclude Lower Carboniferous. The unfossiliferous siliceous dolomite beneath the Cretaceous in the Grierson Bores (West Australian Petroleum Co. Ltd) and in the Brickhouse Bore No. 1 are likely to be equivalents of the Moogooree Limestone because of their regional position relative to the established Devonian of Cape Cuvier Bore and Pelican Hill Bore. McWhae et al. (1958) consider the Grierson pre-Cretaceous sediments Devonian and the Brickhouse pre-Cretaceous Silurian. The map showing the possible extent of the Carboniferous in the Carnarvon Basin (Fig. 24) is based very largely on the assumption that the sediments in the above three bores are Carboniferous.

*Fossils*.—Fossils have now been found throughout the Moogooree Limestone; at least twelve separate fossiliferous beds are known apart from scattered fossil occurrences. Most of the fossiliferous beds yield many specimens but few species. In the lower part of the formation the fossils (pelecypods, gastropods, and brachiopods) are preserved mainly as impressions; in the upper part the fossils (brachiopods and bryozoa) are replaced intimately by silica and are easily separated out by dissolving the limestone in dilute acid.

Only the spiriferids have been described; Glenister (1956) described three new species: *Spirifer fluctuosus*, *Punctospirifer plicatosulcatus*, and *Syringothyris spissus*. Thomas (in McWhae et al., 1958) revised the faunal list of Teichert (in Condon, 1954a, p. 25); in addition to the spiriferids, he includes the coral *Syringopora* and brachiopods *Rhipidomella*, *Linoproductus*, *Schellwienella*, *Composita*, *Cleiothyridina*, *Camarotoechia*, and cf. *Eomartiniopsis*. J. M. Dickins (personal communication) has identified Parallellodontidae gen. (cf. *Leptodesma*) sp. nov.; this form appears to be the same species as that occurring in the Gneudna Formation, in the Pelican Hill Bore at 2293 to 2307 feet and in the Cockatoo Sandstone of the Bonaparte Gulf Basin.

*Age*.—From the known ranges of the determined genera, there is no doubt that the Moogooree Limestone is of Lower Carboniferous age. Thomas (1962) considers that a Tournaisian age is indicated.

*Correlation.*—No definite correlation can be established with subsurface sediments in the Carnarvon Basin, but, on the basis of stratigraphic position and lithology, equivalents of the Moogooree Limestone are considered to be present in Rough Range Bore No. 1, Grierson Bores, and Brickhouse Bore No. 1.

The Moogooree Limestone almost certainly can be correlated with the Laurel Formation of the Fitzroy Basin and with the Septimus Limestone of the Bonaparte Gulf Basin (Thomas, 1962).

In Eastern Australia, the lower part of the Rockhampton 'Series' in Queensland, the lower part of the Burindi Group of New South Wales, and the Grampians Beds and Mansfield/Mount Wellington Beds of Victoria may be correlated with the Moogooree Limestone.

*Structure.*—In the outcrop area, the Moogooree Limestone is generally structurally conformable with the underlying Devonian sediments, and like them forms two south-plunging asymmetrical synclines and two west-dipping homoclines. An anticlinal nose is developed between the two synclines. Along the eastern homocline, many structural complications are produced by the irregular erosion surface on which the formation was deposited.

The Moogooree Limestone does not show very great thickening in the synclines; this indicates that, during the deposition of the Moogooree Limestone, the bottom had but little major relief.

*Palaeogeography.*—The natures of the sediments and of the bedding in the Moogooree Limestone indicate a shallow marine environment of deposition with abundant lime but little clastic terrigenous material. The thin-bedded lower part was deposited in somewhat deeper water than the undulate-bedded upper part: almost certainly indicating a quite stable bottom, with the deposition of sediments causing shallowing of the sea.

The deposition of the Moogooree Limestone followed a minor transgression of the sea over the land resulting from a small epeirogenic subsidence or an eustatic rise of sea level. The latter cause is suggested by the presence of lowermost Carboniferous sediments scattered around the Australian continental margin. As the continental area probably was not tilted, the reduction in the amount of terrigenous material entering the sea probably resulted from a marked reduction in rainfall.

The coastline was much less indented than formerly, although there were small estuaries in the recently dissected valleys in the Devonian sediments. The littoral was probably located in the area of present outcrop of Devonian sediments; it is unlikely that the transgression reached onto the Precambrian rocks. The Ajana-Wandagee Ridge probably formed a submarine bank on which shell banks or organic reefs may have developed (the presence of *Syringopora* in the outcrop area shows that reef development was possible). The deeper parts of the minor basins probably received calcareous and siliceous organic muds that would now be dark carbonaceous or bituminous calcareous shale, calcilutite, or chert.

The present western limit of the Carboniferous sediments (Fig. 24) was determined by the pre-Cretaceous erosion of the tilted western side of the Gascoyne Basin; there is no evidence of a shoreline in this area during the Carboniferous.

The whole area of Carboniferous sedimentation in the Carnarvon Basin was most probably part of the continental shelf.

*Economic Geology.*—The Moogooree Limestone is not exploited at present.

The upper part of the formation is eminently suitable for aggregate for road building and concrete. Parts of it would be suitable for lime-burning, although the presence of silica would make much of it useless for this purpose. Parts of the lower part of the formation may be suitable for manufacture of Portland cement, but no confirmatory tests have been carried out.

Only one water well, Ram Paddock Well, Moogooree Station, produces water from the Moogooree Limestone, but it should be capable of much greater exploitation for ground water.

The western equivalents of the Moogooree Limestone (e.g. in Rough Range Bore No. 1) are source rocks for petroleum, and it is possible that limestone or dolomite with joint or solution porosity may be developed in areas of continuing structural elevation such as the Wandagee Ridge, the Weedarra Ridge, and the un-named ridge about 12 miles west of the Bullara Ridge (Fig. 2). As the Moogooree Limestone was followed by terrigenous sediments it would have been protected by them from erosion during the Upper Carboniferous regression.

### *Williambury Formation*

The Williambury Formation was named by Teichert (1949), and defined by Condon (1954a) as the formation consisting of pebbly greywacke, siltstone, and conglomerate, conformable between the Moogooree Limestone below and the Yindagindy Formation above. The name is taken from Williambury Station, about 120 miles north-east of Carnarvon. The formation crops out mainly on Williambury Station. The type section (Figs. 27, 28) is in Gneudna Paddock, 2¼ miles south-east of Williambury Homestead, at Lat. 23° 52½′ S., Long. 115° 10¾′ E., along the upper slopes of a narrow mesa. The lower boundary is well exposed, but the upper boundary is poorly exposed in the plain south of the west end of the mesa. That this boundary is not seriously in error is confirmed by comparing the positions of the exposed limestone beds here with positions of the limestone beds in the type section of the Yindagindy Formation.

The base of the Williambury Formation is revised upwards from that proposed by Condon (1954a, p. 26) to the marked change in lithology from the predominantly calcareous sediments to the pebbly quartzwacke and conglomerate; the original boundary is not satisfactory, particularly for subsurface correlation. The top of the formation is placed at the base of the lowermost thin hard sandy limestone bed of the Yindagindy Formation.

Almost everywhere the Williambury Formation is conformable between the Moogooree Limestone and the Yindagindy Formation. Only at the pre-Permian unconformity, at the south end of the outcrop belts, is it overlain unconformably by formations of the Lyons Group, and at the pre-Cretaceous unconformity at the north end of the western belt of outcrop it is overlain unconformably by the Cretaceous Birdrong Formation.

