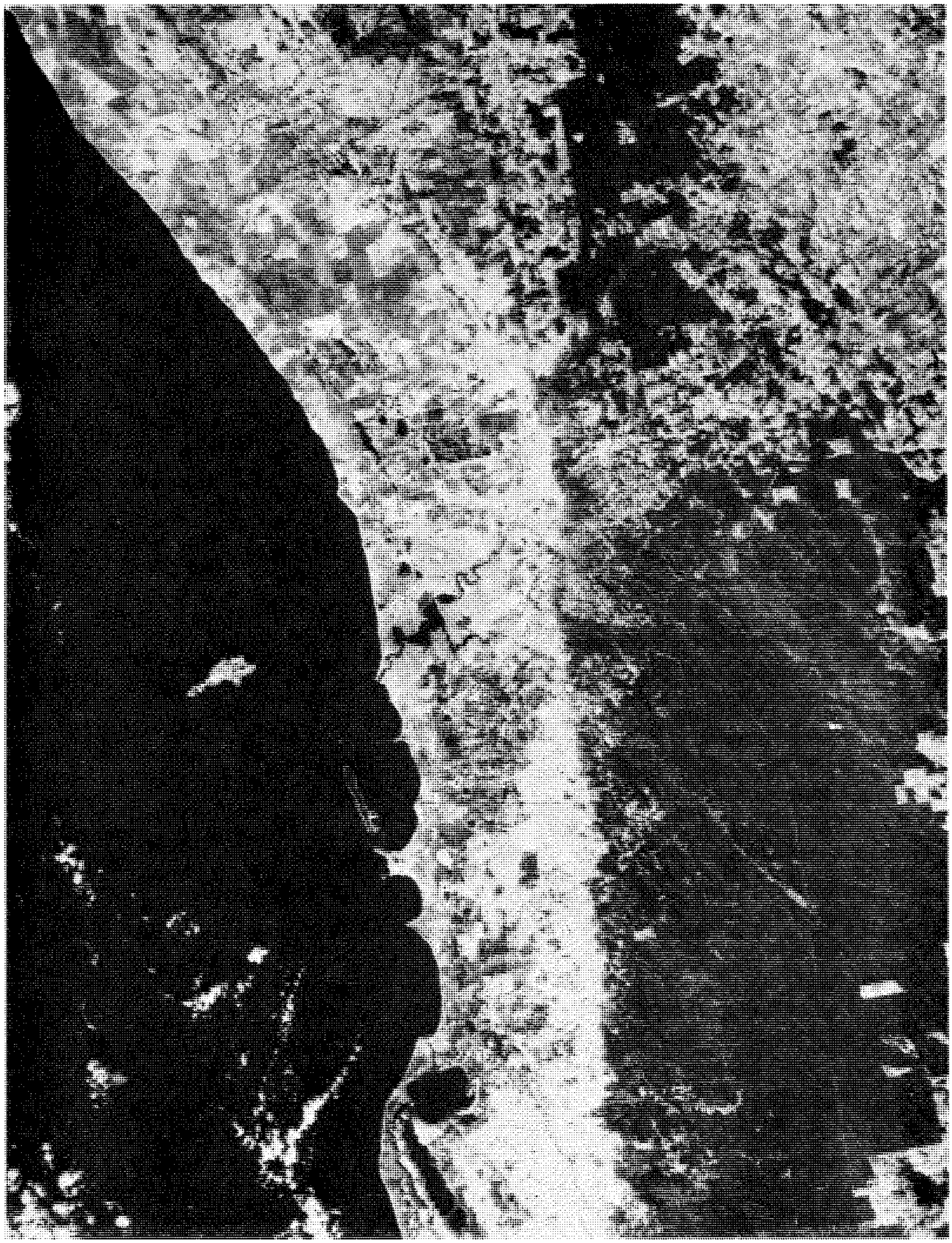
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

BULLETIN 124

GEOLOGY OF THE PERTH BASIN WESTERN AUSTRALIA

1976



Frontispiece. Earth Resources Technology Satellite image (no. E-1149-01370-5) centred over Perth and the Swan River. The prominent north-south line marks the Darling Fault, separating the Yilgarn Block and Darling Plateau on the east (dark pattern due to forest cover) from the Perth Basin and Swan Coastal Plain on the west. The image covers an area of about 24 600 km^2 (177 km by 139 km). It was taken in 1972 at an elevation of 913 km. Made available by the Division of National Mapping of the Department of Minerals and Energy by courtesy of NASA.

(1)-53419

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

BULLETIN 124

GEOLOGY OF THE PERTH BASIN WESTERN AUSTRALIA

by

P. E. PLAYFORD, A. E. COCKBAIN, and G. H. LOW

1976

Issued under the authority of the Hon. A. Mensaros, M.L.A., Minister for Mines

PREFATORY NOTE

During recent years this Geological Survey has directed its main effort towards geological mapping on a scale of 1 : 250 000 in Western Australia. This is a major task but now that some basins and provinces have been mapped completely at that scale it is possible to study such areas in more detail. These studies will be published as Geological Survey Bulletins during the next decade.

This bulletin presents the results of comprehensive mapping and study, embracing both surface and subsurface geology, of the Perth Basin. Much of the basin is covered by Quaternary superficial deposits, and it is only in the northern part that there are any good exposures of the underlying Mesozoic and Palaeozoic section. A number of outlines of the stratigraphy and geological history of the Perth Basin have been compiled earlier mainly from surface geology. However, during the last decade such a large amount of data has been accumulated from geophysical surveys and wells drilled in the search for petroleum and groundwater, that it has now been possible to make a much more detailed study of the subsurface of the basin.

The Perth Basin contains natural gas, heavy-mineral sands, and groundwater resources that are of great economic importance to the State. The search for further petroleum and mineral fields and for additional groundwater reserves is continuing in the basin, and this bulletin will be of considerable importance to this exploration, as it is the first comprehensive account of the regional geology of the basin.

One of the authors of the bulletin, Mr. G. H. Low, who played a major role in the surface mapping programme, died when it was nearing completion. He will be long remembered for his important contributions to this and many other aspects of the geology of Western Australia.

J. H. LORD,
Director.

5th December, 1975.

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Summary

The Perth Basin is a deep linear trough of sedimentary rocks extending north-south for some 1 000 km in the southwest of Western Australia beneath the coastal area, continental shelf, and continental slope. The basin covers an area of 45 000 km^2 onshore and 55 000 km^2 offshore. The major towns are Geraldton, Perth, and Bunbury. About 70 per cent of the population of Western Australia and most of the secondary industry lie within the area of the basin.

The land surface is flat to gently undulating, partly forested in the south and largely covered by sandplain in the north. Most of the area is used for farming. Fourteen physiographic regions are recognized in the onshore part of the basin, and these may be grouped into coastal plains, plateaus, islands and reefs, and miscellaneous regions.

Exposures are poor in the Perth Basin, and much of our knowledge of the geology is based on borehole and geophysical data resulting from petroleum exploration. There is an extensive Quaternary cover (sand, laterite, and alluvium) over the basin; the best outcrops of older rocks are in the northern Perth Basin around Geraldton, Mingenew, and Hill River.

The Perth Basin is essentially a half-graben bounded on the east by the north-trending Darling Fault, 1 000 km long, which separates the basin from the Archaean rocks of the Yilgarn Block. Three north-trending inliers (Northampton and Leeuwin Blocks and Mullingarra Inlier) of Proterozoic crystalline basement occur within the basin, and together with shallow basement ridges (Ajana, Turtle Dove, Beagle, Harvey, and Mullingarra Ridges) separate deeper sub-basins (Dandaragan and Bunbury Troughs, Coolcalalaya, Irwin, Abrolhos, and Vlaming Sub-basins).

Phanerozoic sedimentary rocks in the Perth Basin may exceed 15 000 m in thickness, and are best developed in the Dandaragan and Bunbury Troughs and the Vlaming Sub-basin. The oldest rocks forming part of the basin sequence are very thick deposits of Proterozoic age which are known in the Irwin Sub-basin (Yandanooka Group) and east of the Darling Fault (mainly Moora and Cardup Groups). The total thickness of these deposits probably exceeds 10 000 m.

Pre-Permian Phanerozoic sediments are confined to the northern part of the Perth Basin. The oldest are red beds (Tumblagooda Sandstone) over 3 000 m thick, which are thought to be of Silurian age. They were probably deposited during a major period of block faulting, possibly associated with development of the Darling Fault. Devonian rocks are not known in the basin but remanié spores in a Cretaceous unit suggest that they may occur in the subsurface.

Permian and later sediments are widespread throughout the Perth Basin. In the north, the Permian consists of marine and non-marine rocks. The Lower Permian succession commences with glacigene rocks (Nangetty Formation) followed by shale, limestone, sandstone, coal measures, and siltstone (Holmwood Shale, High Cliff Sandstone, Irwin River Coal Measures, and Carynginia Formation). The sequence, aparat from the coal measures, is marine. It is overlain with slight angular unconformity by continental Upper Permian deposits (Wagina Sandstone). In the south the whole Permian section is continental and consists of a thick coal measures unit (Sue Coal Measures) conformably overlain by an Upper Permian to Lower Triassic sandstone (Sabina Sandstone). The total thickness of Permian rocks in the basin probably exceeds 2 600 m.

The Triassic is represented in the northern Perth Basin by a marine shale at the base (Kockatea Shale) followed by paralic and continental siltstone and sandstone (Woodada Formation and Lesueur Sandstone). The contact with the underlying Permian rocks is a mild angular unconformity. In the south the Triassic sequence is wholly continental, and consists of a sandstone unit (Lesueur Sandstone) which conformably overlies the Sabina Sandstone. The total Triassic section may be more than 2 500 m thick.

Jurassic rocks are widespread, their maximum thickness being at least 4 200 m. They are continental except for a thin marine to paralic Middle Jurassic sequence in the north and west-central parts of the basin (Champion Bay Group and Cadda Formation). Fluviatile deposits make up most of the Jurassic section (Cockleshell Gully Formation, Chapman Group, and Yarragadee Formation) and these are largely believed to have been shed from the Yilgarn Block while active movement was taking place along the Darling Fault.

The oldest Cretaceous rocks are paralic deposits (Yarragadee Formation) representing the final phase in the predominantly continental sedimentation which began in the Middle to Late Triassic and continued to the early Neocomian without major interruption. An important angular unconformity separates these rocks from the succeeding marine, paralic, and continental Lower Cretaceous sequence (Warnbro Group). Basalt flows were extruded along valleys on this unconformity surface during the Neocomian in the southern Perth Basin. Upper Cretaceous rocks consist mainly of glauconitic sediments and chalk (Coolyena Group). Cretaceous rocks similar to the Warnbro and Coolyena Groups overlie basalt in a Deep Sea Drilling Project drillhole west of Geraldton. The Cretaceous sequence is at least 3 000 m thick in the onshore part of the basin and it probably thickens to as much as 12 000 m below the continental shelf.

No rocks of proved Tertiary age are exposed in the Perth Basin, but a thin unfossiliferous unit cropping out in the north (Victoria Plateau Sandstone) is believed to be of this age. In the subsurface Tertiary rocks occur widely beneath the continental shelf and slope and are at least 600 m thick. They extend beneath the Perth metropolitan area, where Paleocene and Eocene deposits (Kings Park Formation) fill a steep-sided valley (the "ancestral Swan River") or submarine canyon eroded into Cretaceous rocks.

Quaternary deposits are thin but widespread in the Perth Basin. Their total maximum thickness is about 150 m. Laterite and associated sand are the most extensive of these deposits, and are most probably mainly of Pleistocene age. However, lateritization is still proceeding in the southern part of the basin, and it may have occurred at intervals from late Tertiary times to the present.

A Holocene to early Pleistocene or late Tertiary series of coastal-dune, beach, and shallow-marine deposits (Kwinana Group) occurs on the coastal plain. These deposits occur in belts associated with successive shorelines, the sea-level oscillations having probably been controlled by both eustatism and tectonism.

The tectonic style of the Phanerozoic sequence is characterized by intense normal faulting. Compressional tectonics seem to have been restricted to the Proterozoic rocks, although there is evidence of Cainozoic reversal of movement along the Hardabut Fault, which marks the northwest margin of the basin. Seismic and outcrop evidence suggest that most faults in the basin dip at angles of between 55° and 80°. Many of the larger faults are believed to have operated during sedimentation.

The Darling Fault is the dominant structural feature of the basin. It is about 1 000 km long and its maximum throw may exceed 15 km. Proterozoic rocks adjoining the fault show evidence of major compression, and this evidence suggests that the fault originated as a transcurrent fault (probably with reverse dextral displacement) in late Proterozoic or early Palaeozoic times. Later pull-apart stress (possibly during the Early Silurian) resulted in development of the normal Darling Fault. Movement may also have occurred during the Permian, but the greatest movements took place in the interval between the Middle Triassic and the earliest Cretaceous. For most of its length the fault seems to have been quiescent (apart from minor continuing movement resulting from differential compaction) since the Neocomian. However, some activity probably continued in the area of the present Darling Scarp during the Cretaceous and part of the Cainozoic.

Most of the other large faults in the basin have also been inactive since the Neocomian. The Jurassic and older rocks are intensely faulted throughout most of the basin, the faults generally trending north to north-northwest.

The Proterozoic rocks in and adjoining the Perth Basin have been involved in large-scale folding, in marked contrast to the Phanerozoic sequence, in which the only conspicuous flexuring occurs in association with faults. The best developed folds in Phanerozoic rocks are drape structures over grabens (synclines) and horsts (anticlines). Differential compaction combined with normal growth faulting may have played an important role in development of these structures.

The geological history of the Perth Basin in relation to plate tectonics can be conveniently divided into three parts, a Proterozoic (pre-Gondwanaland) phase, a Palaeozoic to Early Cretaceous (Gondwanaland) phase, and an Early Cretaceous to Holocene (post-Gondwanaland) phase.

During the Proterozoic phase an extensive sea was apparently present along the western side of the Yilgarn Block, and great thicknesses of sedimentary rocks (many of them volcanogenic) were deposited. The seaway was apparently closed and the sediments were strongly folded during the late Proterozoic or early Palaeozoic, and this may have marked the welding together of crustal plates to form Gondwanaland. During the period from the Silurian to the early Neocomian a very thick sequence of sediments, largely continental, was deposited in the Perth Basin in association with strong movement along the Darling Fault and other faults in the basin. This marks the Gondwanaland phase in the history of the Perth Basin, when Australia is thought to have formed part of the supercontinent. The main break-up of Gondwanaland in this area and the formation of the Indian Ocean apparently began during the Neocomian. The separation is thought to be marked by the intra-Neocomian unconformity. The post-Gondwanaland or drift phase after the middle Neocomian is marked by marine sedimentation from the west in the central and western parts of the Perth Basin, in contrast to the earlier marine incursions from the north into the predominantly continental regime.

The Perth Basin has been tectonically quiet since the middle Neocomian, with little active faulting, in contrast to the strong activity during the earlier phase of rifting. Separation of the Antarctic and Australian plates is thought to have taken place during the Eocene. This was followed by epeirogenic uplift of the Yilgarn Block and of at least some parts of the Perth Basin.

The most important elements of the economic geology of the Perth Basin are natural gas, heavy-mineral sands, and groundwater. Two gas fields, Dongara and Mondarra, are currently producing gas, which is piped to Perth and neighbouring industrial areas. Two other fields, Gingin and Walyering, produced for short periods. Dongara is the largest field, with original reserves of about $12 \times 10^9 m^3$. Production is from Triassic and Permian sands. Mondarra produces from Permian sandstone, while the Gingin and Walyering gas reservoirs (now largely depleted) are of Jurassic age.

Heavy-mineral sands occur in shoreline deposits of early Pleistocene or late Tertiary to Holocene age, and these are being exploited at several localities from Eneabba in the north to Capel in the south.

There are large reserves of potable groundwater in the Perth Basin. The main aquifers are Jurassic, Cretaceous, and Quaternary in age and are important sources of water for the Perth area and for various towns in and adjoining the basin.

CHAPTER 1

Introduction

LOCATION OF AREA

The Perth Basin extends almost north-south for some 1 000 km along the southwestern side of the Australian continent (Fig. 1). The basin ranges from about 80 to 175 km in width and covers a total area of some 45 000 km^2 on land and 55 000 km^2 on the continental shelf.

PRESENT INVESTIGATION

The Geological Survey of Western Australia has mapped the Perth Basin between the south coast and latitude 28°S (the northern margin of the Geraldton 1 : 250 000 Sheet). The field work was conducted during the years 1962 to 1970 by P. E. Playford, G. H. Low, and D. C. Lowry. Vertical air-photographs were used for the mapping, and a series of 1 : 250 000 maps have been compiled (Lowry, 1967 and 1974; Playford and others, 1970; Low, 1971a and b, and 1972a, b, c, d; and Muhling and Low, 1973).