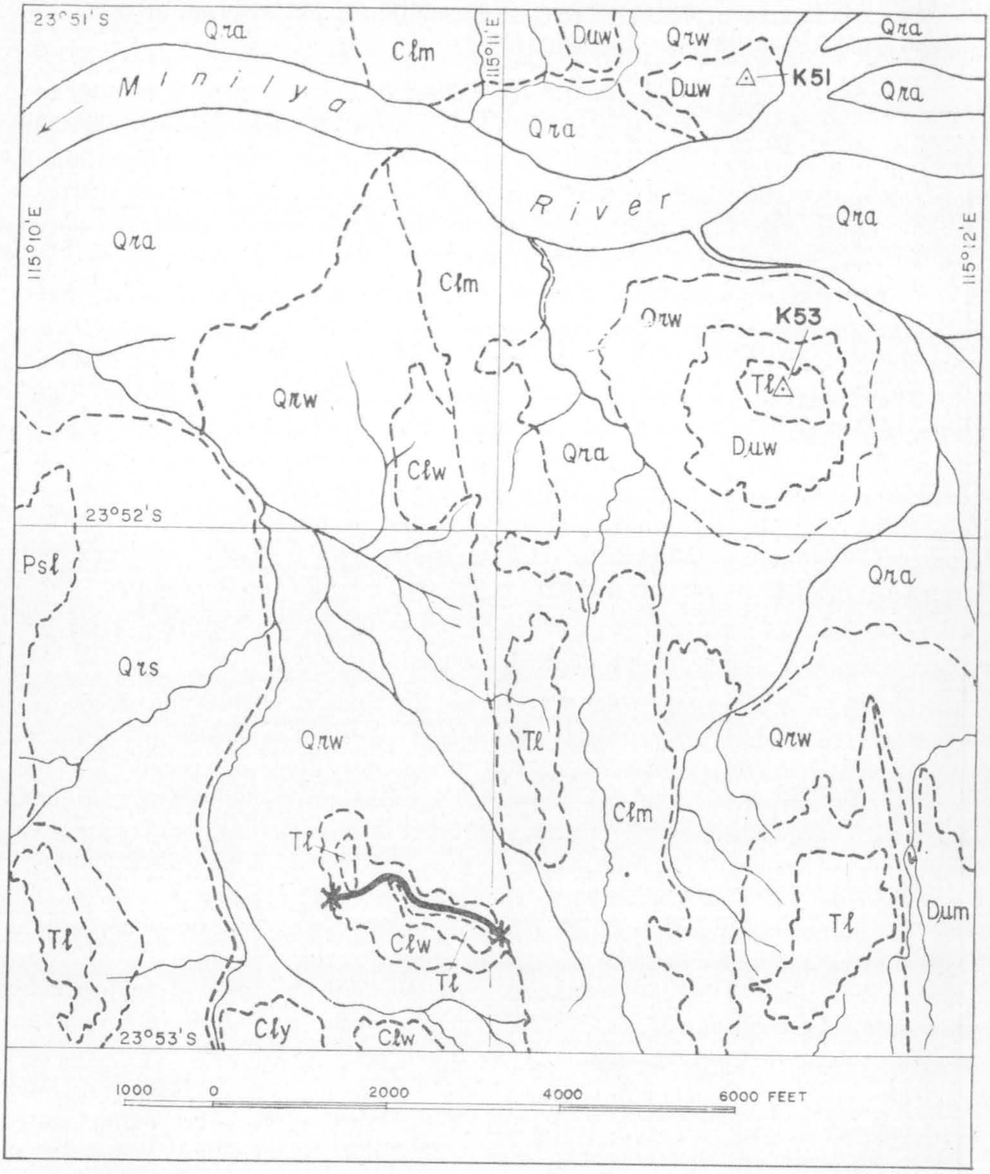



Fig. 27. Type locality, Williambury Formation

Qra - Alluvium
Qrs - Sand
Qrw - Wash
Tl - Laterite
Psl - Lyons Group
Cly - Yindagindy Formation
Clw - Williambury Formation
Clm - Moogooree Limestone
Duw - Willaraddie Formation
Dum - Munabia Sandstone

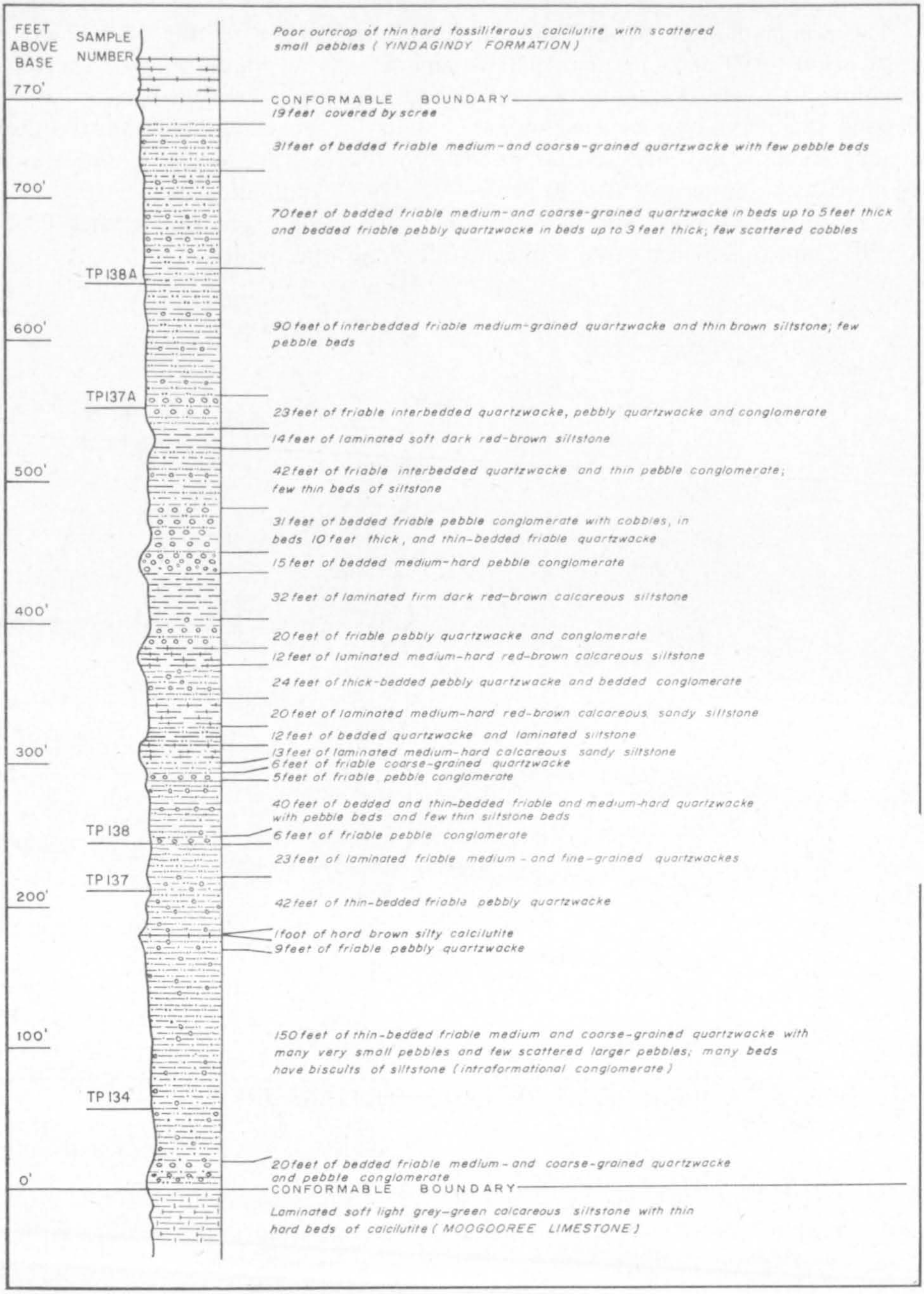



Fig. 28 Type section, Williambury Formation

*Lithology.*—The Williambury Formation is made up of about 55 percent quartzwacke, 30 percent conglomerate and pebbly quartzwacke, and 15 percent siltstone.

The dominant quartzwacke and the arenaceous matrix of the conglomerate consist of 30 to 60 percent subangular to angular quartz grains, 20 to 40 percent subangular to rounded fragments of black chert, up to 10 percent subangular to subround fragments of quartzite, minor amounts of mica (muscovite and biotite) including some large flakes, red jasper, blue tourmaline, and feldspar, and a silt-clay matrix amounting to 20 to 30 percent of clay (? kaolinitic) and quartz. The grainsize sorting is poor and porosity low; the median grainsize ranges from about 0.1 mm to 2.0 mm; the sediments are very little indurated.

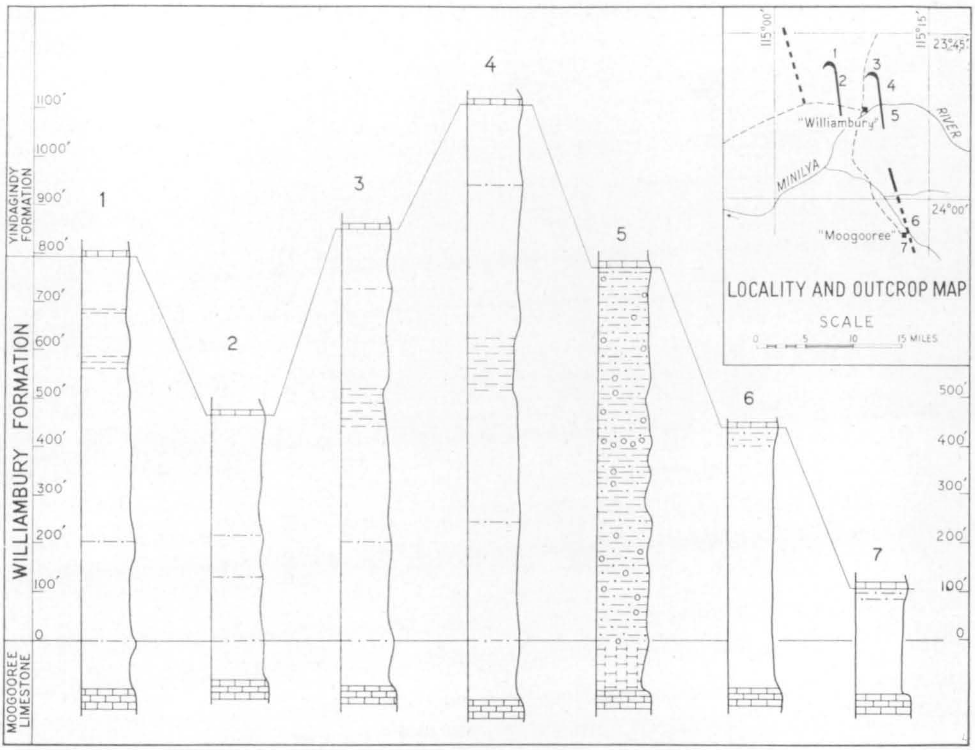



Fig. 29. STRATIGRAPHICAL COLUMNS, WILLIAMBURY FORMATION

The pebbles of the conglomerate and pebbly quartzwacke are mainly black chert and white quartz with few quartzite, phyllite, and red jasper pebbles; they are subround to round and mainly ovoid; a few are subspherical. They are estimated to make up about 30 to 50 percent of the conglomerate beds and from 10 to 30 percent of the pebbly quartzwacke beds, and they occur as scattered pebbles in some of the quartzwacke. They range in size from about 9 inches downwards; the most abundant size range appears to be about ¾ inch to 2 inches.