In addition, two maps at a scale of 1 : 500 000 (Plates 1 and 2) have been prepared for this bulletin, covering the basin south of latitude 27° 15′S. The area between latitudes 27° 15′S and 28°S has not been mapped by the Geological Survey, and this part of Plate 1 has been compiled from mapping by Johnstone and Playford (1955). A solid geology map of the basin (scale 1 : 1 000 00) has been prepared (Plate 3) and there are four 1 : 100 000 maps (Plates 5-7, 9), and one 1 : 25 000 map (Plate 8), of key outcrop areas.

A. E. Cockbain is primarily responsible for compilation of subsurface data on the basin. J. R. Forth prepared the section dealing with groundwater in the economic geology chapter. The rest of the text was written by P. E. Playford.

PREVIOUS INVESTIGATIONS

Prior to the mid 1950's there was relatively little known about the regional geology of the Perth Basin. Studies of specific areas had been made by the Geological Survey (mainly in connection with underground water and coal prospects) and by the University of Western Australia, but no basin-wide surveys

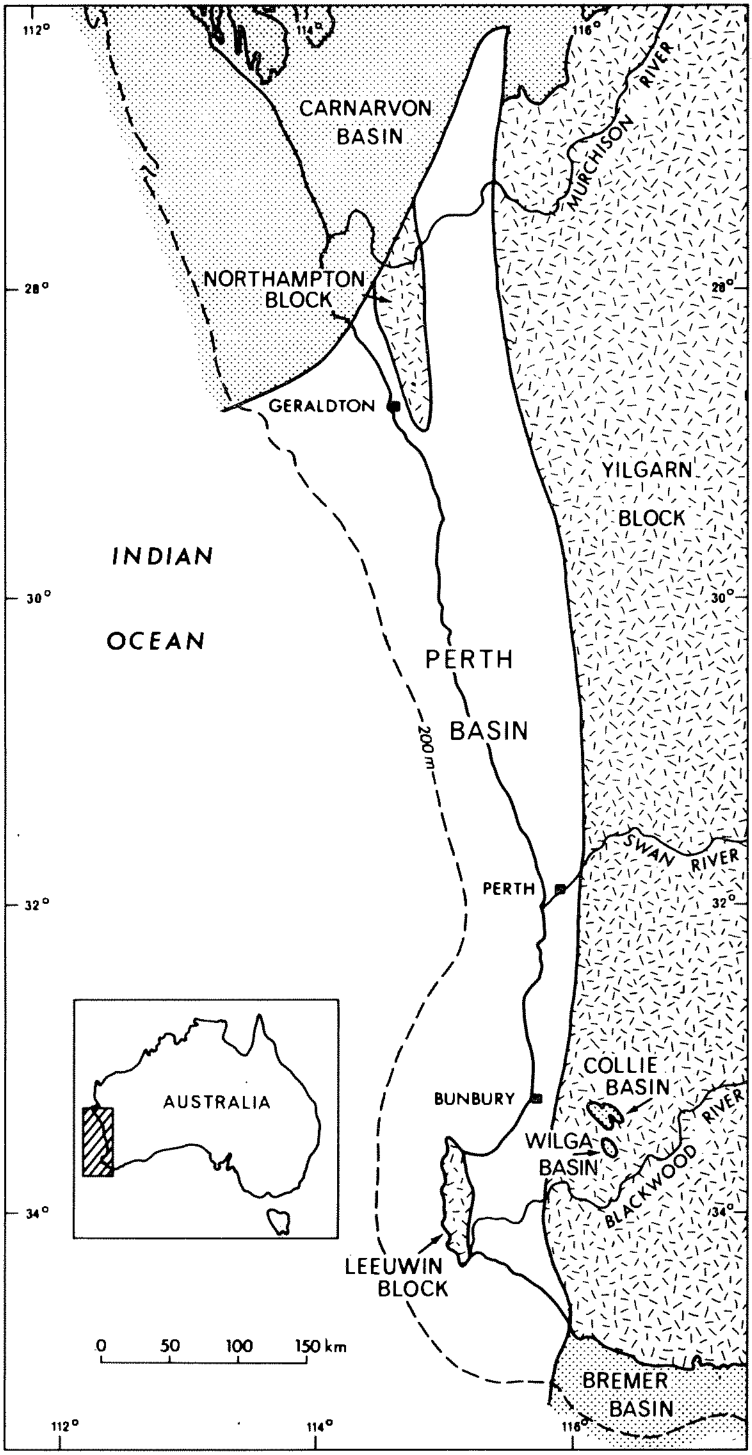

Figure 1. Location map, Perth Basin.

had been carried out. Maitland (1919), Clarke and others (1944), Teichert (1947a), and Fairbridge (1948a and 1953) summarized the geology of the basin as it was then known.

Among the more important early investigations of particular parts of the basin were those by Campbell (1910) on the area between Arrino and Northampton, Clarke and others (1951) on the Permian of the Irwin River area, and Johnson and others (1954) on the area from Yandanooka to Northampton. More recent detailed studies have been made by P. E. Playford (1959) on the Jurassic of Geraldton, G. Playford (1959) on the Permian of the Woolaga Creek area, and Logan and Chase (1961) on the Proterozoic sequence near Moora.

The first regional geological survey of the Perth Basin was carried out by West Australian Petroleum Pty Ltd (referred to in this bulletin as Wapet) during the years 1954-1958. This work formed the foundation of our present knowledge of the surface geology of the basin as a whole. The geologists who were principally involved in Wapet's Perth Basin mapping were P. E. Playford, S. P. Willmott, and D. Johnstone. Their results are contained in two unpublished reports (Johnstone and Playford, 1955; Playford and Willmott, 1958) which have been made available to the Survey. These were of considerable assistance in our mapping, and the Playford and Willmott report has been used freely in compiling parts of this bulletin.

Palynological study of the Perth Basin sediments was carried out by B. E. Balme in association with the Wapet studies. This work provided the first reliable means of dating the continental to paralic rocks that constitute much of the succession, and it represented a major contribution to our understanding of the geology of the basin (Balme, 1956, 1957, 1963, 1964a, 1964b, 1969).

Part of the information obtained from the Wapet survey of the Perth Basin was summarized by McWhae and others (1958). The most recent summary of the geology is by Playford and others (1975). The results of subsurface geological studies have been published by Johnstone (1964), Johnstone and Willmott (1966), Hosemann (1971), Bird and others (1971), and Jones and Pearson (1972). Johnstone and others (1973) have reviewed the geology of southwestern Australia, including the southern Perth Basin. A bibliography of publications on the geology of the basin is given by Raine and Smith (1972).

The great thickness of the sedimentary sequence in the Perth Basin was not appreciated until gravity traverses were made through Perth by Vening Meinesz (1948) and through Bullsbrook by Thyer (1951). These were followed by regional gravity and aeromagnetic surveys of the basin by the Bureau of Mineral Resources (Thyer and Everingham, 1956; Quilty, 1963). Wapet and its associated companies have since carried out numerous geophysical surveys in the Perth Basin, and they have also drilled many wells in the search for oil and gas. These have produced a wealth of subsurface information, which is continually expanding.

Cockbain commenced his subsurface study of the Perth Basin (mainly utilizing Wapet subsurface data made public under terms of the Petroleum Search Subsidy Act) while employed by Ashburton Oil N.L., and the company has made available the report on this work (Cockbain and Lehmann, 1971).

CULTURE

The first European contacts with the area of the Perth Basin were made by the Dutch navigators of the early 17th century, beginning with Frederick Houtman in 1619 (Heeres, 1899). Their voyages and shipwrecks are commemorated by a number of place names along the coast (for example, Cape Leeuwin, Rottnest Island, Houtman Abrolhos). However, during the 17th and 18th centuries the area was regarded as being of no commercial interest, and the first European settlement did not occur until 1829, when the British Government established the Swan River Colony at Perth.

Prior to European settlement the Perth Basin area had been inhabited by several thousand Aborigines. These nomadic people had occupied the area for at least 25 000 years (Merrilees and others, 1973), but they were rapidly decimated after the arrival of Europeans, and the last of the Bibbulmun people of the Swan River died in 1907. Today there is little trace of their long occupation of the Perth Basin area, apart from numerous place names.

Perth is the capital city of Western Australia and is by far the largest centre of population in the State. The population of the Perth metropolitan area (including that of the port, Fremantle) amounted to 639 622 in 1971 out of a total State population of 1 027 372. The next largest city in the area is Bunbury (population 17 762), followed by Geraldton (15 530). Other large country towns include Augusta, Busselton, Pinjarra, Mandurah, Rockingham, Moora, and Dongara.

The only large-scale industrial development in the basin is in the Perth-Fremantle-Kwinana area. Much of the land elsewhere is occupied by farms with wheat, sheep, and cattle production predominating in the north, and cattle (especially dairy cattle) in the south. Extensive areas of the sandplain that occupies much of the basin have recently been developed for agriculture.

The Perth Basin is traversed by an extensive network of roads and tracks, allowing ready access to most areas. The principal roads are sealed; the rest are mainly surfaced with laterite gravel.

ACKNOWLEDGEMENTS

We wish to thank the management of West Australian Petroleum Pty Ltd (Wapet) and Ashburton Oil N.L. for making available unpublished reports on the geology of the Perth Basin. Special thanks are due to S. P. Willmott and

D. Johnstone of Wapet and to P. R. Lehmann (formerly of Ashburton) for their contributions to these reports, which have been of considerable assistance in compiling the present publication.

We would also like to express our appreciation to D. C. Lowry (formerly of the Geological Survey) for the important part that he played in mapping the Perth Basin, and to B. E. Balme, M. H. Johnstone, D. K. Jones, J. R. H. McWhae, and G. J. Demaison for their assistance and advice during various stages of the project.

CHAPTER 2

Physiography

INTRODUCTION

The Perth Basin area is rather featureless; there are no conspicuous ranges of hills or mountains other than the Darling Range along the eastern boundary. Sandplain covers large areas, and both outcrop and good soil are essentially restricted to the major river valleys.

The area has a typical mediterranean climate, characterized by hot, dry summers, and cool, wet winters. During the summer months (December-February) the average maximum temperature in Perth is 28.8°C, and the average minimum is 17.1°C. In the winter (June-August) the equivalent temperatures are 17.7°C maximum and 9.3°C minimum. The average annual rainfall ranges from 1 016 mm in Augusta to 883 mm in Perth, 462 mm in Geraldton, and about 250 mm in the basin north of the Murchison River. Approximately 60 per cent of this rain falls in the winter months, and less than 5 per cent in the summer, the rest being distributed between spring and autumn.

The vegetation of the Perth Basin area is described by Gardner (1942), Speck (1958), and McArthur and Bettenay (1960). The most distinctive vegetation is the low heath of the sandplain country. The sandplain in its natural state has a very barren appearance, with few trees. This is not due to sparcity of rainfall, but to mineral deficiencies as a result of podzolization. The advent of modern fertilizers with added trace elements has allowed this poor soil to be developed for agriculture, and consequently large areas of sandplain have been cleared over the past 20 years.

In the northern part of the Perth Basin thick vegetation, consisting of *Acacia* and various eucalypts, is only developed on the heavier soils in dissected areas, and along river valleys. Most dissection, and some of the best soil, occurs just west of the Darling Fault and in the area north and east of Geraldton underlain by Jurassic sediments and Precambrian basement rocks. Most of the vegetation in these areas has now been cleared for agriculture.

At the southern end of the Perth Basin and along the Darling Range the lateritic soils are covered with thick forest. The principal trees are the eucalypts jarrah and marri, with extensive developments of tall karri forests over Precambrian rocks between Capes Leeuwin and Naturaliste and along the south coastal areas. Jarrah and karri are valuable hardwoods, and the forests support a vigorous timber industry.

Another distinctive zone of vegetation is developed along the belt of dune limestone near the coast. In the southern area this belt is covered by forest, the largest trees being the eucalypts tuart and jarrah, with a moderate to dense undergrowth of scrub.

The Perth Basin is drained by numerous ephemeral rivers and streams. Among the largest are the Murchison, Chapman, Greenough, Irwin, Arrowsmith, Hill, Moore, Swan, Canning, Serpentine, Murray, Collie, and Blackwood. Several of these, especially the Swan, Murray, Collie, and Blackwood, have well-developed estuaries.

The onshore Perth Basin lies within the South West or Swanland physiographic division of Jutson (1934) and the Donnybrook Sunkland and Swan Coastal Belt of Gentilli and Fairbridge (1951). We have differentiated the land area into 14 physiographic regions, based on their topographic and geologic characteristics (Fig. 2). They can be broadly grouped into coastal plains (Swan and Scott Coastal Plains), plateaus (Darling, Victoria, Dandaragan, and Blackwood Plateaus), islands and reefs, and miscellaneous regions (Naturaliste, Arrowsmith, Chapman, Lockier, Yarra Yarra, and Badgeradda Regions).

The submarine areas of the basin comprise the continental shelf, continental slope, and continental rise. The Naturaliste Plateau and Perth Abyssal Plain are other submarine physiographic features related to the Perth Basin.

Finkl and Churchward (1973) have recently applied the etchplain concept in subdividing the onshore areas here called plateaus and miscellaneous regions. They recognize a number of major landscape units which they call incipient (lateritic) etchplains, partial (lateritic) etchplains and semi-stripped etchplains. In addition, Finkl and Churchward also recognize etchscarps (the Darling and Gingin Scarps) and etch-entrenchments (river valleys incised in the plateaus). Their local subdivisions, which differ from ours, are defined mainly on relief, drainage texture, and soil material. The original paper should be consulted for details.

The following is a summary of the geomorphology of the physiographic regions recognized in this bulletin.

COASTAL PLAINS

SWAN COASTAL PLAIN

The Swan Coastal Plain (Saint-Smith, 1912) is a low-lying, gently undulating area covered largely by Holocene and Pleistocene coastal-dune and shoreline deposits, with belts of alluvium in front of the Darling Scarp and along the river valleys. For most of its length the plain is bordered by the Whicher, Darling, and Gingin Scarps, and by the present coastline. Soils and related aspects of the geomorphology of the plain are described by McArthur and Bettenay (1960), and a comprehensive description of the geology, geomorphology, and culture is given by Seddon (1972).

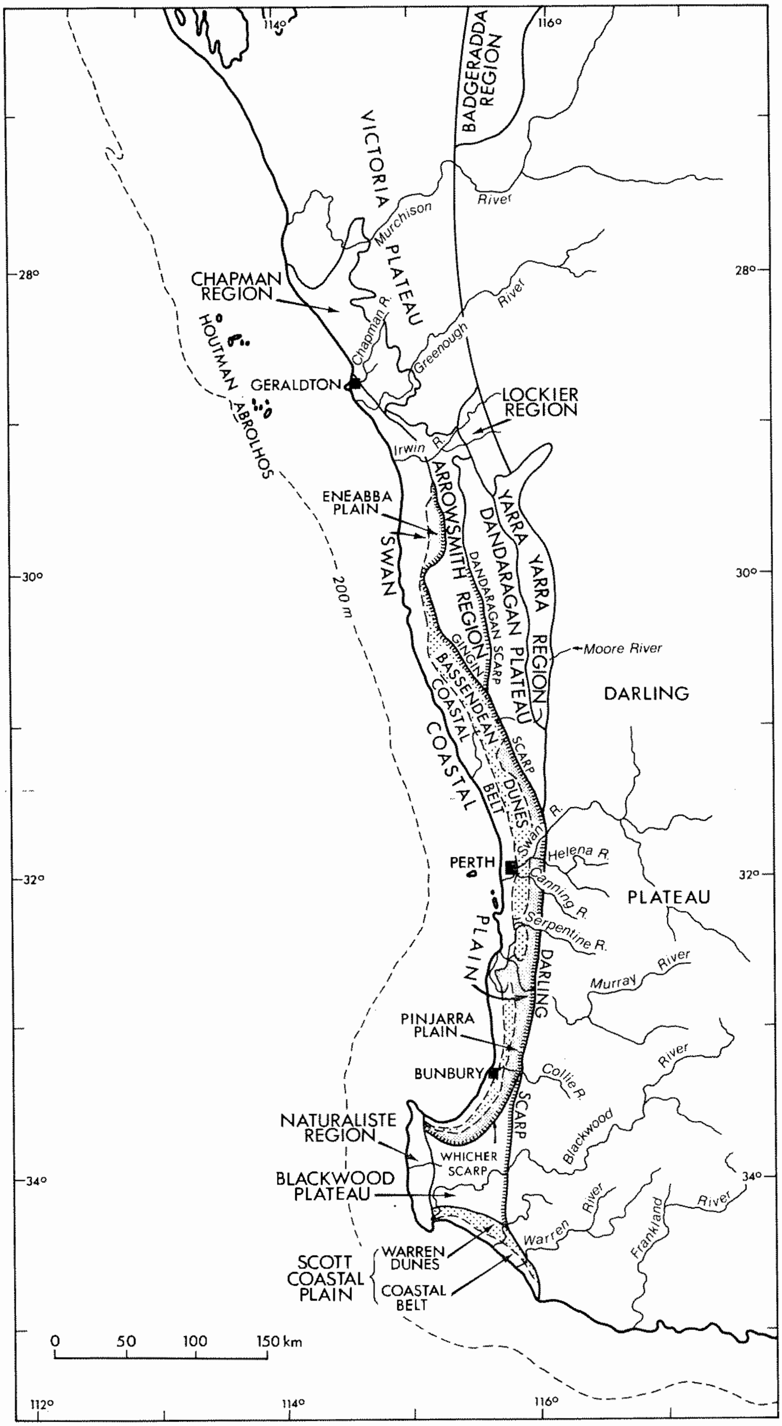

Figure 2. Physiographic regions, Perth Basin and adjoining areas.