The siltstone is dark, red-brown, laminated, and calcareous, ranging from sets up to 32 feet thick down to thin partings between the arenaceous beds. The grain-size is mainly between 0.02 and 0.06 mm, but there is commonly some clay and some sand grains; mica is present on some bedding planes.

The whole formation is cross-bedded on a very large scale: the sets are up to 50 feet thick. The siltstone forms mainly the bottomsets, the quartzwacke and conglomerate mainly foresets. The foresets face both down the dip and up it, and some, probably, are oblique.

Although outcrop is poor along the western outcrop belts there appear from the pebbles strewn over the surface to be fewer and smaller pebbles in these areas than in the eastern belt.

It may be expected that the formation maintains its lithological character for only a short distance into the basin from the outcrop; it is likely to grade into an interbedded quartzwacke-siltstone formation, and from that it probably grades into a calcareous siltstone or shale, such as that found in Rough Range Bore No. 1 between 10,705 and 12,280 feet.

*Distribution and Thickness.*—The Williambury Formation crops out parallel to and west of the Moogooree Limestone. The main (eastern) outcrop belt runs for 13½ miles from 4 miles slightly east of north of Williambury to 4½ miles north of Moogooree. It is interrupted in several places towards its southern end by overlap of the Lyons Group. The middle outcrop belt is 9 miles long, from 6½ miles north-west to 4 miles south-west of Williambury. The western outcrop belt is very poorly exposed, but can be traced as trends showing through thin sand for 9½ miles north-north-west from the Middalya/Williambury Road 6½ miles west of Williambury.

Because of the poor exposure of the formation generally, reliable thickness measurements are few; the following thicknesses are mainly computed from outcrop width scaled from air-photographs and the best available dip measurements on the adjoining formations. Errors of 10 percent are quite likely. In the eastern outcrop belt thickness ranges from 1110 feet north-east of Williambury to 850 feet in the syncline and to 400 feet north of Moogooree. In the middle outcrop belt the thickness decreases southward from 850 feet in the syncline to 450 feet at the south end. There is very little variation in outcrop width in the western belt, where the formation is about 600 feet thick.

The generally greater thicknesses in the syncline indicate relief of differential subsidence in these areas during deposition of the Williambury Formation. The unusual thickness north-east of Williambury may indicate a delta lobe at a river mouth.

The Williambury Formation is well exposed only in the scarps of mesas, where it is protected by the laterite crust; elsewhere the formation forms a pebble-strewn plain that appears moderately dark on air-photographs with commonly very little sign of bedding trends. It supports only a very sparse vegetation.

*Fossils.*—No fossils have been found in the Williambury Formation. In the possibly equivalent sediments in Warroora Bore No. 1, Balme found spores of probable Carboniferous age (McWhae et al., 1958).

*Age.*—The age of the Williambury Formation must be determined by reference to the conformable adjoining formations. The Moogooree Limestone is Lower Carboniferous (probably Tournaisian) and the fossiliferous Yindagindy Formation is probably also Lower Carboniferous. Although the general age is thus fairly certain, the doubt about the precise age of the Yindagindy Formation makes it impossible to date the Williambury Formation precisely.

*Correlation.*—For the present the Williambury Formation must be joined with the Moogooree Limestone for purposes of correlation. The only bores in the Carnarvon Basin with sediments possibly equivalent to the Williambury Formation are Rough Range No. 1 (10,705 to 12,280 feet) and Warroora No. 1 (4951 to 5992 feet—McWhae et al., 1958).

*Structure.*—The Williambury Formation closely follows the Moogooree Limestone in structure. The main difference is the thickening of the Williambury Formation in the synclines, implying the development of structural relief before or during deposition.

*Palaeogeography.*—The Williambury Formation was deposited in a deltaic environment, with very large amounts of terrigenous sediments forming cross-bedded delta sheets up to 50 feet thick. At least in the area of outcrop, the bottom was practically horizontal as successive delta sheets foreset in different, and sometimes opposite, directions. The deposition of this thick delta deposit, the topsets of which were near sea level, implies either a rising sea level or a subsiding bottom. A rising sea level would tend to move the delta landwards; the fact that the deltaic material is built up to thicknesses of 400 to 800 feet suggests stability of sea level and subsiding bottom. The greater thickness in the syncline suggests that these areas subsided faster than elsewhere.

By the nature of the deposits the coastline must have been very close to the present outcrop area and may even have been basinwards of it.

The instability of the area of deposition may have had a counterpart in a rise of the hinterland; certainly a heavy rainfall produced the large run-off required to transport the large amount of terrigenous sediment. The large amount of pebble material would have been transported only a moderate distance in fairly swift streams. The material was derived mainly from sedimentary rocks, probably Precambrian; the valleys had not been cut into the crystalline Precambrian rocks

*Economic Geology.*—The Williambury Formation and its likely lateral equivalents are aquicludes that provide impervious cover to the permeable Moogooree Limestone; they would probably be suitable as cap rocks to a petroleum reservoir in the Moogooree Limestone or its equivalents.

It would provide good road-building material, for base courses especially, and would be easily excavated by earth-moving equipment.

### *Yindagindy Formation*

The Yindagindy Formation, named by Teichert (1950), was defined by Condon (1954a) as ' the formation of coarse to medium-grained greywacke with intercalated thin hard oolitic limestone beds, conformably overlying the Williambury Formation

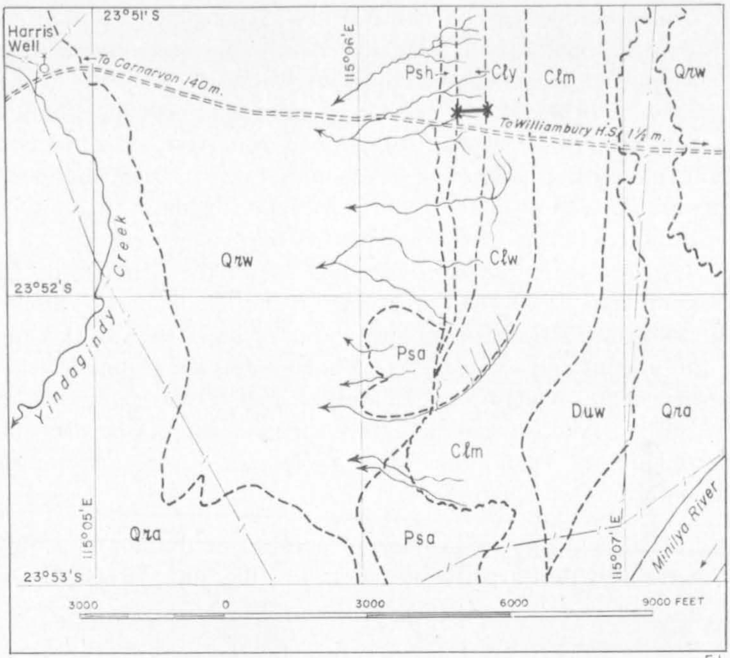



Fig. 30. Type locality— Yindagindy Formation

| | |
|---|---|
| Qrw - Wash | Cly - Yindagindy Formation |
| Qra - Alluvium | Clw - Williambury Formation |
| Psa - Austin Formation | Clm - Moogooree Limestone |
| Psh - Harris Sandstone | Duw - Willaraddie Formation |

and disconformably underlying the Harris Sandstone.' This definition should be revised slightly by the addition of ' or unconformably underlying the Lyons Group.'

The name (pronounced yin′-da̱-gin′-dē) is taken from Yindagindy Creek, the local name of the creek flowing south into the Minilya River four miles south-west of Williambury Homestead. The creek crosses the north end of the outcrop belt that includes the type locality. The type locality (Fig. 30) is immediately north of the Williambury-Middalya road, 2½ miles west of Williambury Homestead at Lat. 23° 51′ S., Long. 115° 6½′ E. The type section (Fig. 31) runs from near the top of a gentle western slope, along a shallow small watercourse to the foot of the east-facing scarp of a small hill of Harris Sandstone; the section is not well exposed, but rock in place can be found in most places within a foot of the surface. Many of the hard limestone beds are exposed, and parts of the intervening sediments.