A series of shoreline and associated dune deposits ranging from early Pleistocene or late Tertiary to Holocene in age, are recognized on the Swan Coastal Plain (McArthur and Bettenay, 1960; Lowry, 1965; Baxter, 1974). These deposits generally show a progressive decrease in age and elevation passing from east to west. The oldest (and highest) deposits occur on the Darling Scarp, while the youngest (and lowest) adjoin the present coast and extend offshore to the reefs and islands. They occur in bands which generally parallel the Gingin, Darling, and Whicher Scarps and the present coast. The most recent changes in sea level are evidenced by Holocene wave-cut benches in the Tamala Limestone (the 10-11 foot, 5-6 foot, and 2-3 foot sea levels of Fairbridge, 1953).

This succession of shorelines is generally ascribed to eustatic changes in sea level associated with waxing and waning of the ice caps during the Pleistocene (Fairbridge, 1953 and 1954; McArthur and Bettenay, 1960). Similar Pleistocene shorelines elsewhere in the world have similarly been explained by some authorities as being due to eustatism (Fairbridge, 1961).

While we agree that eustatic changes in sea level are likely to have controlled the positions of at least some of the shorelines, the picture may be complicated by tectonism. It is possible that in the area of the Darling Scarp the Darling Fault has been active during the Cainozoic. Although there has been no activity along the fault in historic times, it could conceivably have moved during the Pleistocene, and such movement would have influenced the shoreline positions. Moreover, even if the Darling Fault has been quiescent during deposition of the various shorelines deposits, epeirogenic uplift of the Darling Plateau is believed to have taken place during the Tertiary and may have continued to the present day. Total uplift of the plateau since the Eocene has probably amounted to at least 300 m (Cope, 1975). If uplift of the plateau was not accompanied by concomitant movement along the Darling Fault, the Perth Basin must also have been uplifted, although the uplift is expected to have diminished towards the western and southern margins of the basin owing to peripheral sagging of the continent. If pulses of uplift occurred during the late Tertiary and Pleistocene, these together with eustatic changes of sea level, could have jointly controlled the succession of shorelines on the Swan Coastal Plain.

There is evidence that at least one of the shorelines has been warped. The base of the Yoganup Shoreline deposits (probably late Tertiary or early Pleistocene) ranges in elevation from about 47 m in the south near Yoganup to about 37 m in the north near Dardanup (J. Sofoulis, written comm., *in* Cope, 1975). This northerly slope of about 1 : 2 500 may be related to Quaternary upwarping of the Jarrahwood Axis, which appears to run east-west through the Blackwood Plateau (Cope, 1975). It confirms that the present elevation of these shoreline deposits is not entirely limited by relative elevations of eustatic sea levels, but is at least partly controlled by tectonism.

Geomorphic units associated with the shorelines on the Swan Coastal Plain have been named by McArthur and Bettenay (1960)—the Ridge Hill Shelf (probably late Tertiary or early Pleistocene), Bassendean Dune System (probably early to middle Pleistocene), Spearwood Dune System (late Pleistocene), and Quindalup Dune System (Holocene). Baxter (1974) has also named a number of shorelines having economic significance for heavy-mineral sands. These are discussed (and slightly modified) in the economic geology section of this bulletin, and are shown on Figure 64.

We recognize four main subdivisions of the Swan Coastal Plain; these are the Coastal Belt, Bassendean Dunes, Pinjarra Plain, and Eneabba Plain.

The *Coastal Belt* consists of the Holocene shoreline deposits and dunes (the Quindalup Dune System of McArthur and Bettenay, 1960), backed by hills of late Pleistocene dune limestone (the Spearwood Dune System of McArthur and Bettenay). The belt is commonly about 8 km wide, reaching a maximum of some 20 km.

Dunes of the Quindalup Dune System are composed of lime and quartz sand, and reach a maximum elevation of about 200 m, near Hamelin Bay. The dunes are generally oriented parallel to the present coast. However, in the northern part of the basin the prevailing south-southwesterly winds are very strong, and the dunes are oriented parallel to this wind direction. Good examples of such longitudinal dunes occur near Dongara.

The Spearwood Dune System is believed to have developed during the late Pleistocene Würm Glacial Period (Teichert, 1967), when sea level stood lower than today. Successive positions of the coast during this period are marked by lines of dune limestone. These extend offshore, forming parallel lines of islands and submerged reefs. Eolianite of the Spearwood Dune System (Tamala Limestone, or "Coastal Limestone" of earlier usage) is exposed in cliffs along some sections of the coast (Fig. 45). It generally forms hills of relatively low relief following the old dune topography but greatly lowered by rain-water solution.

Well-developed cave systems occur in the limestone in a number of localities in the Coastal Belt between Dongara and Yanchep; prominent examples include Stockyard Gully and Weelawadji Caves north of Hill River, and the Yanchep Caves.

The Tamala Limestone is commonly leached at the surface, leaving a residue of yellow to white quartz sand. The contact between sand and unleached limestone is irregular, with rounded pinnacles of limestone extending upwards into the sand. In some places where vegetation has been removed the sand has been blown away, exposing the irregular limestone surface. This results in a distinctive and unusual topography, spectacular examples being The Pinnacles and Tombstone Rocks, near Cervantes (Fig. 3).

The flood plain of the Greenough River near its mouth (at the northern end of the Coastal Belt) is known as the Greenough Flats. The flats are divided into two parts by a low sand-covered ridge of Pleistocene eolianite (Tamala

Limestone) parallel to the coast. The river flows north for some 16 km along the outer flats before breaking through the coastal sand dunes. The river mouth must have been progressively displaced northwards by migrating dunes driven by the extremely strong prevailing south-southwesterly winds. Trees on the flats have been bent over parallel to this wind direction, growing almost horizontally.

The *Bassendean Dunes* occur in a zone up to 20 km wide between the Coastal Belt and the Pinjarra Plain or the Darling Scarp. They form low hills of quartz sand having elevations up to a maximum of some 100 m above sea level. Swampy areas and small lakes commonly occur in the interdune valleys. The dunes are generally oriented parallel to the present coast. McArthur and Bettenay (1960) referred to these dunes as the Bassendean Dune System. They represent a belt of coastal dunes and associated shoreline deposits which are believed to have accumulated during the early to middle Pleistocene, probably during interglacial periods of high sea level. The deposits originally consisted largely of lime sand with smaller proportions of quartz sand, but the carbonate has since been almost entirely leached out in most areas. The present shape of the dunes is largely inherited from that of the original coastal dunes, but the relief has been much diminished as a result of leaching.

Figure 3. The Pinnacles, developed in Tamala Limestone near Cervantes. The cylindrical columns of limestone represent strongly lithified fillings of solution pipes which formed in the eolianite during an earlier erosion cycle. The surrounding softer eolianite has been decalcified leaving a residue of sand, which has since been blown away to expose the resistant columns.

The *Pinjarra Plain* was named by McArthur and Bettenay (1960). It is a piedmont and valley-flat alluvial plain developed in front of the Darling, Whicher, and Gingin Scarps, and along the main river courses. The plain is generally about 8 km wide, but it is considerably wider (east-west) along the river valleys. In elevation it ranges up to 160 m above sea level. The plain is surfaced mainly by clays and loams in the valley flats and by poorly sorted clayey sands and gravels in the piedmont zone.