The base of the Yindagindy Formation is taken at the bottom of the lowermost hard limestone bed above the pebbly quartzwacke without limestone. The top is ferruginous and above it the rock is clean quartz sandstone or pebbly quartzwacke, neither of which is ferruginous.

*Relationships.*—Everywhere in the outcrop area, the Yindagindy Formation rests conformably on the Williambury Formation. In the type locality there is no obvious structural discordance between the Yindagindy Formation and the Harris Sandstone, although the sharp change in lithology from coarse quartzwacke, strongly ferruginous, to clean quartz sandstone was early taken to indicate a disconformity (Condon, 1954a, p. 30), and later work confirmed this: only two miles south of the type locality the base of the Lyons Group rests on Moogooree Limestone, the Williambury Formation and Yindagindy Formation having been removed by erosion before deposition of the Lyons Group sediments. In the outcrop belt between the Minilya River and its South Branch there is a break in outcrop where the Austin Greywacke of the Lyons Group rests on the Moogooree Limestone. The Lyons Group rests on an uneven surface of the Yindagindy Formation north and south of Moogooree Homestead, and about 4½ miles slightly east of south of Moogooree the unconformity crosses the Yindagindy Formation, which does not crop out farther south. Outcrop in the western belt is very poor, but trend-lines showing through the sand indicate a slightly irregular contact between the Yindagindy Formation and the Austin Greywacke along most of the outcrop and a strong erosional unconformity at the south end.

*Lithology.*—The Yindagindy Formation consists of dominant pebbly quartzwacke and intercalated thin hard limestone beds; the quartzwacke is similar to

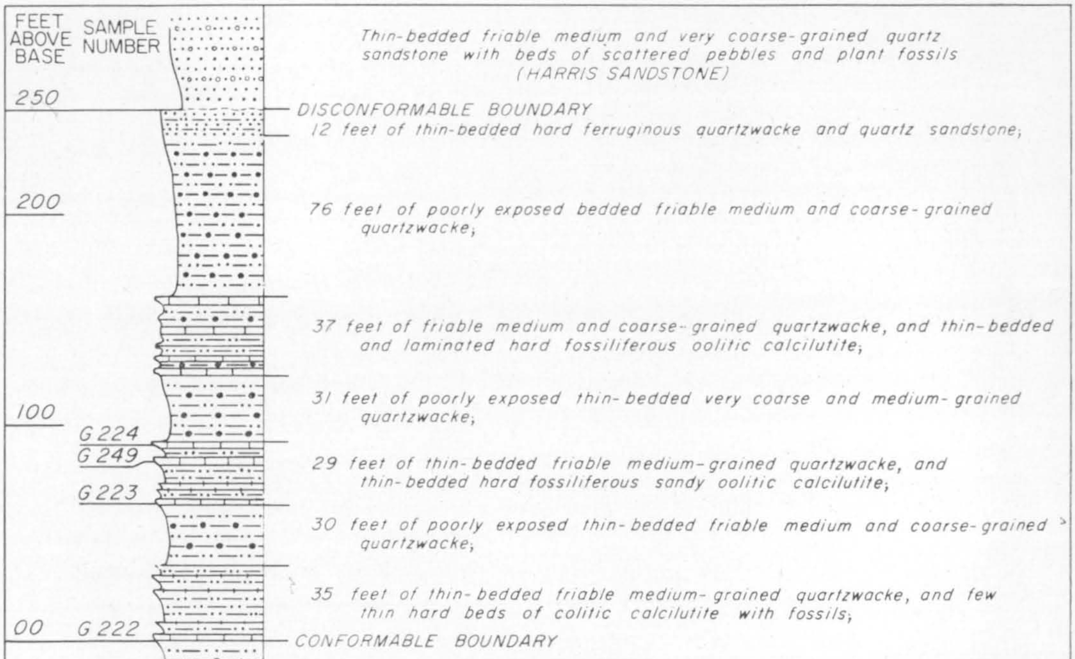



Fig. 31. Type section, Yindagindy Formation

that of the Williambury Formation but contains fewer and smaller pebbles (of the same rock types), more feldspar and mica, and in the upper part a small amount of garnet.

Most of the limestone beds consist of hard light bluish grey oolitic calcilutite with quartz sand up to about 15 percent; some of the beds are not oolitic, some are not sandy, and a few contain small pebbles of quartzite and chert. Most of the limestone beds contain marine fossils; some of them are crowded with small brachiopod valves which do not weather out.

In some areas, e.g. four miles south-south-west of Williambury and from $1\frac{3}{4}$ miles north to $4\frac{1}{2}$ miles a little east of south of Moogooree, the limestone beds are much more prominent than in the type locality: in a well-exposed section $1\frac{3}{4}$ miles north of Moogooree the limestone forms 65 percent of the formation.

*Distribution and Thickness.*—Like the other Carboniferous formations, the Yindagindy Formation crops out in three belts (Fig. 32). The eastern belt is broken into two main parts by the unconformable overlap of sediments of the Lyons Group; it extends for two miles south from two miles east-south-east of Williambury, for two miles south from six miles north of Moogooree and then for $6\frac{1}{2}$ miles slightly east of south from $1\frac{3}{4}$ miles north of Moogooree. Moogooree Homestead is built on an outcrop of Yindagindy Formation.

The middle outcrop belt extends southward for $8\frac{1}{2}$ miles from $5\frac{3}{4}$ miles north-west to $2\frac{1}{4}$ miles west of south of Williambury; this is interrupted near the south end by overlapping sediments of the Lyons Group.

The western belt is covered by a thin veneer of sand, but trend-lines show through the sand and fragments of limestone on the surface establish the identity of the formation. This belt extends north-north-west for $9\frac{1}{2}$ miles from 500 yards north of the Middalya-Williambury road, 7 miles west of Williambury.

In the eastern belt thicknesses of the Yindagindy Formation are very variable because of its erosion before the deposition of the Lyons Group. Maximum thicknesses in the several outcrop areas from north to south of the eastern belt are 300 feet, 270 feet, 95 feet ($1\frac{1}{2}$ miles north of Moogooree), and 200 feet near the southern end. In the middle belt the thickness is about 250 feet in the syncline, fairly uniformly about 270 feet along most of the outcrop, and about 380 feet at the south end (on the anticlinal nose where the formation is dominantly of limestone). In the western belt the outcrop width is fairly uniform and indicates a thickness of about 300 feet ($\pm$ 50 feet).

*Fossils.*—Although many of the limestone beds are crowded with fossils, good specimens are hard to obtain as they do not weather out and are not easy to extract from the rock; partly because of this the fauna has not been examined in detail by palaeontologists. In the field, the following fossils have been seen: small ?rhynchonellid brachiopods (very abundant), athyrid and spiriferid brachiopods (common in some beds), crinoid stem ossicles and brachials (abundant in some beds), small gastropods, a single nautiloid, and ostracods.

*Age.*—As the fossil species have not been determined they are not available to help in determining the age of the Yindagindy Formation. They are quite

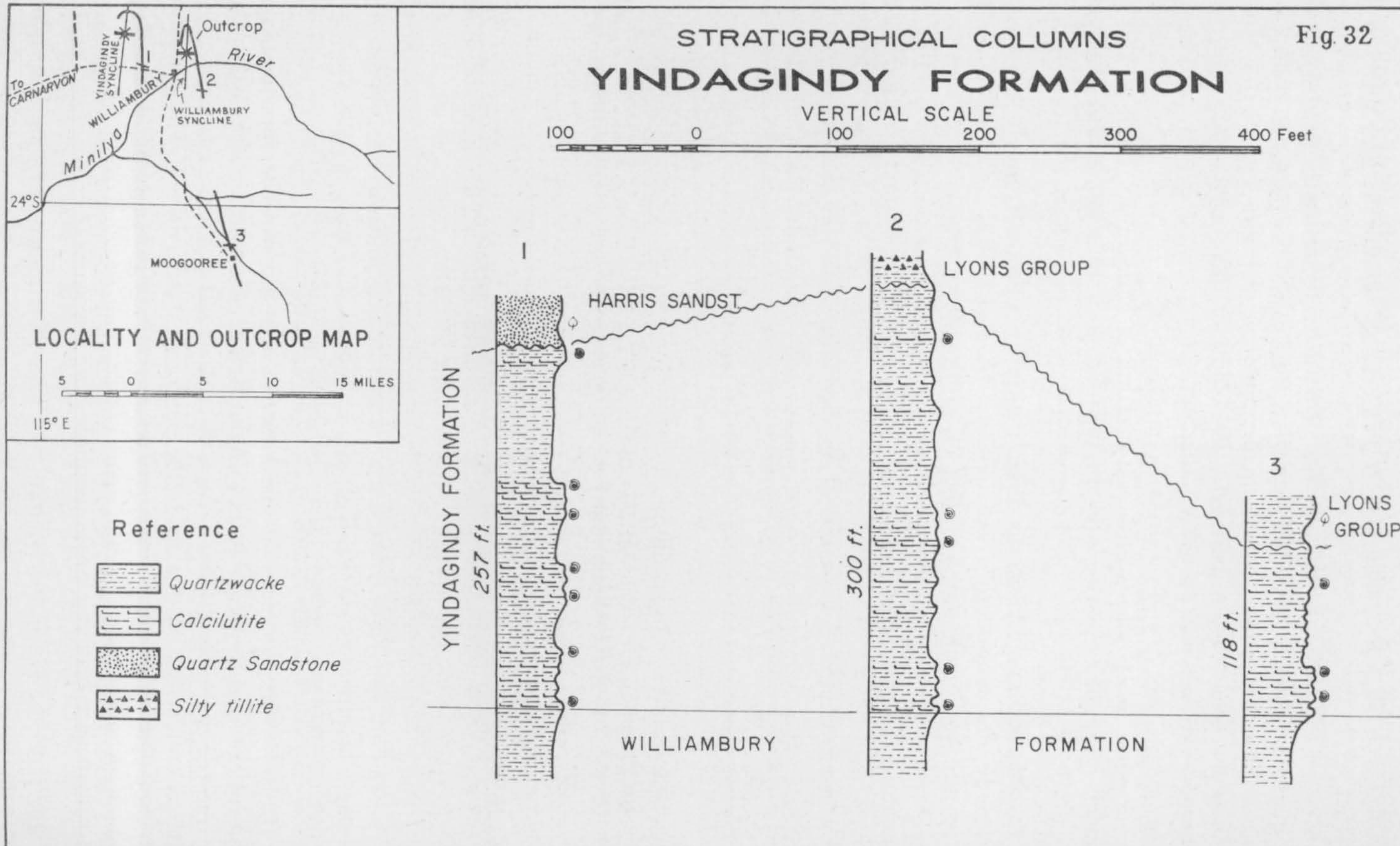


Fig. 32
STRATIGRAPHICAL COLUMNS
YINDAGINDY FORMATION
VERTICAL SCALE
100 0 100 200 300 400 Feet
LOCALITY AND OUTCROP MAP
Outcrop
River
To CARNARVON
YINDAGINDY SYNCLINE
WILLIAMBURY
WILLIAMBURY SYNCLINE
Minilya
24°S
MOOGOOREE
5 0 5 10 15 MILES
115° E
Reference
Quartzwacke
Calcilutite
Quartz Sandstone
Silty tillite
HARRIS SANDST.
LYONS GROUP
LYONS GROUP
YINDAGINDY FORMATION
257 ft.
300 ft.
118 ft.
WILLIAMBURY
FORMATION

different in aspect from those in the lowermost bed of marine fossils in the Lyons Group, which Dickins & Thomas (1959) regard as probably Sakmarian, and somewhat like some of the forms in the Frasnian Gneudna Formation. The erosional unconformity, where the erosion in places removed the whole of the Devonian and Carboniferous sediments between the deposition of the Yindagindy Formation and that of the Austin Greywacke of the Lyons Group, indicates that the Yindagindy Formation is considerably older than the Sakmarian Formation.

The Yindagindy Formation is probably Lower Carboniferous in age, but cannot be dated more closely.

*Correlation.*—At present the Yindagindy Formation must be joined with the Moogooree Limestone and the Williambury Formation for purposes of correlation.

*Structure.*—The Yindagindy Formation is structurally conformable with the Williambury Formation. It is not exposed in the axial region of the Williambury Syncline, but only in the west-dipping homocline that extends from its east limb. The Yindagindy Syncline plunges at about 10° south; the long east limb dips at about 30° and passes into an anticlinal nose plunging at about 7° south; the west limb is very short, probably against a steep contact with Precambrian rocks, and very much contorted by what appears to be slump folding. In the western outcrop belt the sediments dip west at about 20°.

*Palaeogeography.*—A reduction in the relief in the hinterland and an increase in the stability of the area of deposition as compared with those of the time of deposition of the Williambury Formation is shown by the smaller grainsize of the terrigenous clastic sediments and by the presence of marine calcilutite. The present outcrop area was covered by the sea. The shoreline was farther inland than during deposition of the Williambury Formation; it had minor indentations in the area of the synclines.

The slump folding on the west limb of the Yindagindy Syncline and the reduction in proportion of terrigenous sediment in the area of the anticlinal nose and in the Moogooree area indicate appreciable relief on the sea bottom.

The structural concordance of the Harris Sandstone and the Yindagindy Formation of the type locality probably indicates that there, very little has been removed from the top of the Yindagindy Formation; if this is so, the sea regressed and sedimentation ceased in the area of outcrop after the Yindagindy Formation had been deposited. Subaerial weathering took place and the exposed coastal plain of sediments was dissected by stream erosion; the southward part of the outcrop area was structurally (and topographically) higher than the northern and was eroded more strongly: an erosion surface was cut through the Carboniferous and Devonian sediments and into the Precambrian rocks near Mount Sandiman. This emergence continued through the Upper Carboniferous until the major transgression in earliest Permian time.

*Economic Geology.*—The Yindagindy Formation may be considered as a variation of the Williambury Formation and has similar economic possibilities. Where the limestone is well developed it may be of use as a source of aggregate for concrete and road surfacing and possibly for cement manufacture; it is commonly too sandy for lime-burning.