McArthur and Bettenay (1960) suggest that development of the Pinjarra Plain began after retreat of the sea at the end of the Mindel-Riss Interglacial Period. However, it now seems likely that it first formed even earlier. The Bassendean Dune System developed on the surface of the plain, while the Spearwood and Quindalup Dune Systems represent successively younger coastal deposits.

The *Eneabba Plain* is a low-lying area between the Coastal Belt and the northern re-entrant of the Gingin Scarp. It is built up of a series of early Pleistocene (or late Tertiary) shoreline, lagoon, and dune deposits having locally high concentrations of heavy minerals. These deposits are associated with a series of low alluvial fans fronting the Gingin Scarp.

SCOTT COASTAL PLAIN

The Scott Coastal Plain is a low-lying swampy region, up to 15 km wide, along the south coast. It includes a series of early Pleistocene (or late Tertiary) to Holocene dune and shoreline deposits similar to those occurring on the Swan Coastal Plain. These are also discussed in the economic geology section of this bulletin, and are shown on Figure 64.

The Scott Coastal Plain is broadly divided into two main subdivisions, the Coastal Belt and the Warren Dunes, although there is commonly no clear-cut boundary between the two.

The *Coastal Belt* consists of modern dunes backed by a discontinuous development of Tamala Limestone. The coast of Flinders Bay is actively prograding at present.

The *Warren Dunes* are represented by scattered hills and ridges of podzolized sand, with intervening swamps.

PLATEAUS

DARLING PLATEAU

The Darling Plateau is a laterite-capped plateau overlying Archaean crystalline rocks immediately east of the Perth Basin. It rises to an average elevation of about 400 m above sea level and is dissected by a number of rivers. The plateau is bounded to the west for part of its length by the *Darling Scarp*.

the fault-line scarp of the Darling Fault. The scarp has its strongest expression between Muchea and Dardanup, where it is up to 400 m high and is dissected by youthful streams. In this area movement along the fault may have continued in to the Cainozoic, where as elsewhere it may have been essentially quiescent since the mid-Neocomian.

The Darling Scarp formed coastal cliffs during the late Tertiary or early Pleistocene. It joins the Gingin and Whicher Scarps, which also formed parts of the coastline at that time, but are believed to be purely scarps of marine erosion rather than fault-line scarps.

Uplift of the Darling Plateau probably began during the mid-Tertiary, prior to the main period of lateritization in the area (Playford, 1954; Prider, 1966; Finkl, 1971; Cope, 1975). It may be continuing today.

DANDARAGAN PLATEAU

The Dandaragan Plateau is a sand and laterite-capped plateau, overlying Cretaceous sediments, which stands some 200 to 300 m above sea level in the central part of the Perth Basin. The surface of the plateau is flat to gently undulating, and for large areas it is essentially undissected. Most of the precipitation is absorbed by the surface sand and laterite.

The plateau is bounded to the west and southwest by the *Dandaragan* and *Gingin Scarps.* The Dandaragan Scarp is a fairly prominent topographic feature up to some 50 m high, which separates the southern part of the Arrowsmith Region from the Dandaragan Plateau. The Gingin Scarp is more conspicuous, being up to 75 m high. The linearity of this scarp, especially in the area between the Moore River and Muchea, led to conjecture that it represented a fault scarp (Woodward, 1917). However, it is now thought to have formed as a scarp of marine erosion associated with an early Pleistocene or late Tertiary high stand of sea level. At its northern end the scarp steps eastward and separates the Arrowsmith Region from the Eneabba Plain.

VICTORIA PLATEAU

The Victoria Plateau is a large, gently undulating area of sandplain north of the Irwin River, which extends into the southern Carnarvon Basin. It averages about 250 m above sea level. The sandplain overlies laterite, which crops out around the edges of breakaways where the plateau has been dissected, and in some larger areas where the sand has been stripped away. In the Perth Basin part of the plateau, the laterite in turn overlies ?Tertiary, Jurassic, and Permian sediments. In the Carnarvon Basin the plateau also overlies Cretaceous rocks. Elongate sand dunes have developed in some areas on top of the plateau. These are yellow in the south and red in the north; presumably this change in colour has a climatic origin, perhaps associated with an increase in temperature and decrease in precipitation to the north. There is little surface drainage, as most of the rainfall is absorbed by the porous sand.

The Greenough and Murchison Rivers have cut through the plateau in a series of large incised meanders. Rejuvenation of these rivers is believed to have resulted from uplift of the plateau. This uplift preceded lateritization in this area, and probably took place in middle to late Tertiary times (Playford, 1954).

BLACKWOOD PLATEAU

The Blackwood Plateau is a gently undulating laterite and sand-covered area between the Swan and Scott Coastal Plains, ranging in elevation from about 80 to 180 m above sea level. It is lower than the adjoining Darling Plateau to the east, and has also been referred to as the "Low Plateau" (McArthur and Bettenay, 1960; Finkl, 1971). The laterite of the plateau overlies Cretaceous and Jurassic sediments. Cope (1972) suggested that the Blackwood Plateau was subject to broad upwarping along an east-west axis (the Jarrahwood Axis) during middle to late Tertiary times. He now believes (Cope, 1975) that warping continued into the Quaternary.

The northern margin of the Blackwood Plateau is marked by the *Whicher Scarp*, which is an average of about 50 m high. It is believed to have formed as a scarp of marine erosion during an early Pleistocene or late Tertiary period of high sea level. There are remnants of two high-level shorelines on the scarp, at elevations of 90 m and 75 m above present sea level (Lowry, 1965). There is no well-developed scarp at the southern margin of the plateau.

MISCELLANEOUS REGIONS

NATURALISTE REGION

The Naturaliste Region is a belt of relatively rugged country between Capes Leeuwin and Naturaliste. It consists of Precambrian crystalline rocks, largely capped by laterite, with Pleistocene dune limestone (Tamala Limestone), and Holocene coastal sand dunes.

The topography of the region shows a steep rise from the coastline to elevations of up to 220 m above sea level.

Spectacular caves are developed in the limestone at a number of localities between Yallingup and Augusta, well-known examples including Yallingup, Mammoth, Lake, and Jewel Caves. Their origin is discussed by Lowry (1965), who divides them into two groups: "stream caves" and "lake caves". Spelean deposits containing remains of extinct marsupials have been found in several caves, the best examples being Mammoth and Strong's Caves (Glauert, 1948; Cook, 1963; Lundelius, 1960; Merrilees, 1968).

Figure 4. View over the Swan Coastal Plain from the Gingin Scarp beside Cockleshell Gully. Note the typical sand-heath vegetation which characterizes much of the central Perth Basin. Cockleshell Gully (on the left) discharges into a number of ephemeral lakes (visible in the background) behind the coastal belt of Tamala Limestone and modern dunes. The slope in the foreground is surfaced by sand and laterite, which extend down almost to the level of the coastal plain.

Figure 5. View of the Moresby Range (Chapman Region) taken over the valley of the Chapman River. ***The prominent mesa on the right is*** **Mount Sommer.**

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ARROWSMITH REGION

The Arrowsmith Region is an undulating sandy area with hills of Cretaceous and Jurassic rocks, commonly capped by laterite. Some of the hills are flat topped, but in many the laterite surface slopes towards the present drainage channels. The area is drained by the Irwin, Arrowsmith, and Hill Rivers, and by a number of smaller watercourses, including Cockleshell Gully (Fig. 4). Some of these streams do not reach the sea, but terminate in swamps and lakes on the adjoining Swan Coastal Plain (Fig. 4).

The Arrowsmith Region occurs between the Swan Coastal Plain on the west and the Dandaragan Plateau, Lockier Region, or Victoria Plateau on the east. For much of its length the region is bounded on its west side by the Gingin Scarp and on the east by the Dandaragan Scarp.

CHAPMAN REGION

The Chapman Region is an area of Precambrian, Triassic, and Jurassic rocks drained by the Greenough and Chapman Rivers and their tributary streams. Pleistocene Tamala Limestone also occurs along the coast. Small flat-topped remnants of the Victoria Plateau (laterite capping Jurassic sediments) occur throughout much of the area, giving it a distinctive topography (Fig. 5). Precambrian rocks generally form rounded hills below the old plateau level in this area.

LOCKIER REGION

The Lockier Region is the area west of the Darling Plateau drained by the Lockier River, the upper part of the Irwin River, and the headwaters of the Arrowsmith River. It is underlain by Proterozoic, Permian, and Jurassic sediments and by Precambrian granitic rocks. Flat-topped outliers of the Victoria and Dandaragan Plateaus occur in the area. These are capped by laterite and sand, with thin developments of ?Tertiary sandstone below the laterite in some areas, overlying Permian sediments. The Precambrian rocks form a line of rounded hills (the Mullingarra Inlier).

Soils in the region are typically clayey, apart from sands capping and skirting the plateau outliers.

YARRA YARRA REGION

The Yarra Yarra Region forms a north-south strip between the Darling and Dandaragan Plateaus. The area is characterized by essentially internal drainage, with intermittent streams feeding into numerous swamps and salt lakes, the largest of which are the Yarra Yarra Lakes (Fig. 6). Chains of these lakes connect after very heavy rain, forming broad streams which flow south to the Moore River. In this way part of the drainage of the area periodically reaches the sea.

The Yarra Yarra Region is underlain by Precambrian crystalline rocks and by Proterozoic, Permian, Jurassic, and Cretaceous sediments. Laterite development is fairly extensive, and the soils range from sandy to clayey. The average elevation of the area is about 200 m, falling gradually to the south.

BADGERADDA REGION

The Badgeradda Region is situated immediately east of the Darling Fault at its northern end. The main part of the region is occupied by conspicuous ranges of Proterozoic sedimentary rocks: the Badgeradda Range, Woodrarrung Range, and Errabiddy Hills. The Badgeradda Range forms a narrow belt of north-south ridges standing as high as 80 m above the surrounding plain. At its southern end this range meets the east-west trending Woodrarrung Range, which is slightly higher, reaching some 100 m above the level of the plain, or about 330 m above sea level.

North of these ranges is a lower area underlain by Perm'an glaical sediments forming part of the Byro Sub-basin of the Carnarvon Basin. A low-lying strip underlain by Archaean rocks occurs to the west of the ranges, adjoining the Victoria Plateau. This strip is surfaced largely by alluvial deposits, and drainage is for the most part internal, into an extensive system of claypans, the largest of which is Bililly Claypan.

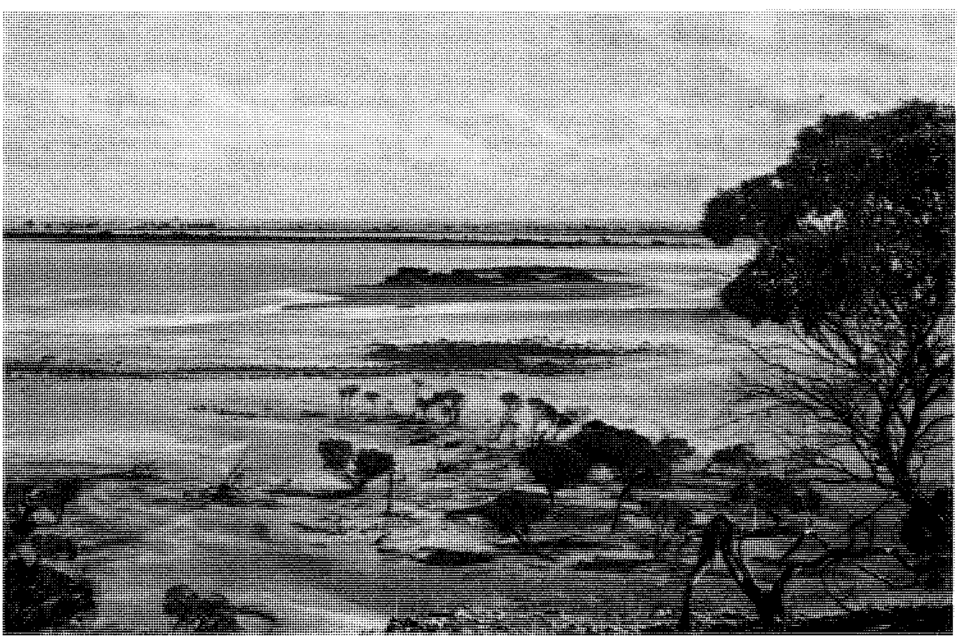


Figure 6. View of the Yarra Yarra Lakes (Yarra Yarra Region) looking south from about 5 km west of Prowaka.

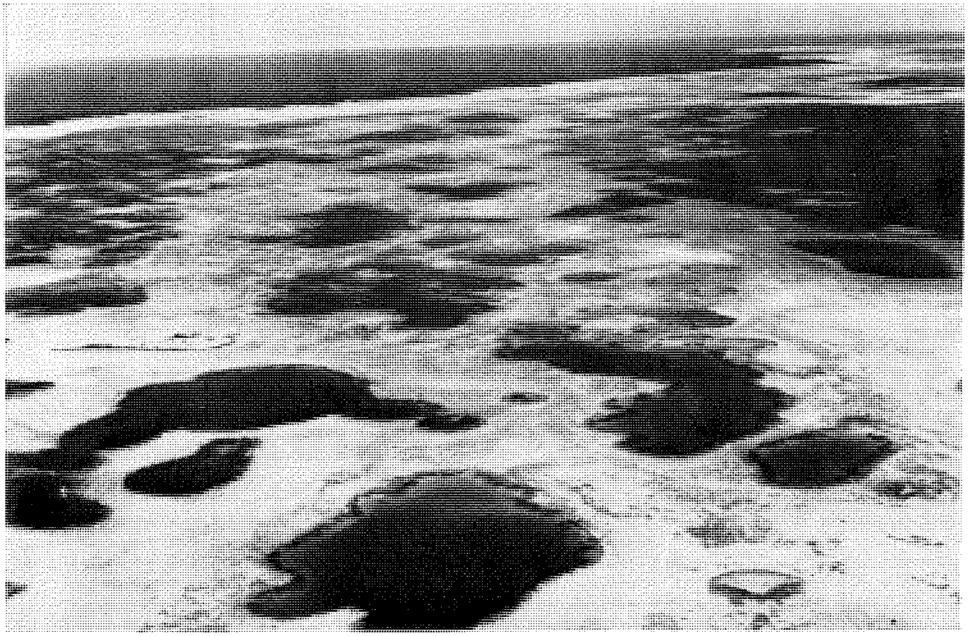


Figure 7. View looking southwest over the western part of the Pelsart Group, Hontman Abrolhos. The deep circular depressions occur in Pleistocene reefal limestone and are probably karst features formed during a period of greatly lowered sea level associated with the Würm glaciation. They are rimmed by prolific living coral. The upper surface of the Pleistocene limestone has been largely planed off at modern sea level, leaving some residual islands. The coral-algal reef rim forming the southern margin of the Pelsart Group can be seen in the background.

ISLANDS AND REEFS

There are numerous islands and lines of reefs developed off the coast in the Perth Basin. Most of these are composed of Tamala Limestone and represent old shoreline deposits which probably formed during intervals of the Würm Glaciation, when sea level was lower than today. They include Rottnest, Garden, and Penguin Islands near Perth (Glenister and others, 1959; Playford, 1950) and many small islands near the coast to the north. Of these, Rottnest is known to have a coral-reef foundation, formed during the Riss-Würm Interglacial period (Teichert, 1967), and in this respect it is similar to many islands of the Houtman Abrolhos, which straddle the northern margin of the basin.

The Houtman Abrolhos archipelago is situated some 80 km off the mainland coast, opposite Geraldton (Fig. 7). It consists of many small, low islands, most of them less than 1 km long, and less than 4 m above sea level. Notable exceptions are East and West Wallabi Islands, the largest in the island chain, which are up to 5 km long and 15 m high.

The Houtman Abrolhos islands consist of three groups, named the Wallabi, Easter, and Pelsart Groups, with another solitary island (North Island) at the northern end of the chain. Each of the island groups (and North Island) is fringed by extensive coral-algal reefs on its southern and western sides (facing the prevailing winds) and by broken reefs to the north. These are the southernmost well-developed coralline reefs in the Indian Ocean. The islands consist of Pleistocene reef, lagoon, and dune limestones, and Holocene coral-algal shingle thrown up by storms.

The islands show a number of conspicuous features that may have developed in response to eustatic changes of sea level during the late Pleistocene and early Holocene. Sea level was apparently at least 7.5 m higher than today when the lagoonal "Wallabi Limestone" was being deposited, and there are several levels of late Pleistocene to Holocene elevated beach ridges and wave-cut platforms which give evidence of various intermediate sea levels. During the period of lowest sea level associated with the last (Würm) glaciation the islands would have been connected to the mainland, while during the periods of high sea level evidenced by elevated wave-cut benches and beach ridges only West Wallabi and East Wallabi Islands would have remained above sea level. Numerous broad, deep, circular depressions are developed on the reef flats composed of Pleistocene reefal limestone (Fig 7). These depressions are probably karst features formed during the last glacial period.