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TABLE 1

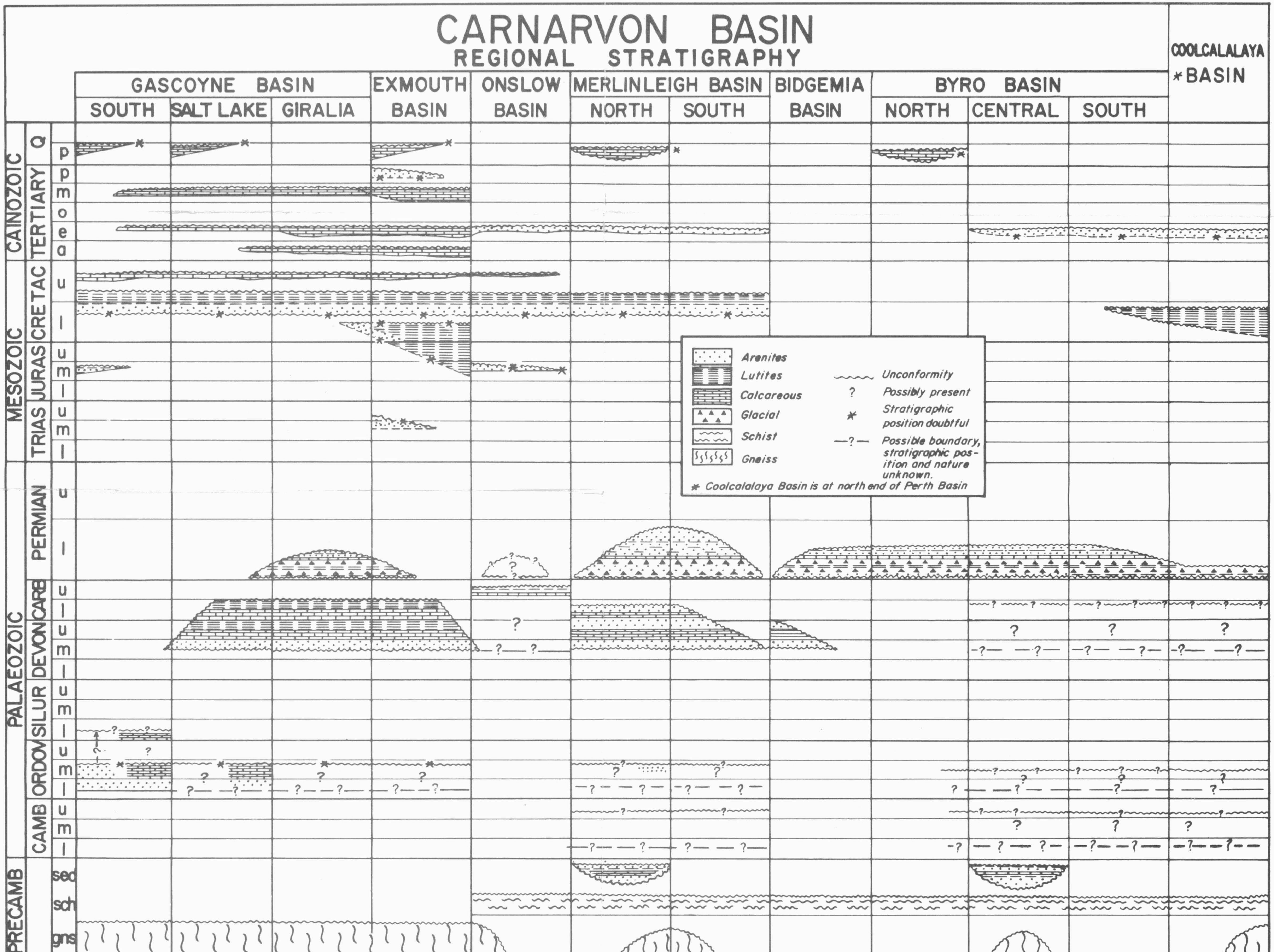
PRE-PERMIAN ROCK UNITS

| Formation | | Lithology | Maximum Thickness (Feet) | Fossils | Relationships | Distribution | | Correlation | Economic Geology |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Outcrop | Subsurface | | |
| **CARBONIFEROUS** | | | | | | | | | |
| ?Lower Carboniferous | Yindagindy Formation | Greywacke, thin oolitic limestone | 380 | Brachiopods, crinoids, gastropods, ostracods | Conformable on Williambury. Unconformable beneath Permian | Williambury and Moogooree Stations | Merlinleigh Basin | | |
| ?Lower Carboniferous | Williambury Formation | Pebbly greywacke, siltstone and conglomerate | 1100 | None known | Conformable on Moogooree, beneath Yindagindy | Williambury and Moogooree Stations | as above | Sequences in Rough Range No. 1 Bore and in Warroora No. 1 Bore | Road gravel |
| ?Tournaisian | Moogooree Limestone | Calcilutite | 1400 | Brachiopods, molluscs, bryozoa | Unconformable on Willaraddie and Munabia. Conformable beneath Williambury | as above | as above | ? Rough Range 1, ? Brickhouse 1. Laurel Fm. Septimus Lst. | Road and concrete aggregate; ? lime and portland cement |
| **DEVONIAN** | | | | | | | | | |
| ?Famennian | Willaraddie Formation | Quartzwacke, siltstone, quartz sandstone and conglomerate | ?4000 | Bryozoa, brachiopods (poorly preserved) | Conformable on Munabia. Unconformable beneath Moogooree | Williambury and Moogooree Stations | Merlinleigh Basin | ? Rough Range 1 | ? cap rock |
| ?Frasnian | Munabia Sandstone | Quartz sandstone | 4450 | Plant fossils | Conformable on and varies laterally into Gneudna. Conformable beneath Willaraddie | as above | as above | | Water, ? oil reservoir |
| Frasnian ?+ Givetian | Gneudna Formation | Quartzwacke, calcarenite and siltstone | 2700 | Corals, brachiopods, molluscs, crinoids, stromatoporoids | Conformable on Nannyarra. Conformable beneath and varies laterally into Munabia. Unconformable beneath Permian | Williambury Station to Mount Sandiman Station | Merlinleigh and Bidgemia Basins | Pelican Hill Bore, Wandagee 1 Bore; Pillara Limestone | ? oil source |
| ?Givetian | Nannyarra Greywacke | Greywacke, feldspathic sandstone and siltstone | 200 | None known | Unconformable on Precambrian. Conformable beneath Gneudna. Unconformable beneath Permian | as above | as above | | ? oil reservoir |
| **? SILURIAN** | | | | | | | | | |
| | Dirk Hartog Limestone | Dolomite, limestone and anhydrite | 2425 | Brachiopods, gastropods, nautiloids, conodonts | Unconformable beneath Birdrong. Conformable on ? Tumblagooda | Nil | Gascoyne Basin, Merlinleigh Basin | Not definite | ? oil source and reservoir |
| **? ORDOVICIAN** | | | | | | | | | |
| | Tumblagooda Sandstone | Quartz sandstone, siltstone | 20,600 | Invertebrate burrows and trails | Unconformable beneath Birdrong, Lyons. ? Conformable beneath Dirk Hartog. Unconformable on gneiss | Lower Murchison River | S. Gascoyne Basin, Coolcalalaya Basin, Merlinleigh Basin | Not definite | Water ? oil reservoir |

TABLE 1—(*continued*)

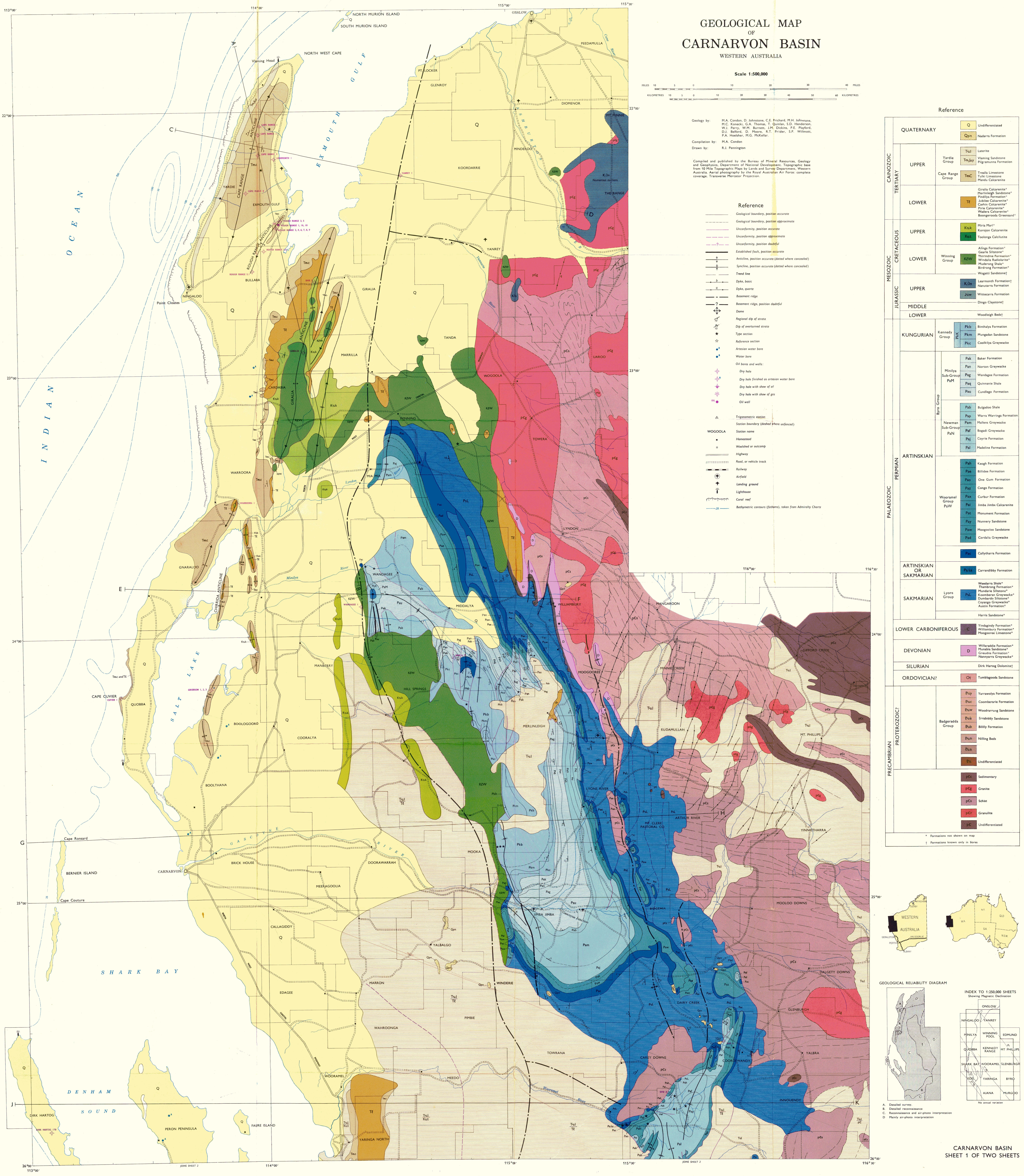
PRE-PERMIAN ROCK UNITS—(*continued*)

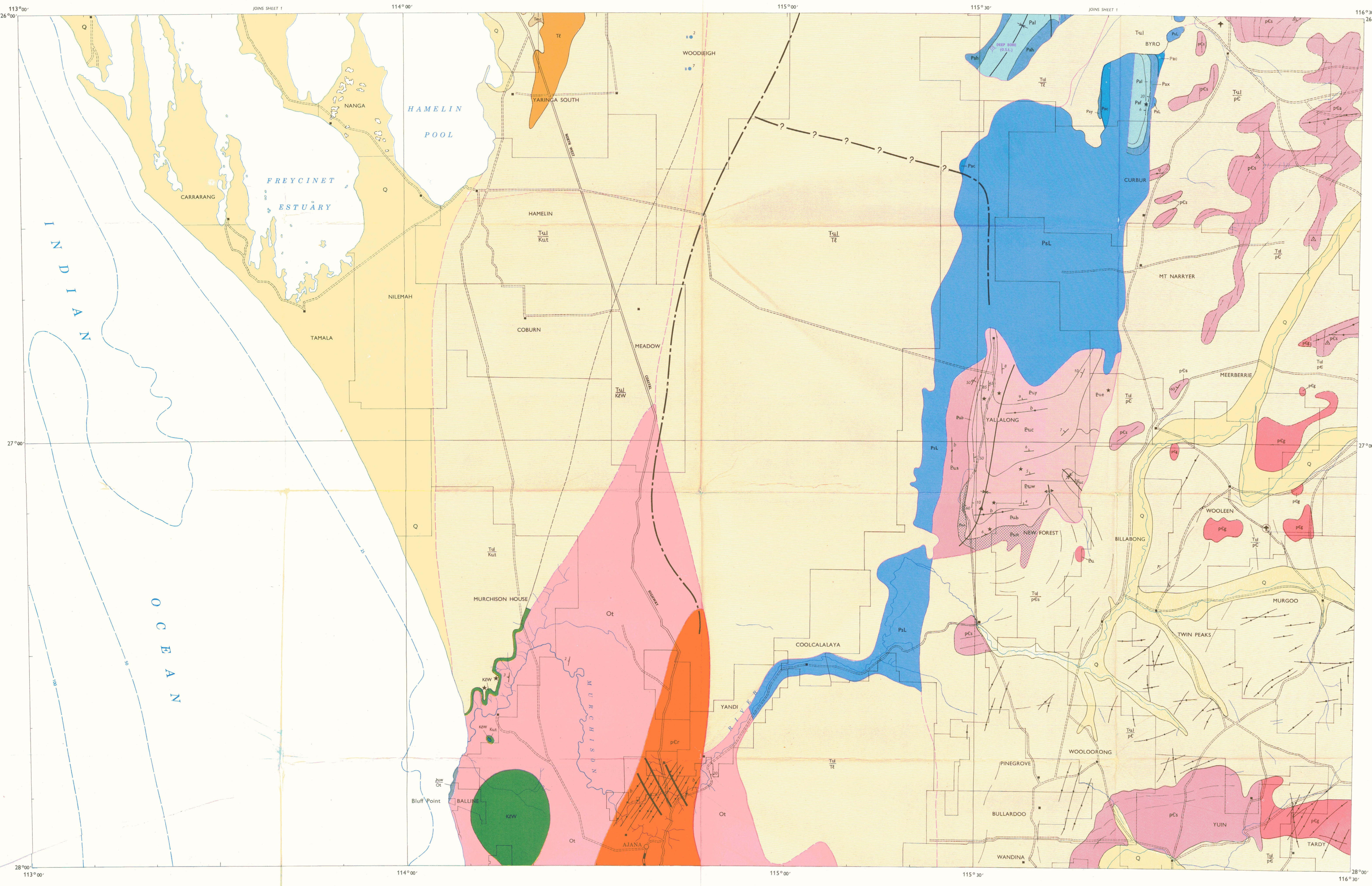
| Formation | | Lithology | Maximum Thickness (Feet) | Fossils | Relationships | Distribution: Outcrop | Distribution: Subsurface | Correlation | Economic Geology |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **PROTEROZOIC** | | | | |
| Badgeradda Group | Yarrawolya Formation | Laminated siltsone and fine-grained quartzwacke | 1435+ | | Conformable on Coomberarie ? Unconformable beneath Lyons Group | S.E. Byro Basin | Byro Basin ? Coolcalalaya Basin | | |
| | Errabiddy Sandstone | Quartz sandstone | | | Lateral variant of part of Coomberarie | as above | as above | | |
| | Coomberarie Formation | Siltstone and fine-grained quartzwacke | 5000 | | Conformable on Woodrarrung, beneath Yarrawolya | as above | as above | | |
| | Woodrarrung Sandstone | Kaolinitic quartz sandstone | 3700 | | Conformable on Bililly, beneath Coomberarie. Unconformable on Precambrian schist | as above | as above | | |
| | Bililly Formation | Quartz sandstone and silty sandstone | 1200 | | Conformable beneath Bililly, ? conformable on Nilling Beds. Unconformable on Precambrian schist | as above | as above | | |
| | Nilling Beds | Sandstone, quartzwacke ? red siltstone | ?3100 | | ? Conformable beneath Bililly. Conformable on Yarramulla | as above | as above | | |
| | Yarramulla Beds (Pua on Plate 1) | Phyllite, slate, quartzwacke | ?17,000 | | May be conformable or unconformable beneath Badgeradda Group | S.E. Byro Basin | Byro Basin, ? Coolcalalaya Basin | | |
| | | | | | **PRECAMBRIAN** | | | | |
| | Indurated Sediments | Quartzite, slate | ? | | ? Unconformable on schist | Lyndon, Gifford Creek, Mount Phillips, Coordewandy | ? | | |
| | Granitic Rocks | Massive and gneissic granite | ? | | Intrude schist | Eastern boundary of basin | | | |
| | Schist | Quartz schist, biotite schist, chlorite schist, sericite schist, hornblende schist | ? | | ? | Eastern boundary of Basin, Carey Downs | | | |
| | Granulite and Gneiss | Granulitic garnetiferous gneiss | ? | | ? | Ajana | Ajana Ridge | | |
| | | Quartz-biotite-feldspar gneiss | | | ? | Carrandibby Range, Glenburgh | ? | | |




Bureau of Mineral Resoures, Geology & Geophysics. July 1964.

WA54-19


GEOLOGICAL MAP
OF
CARNARVON BASIN
WESTERN AUSTRALIA
Scale 1:500,000
Geology by: M.A. Condon, D. Johnstone, C.E. Prichard, M.H. Johnstone, M.C. Konecki, G.A. Thomas, T. Quinlan, S.D. Henderson, W.J. Perry, W.M. Burnett, J.M. Dickins, P.E. Playford, D.J. Belford, D. Moore, R.T. Prider, S.P. Willmott, P.A. Hoelsher, M.G. McKellar.
Compilation by: M.A. Condon
Drawn by: R.J. Pennington
Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Topographic base from 10 Mile Topographic Maps by Lands and Survey Department, Western Australia. Aerial photography by the Royal Australian Air Force: complete coverage. Transverse Mercator Projection.
Reference
INDIAN OCEAN
EXMOUTH GULF
SHARK BAY
DENHAM SOUND
SALT LAKE
GEOLOGICAL RELIABILITY DIAGRAM
INDEX TO 1:250,000 SHEETS
CARNARVON BASIN
SHEET 1 OF TWO SHEETS

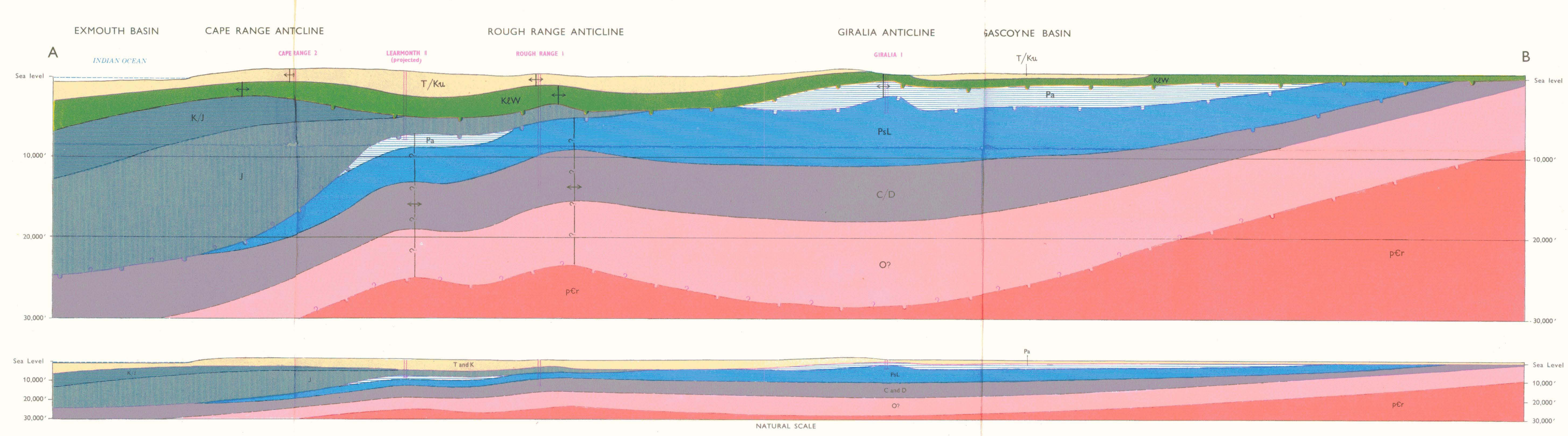


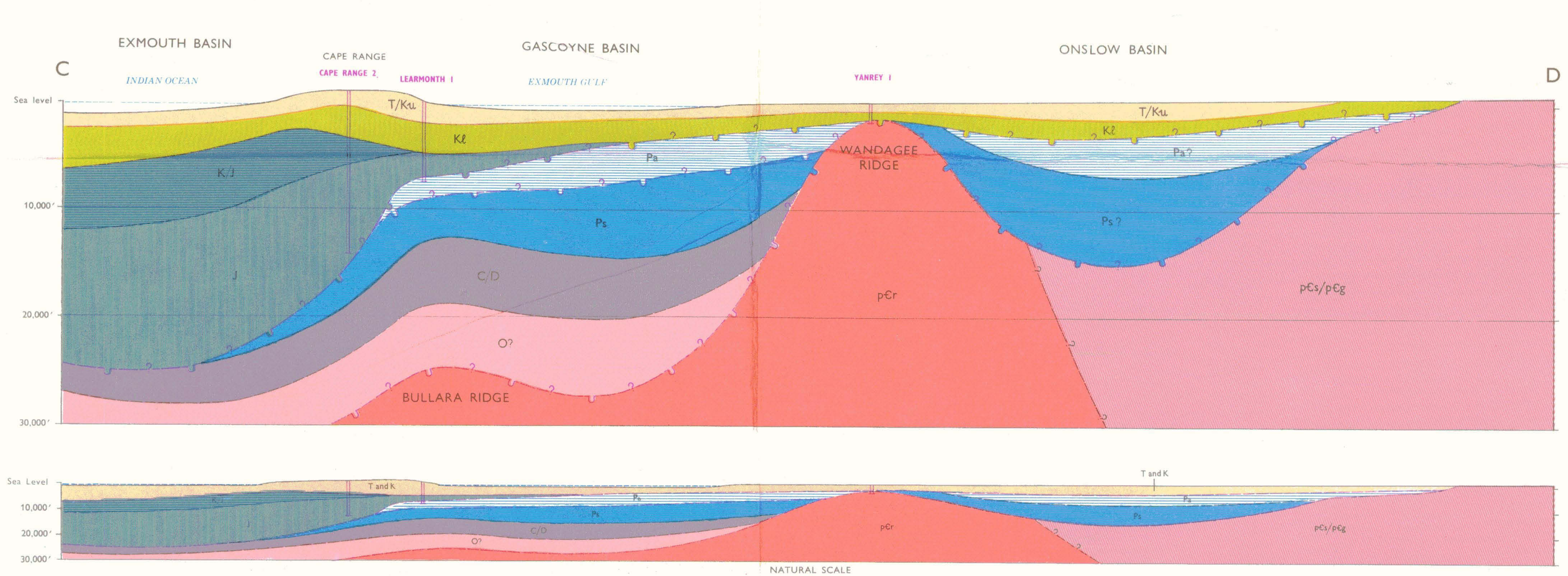

CARNARVON BASIN
SHEET 2

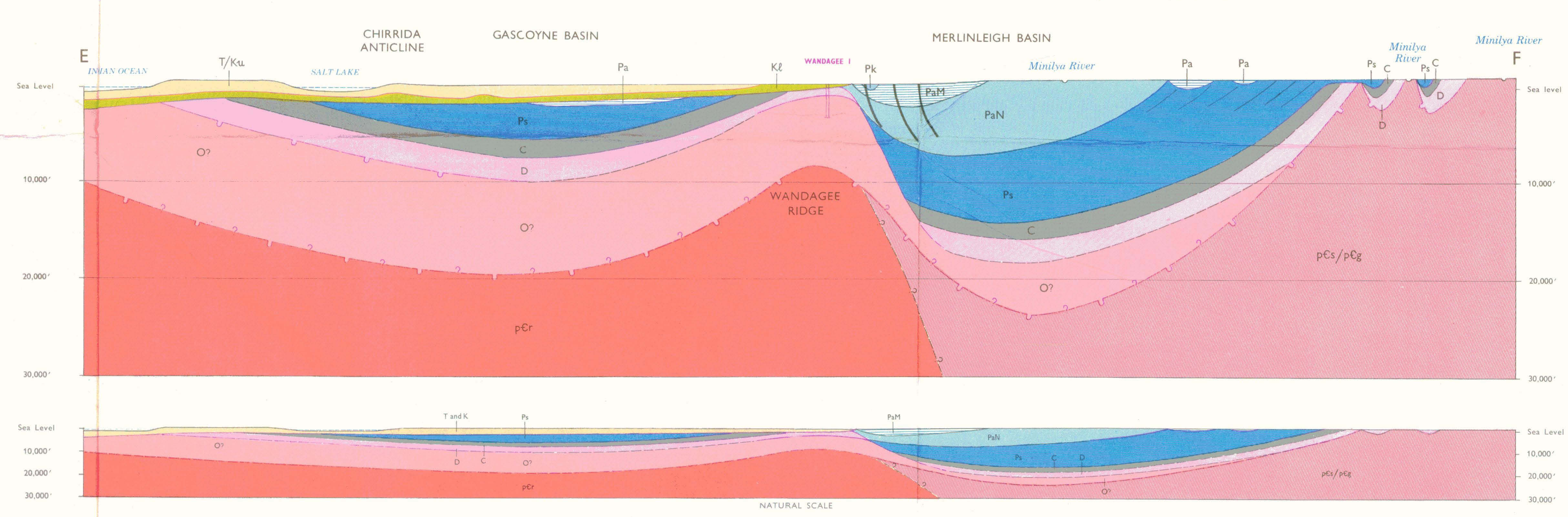
# SECTIONS

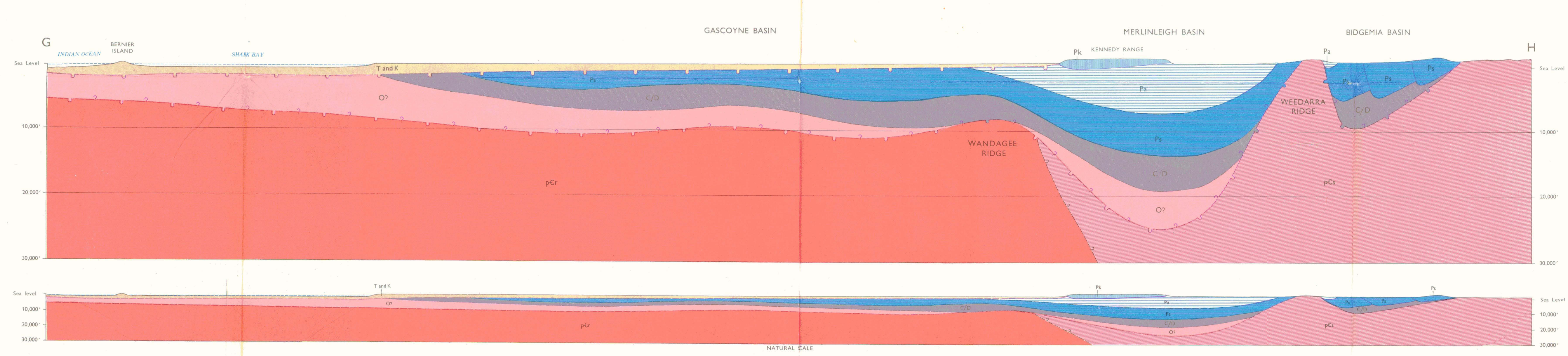
EXAGGERATED VERTICAL SCALE $\frac{V}{H} = 4$

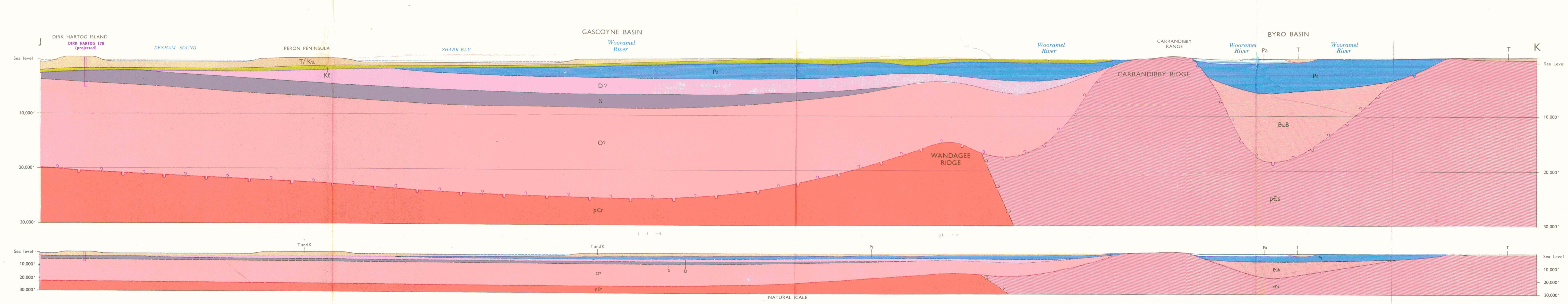
NATURAL SCALE $\frac{V}{H} = 1$




## Reference

**CAINOZOIC and MESOZOIC**

- T and K — Tertiary and Cretaceous
- T/Ku — Tertiary and Upper Cretaceous
- Kℓ — Lower Cretaceous
- KℓW — Winning Group
- K/J — Cretaceous/Jurassic
- J — Jurassic

**PALAEOZOIC**

Permian

- Pk — Kungurian
- Pa — Artinskian
- PaM — Minilya Sub-Group
- PaN — Newman Sub-Group
- Ps — Sakmarian
- PsL — Lyons Group
- C — Carboniferous
- C/D — Lower Carboniferous/Devonian
- D — Devonian
- S — Silurian
- O? — Ordovician ?

**PRECAMBRIAN**

Upper Proterozoic

- PuB — Badgeradda Group

Undifferentiated

- p€g — Granite
- p€s — Schist
- p€r — Granulite

Angular Unconformity

*Note: Laterite and Quaternary units omitted from sections*