Further details of the physiography of the islands are given by Teichert (1947b), Fairbridge (1948b), and Storr (1965).

SUBMARINE AREAS

Bathymetric contours on the sea floor west and south of the onshore Perth Basin are shown on Plates 1 and 2. The information has been compiled from Admiralty charts and marine seismic survey data, with additional information taken from the paper by von der Borch (1968).

The marine physiographic features recognized on the sea floor in this area are the continental shelf, continental slope, continental rise, Naturaliste Plateau, and Perth Abyssal Plain (Fig. 38).

CONTINENTAL SHELF

The continental shelf area of the Perth Basin has been briefly described by Carrigy and Fairbridge (1954). Much of the surface of the shelf is covered by coarse terrigenous sediment, which generally becomes finer grained towards the shelf edge. Shoals and bare rock occur in some areas, most of the rock exposures consisting of Tamala Limestone, with some granitic rocks in the area of the Leeuwin Block.

Carrigy and Fairbridge recognize two main subdivisions of the continental shelf, in the offshore Perth Basin area, which they have named the Rottnest Shelf and Recherche Shelf.

The *Rottnest Shelf* extends from the northern end of the Houtman Abrolhos to Cape Leeuwin, ranging in width from about 90 km in the Abrolhos area to 50 km opposite Perth, 100 km at Geographe Bay, and 45 km between Capes Leeuwin and Naturaliste. The shelf can be subdivided into a broad, gently sloping inner shelf extending to depths of about 50 m, and a narrow, more steeply sloping outer shelf. The break in slope at the edge of the shelf is at about 180 to 200 m. Carrigy and Fairbridge suggest that a number of terraces can be recognized on the shelf at depths of 5-9 m, 18-22 m, 36-46 m, 55-64 m, 101 m, 110 m, 137 m, 155 m, 174 m, and 183 m. These were at least partly related by Carrigy and Fairbridge (1954), and more definitely by Fairbridge (1961) to Quaternary eustatic sea levels. However, it seems possible that they are at least partly tectonically controlled.

The *Recherche Shelf* extends from Cape Leeuwin to Israelite Bay at the edge of the Great Australian Bight. The shelf is about 65 km wide near Cape Leeuwin, but narrows to 45 km just east of the area shown on Figure 38. Inner and outer shelf subdivisions can be distinguished, the inner shelf having a uniform depth of about 45 m, and the outer shelf sloping to the shelf edge at a depth of about 165 m. Carrigy and Fairbridge (1954) refer to terraces on the shelf at depths of about 18-27 m, 35 m, 65 m, 75 m, 90 m, and 140 m.

CONTINENTAL SLOPE

The continental slope extends from the break in slope at the edge of the shelf to about the 4 000 m bathymetric contour, where it passes into the continental rise or the saddle which separates the slope from the Naturaliste Plateau. Much of the continental slope over the Perth Basin is underlain by thick Phanerozoic sedimentary rocks.

A prominent submarine canyon, the Perth Canyon, cuts through the continental slope west of Rottnest Island (von der Borch, 1968). This canyon does not now extend onto the continental shelf, but the deep valley eroded into the Cretaceous rocks and filled with Paleocene to Early Eocene Kings Park Formation may represent an ancient infilled portion of the canyon.

Just east of the Perth Basin and south of Point d'Entrecasteaux, von der Borch (1968) has mapped and named three submarine canyons, the Leeuwin, d'Entrecasteaux, and Broke Canyons. Branson (1974) recognized a terrace near the foot of the slope opposite Geraldton.

CONTINENTAL RISE

The continental rise is a broad, gently sloping area between the continental slope and the abyssal plain, generally between about the 4 000 m and 5 000 m bathymetric contours. We also recognize it as extending around the Naturaliste Plateau.

Site 259 of the Deep Sea Drilling Project (Fig. 38) is situated on the continental rise opposite Geraldton (Veevers and others, 1973). This hole penetrated some 300 m of Quaternary, Tertiary, and Cretaceous sediments, overlying basalt dated as 118-136 m.y. (Heirtzler and others, 1973).

NATURALISTE PLATEAU

The Naturaliste Plateau is a broad area (covering about 120 000 km^2), between depths of about 2 200 and 2 500 m, lying west of the continental shelf opposite Capes Leeuwin and Naturaliste. A sedimentary sequence up to 2 km thick is believed to be present beneath the plateau, but its relationships to the Perth Basin have not yet been defined.

Three deep-sea holes have been drilled on the Naturaliste Plateau (Fig. 38), at sites 258, 264, and RC8-56 (Luyendyk and others, 1973; Hayes and others, 1973; Burckle and others, 1967). The section penetrated in each is illustrated on Figure 38.

PERTH ABYSSAL PLAIN

The Perth Abyssal Plain is a flat area of ocean floor below depths of about 5 000 m. It is situated west of the Perth Basin and north of the Naturaliste Plateau, and forms part of the oceanic Wharton Basin. The plain is underlain by thin sediments resting on oceanic crust.

There is no named abyssal feature at the foot of the continental rise south of the Naturaliste Plateau and the southern end of the Perth Basin. In this area the ocean floor below the continental rise is marked by a series of abyssal hills and plains.

CHAPTER 3

General Geology

INTRODUCTION

Exposures of pre-Quaternary rocks in the Perth Basin are generally poor and discontinuous owing to the extensive covering of sand, laterite, and other superficial deposits, which extend over about 90 per cent of the surface of the basin. In addition, many of the outcrops have been deeply weathered below laterite, and this commonly masks the original nature of the sedimentary rocks.

The best exposures of Phanerozoic rocks older than Quaternary occur along river drainage systems in the northern part of the basin, especially in valleys of the Murchison, Chapman, Greenough, and Lockier Rivers. Poorer exposures occur in valleys of the Hill River and Cockleshell Gully and around Gingin, Dandaragan, Bullsbrook, and intervening areas. In the southern part of the basin (south of Perth) nearly the whole of the surface is covered by Quaternary deposits, and the main pre-Quaternary exposures occur in very small areas around Donnybrook, Bunbury, Black Point, and Fly Brook.

Despite severe outcrop limitations, much of the basic Perth Basin stratigraphy was originally determined from surface mapping. However, subsurface information from geophysics and drilling has greatly expanded our knowledge of the sedimentary sequence, and several of the rock units are known only from well sections. Details of the regional structure of the basin have mainly been obtained by aeromagnetic, gravity, and seismic surveys.

LIMITS OF THE BASIN

The Perth Basin is a deep trough filled with sedimentary rocks, nearly 1 000 km long and averaging about 65 km in width. The total thickness of Phanerozoic sediments may exceed 15 000 m.

The eastern margin of the basin is defined throughout most of its length by the Darling Fault, which generally marks the contact between the Perth Basin Phanerozoic section and the granitic rocks of the Yilgarn Block. However, in some areas Phanerozoic sediments overlap the fault for short distances. Gravity and aeromagnetic surveys indicate that the Darling Fault dies out near the northern end of the Badgeradda Range, and this is taken to be the northern limit of the basin.

In its northern part the basin is bordered to the west by a ridge of relatively shallow basement rocks (the Ajana Ridge), which extends north from the Northampton Block. The northern limit of the basin on the continental shelf is harder to define. It has been drawn along a weakly defined basement arch (the Batavia Arch) which passes beneath the Houtman Abrolhos from the western end of the Northampton Block.

The boundary between the Perth and Bremer Basins has not been adequately delineated on the continental shelf owing to the lack of suitable geophysical control.

The western and southern offshore margins of the Perth Basin have not been precisely defined. However, significant thicknesses of Phanerozoic sedimentary rocks probably extend to about the foot of the continental rise (close to the 5 000 m bathymetric contour). The relationships of the Naturaliste Plateau to the Perth Basin have also not been resolved. A thick sedimentary section is believed to be developed below the plateau, but it may be best to regard this as forming part of a separate sedimentary basin. These matters may be clarified when the full results of recent seismic surveys in the area become available.

BASEMENT ROCKS

The basement complex adjoining and underlying the Perth Basin consists of Archaean and Proterozoic igneous and metamorphic rocks. These are exposed in the Yilgarn Block, Northampton Block, Leeuwin Block, and Mullingarra Inlier (Fig. 8). Precambrian basement rocks penetrated in wells drilled in the Perth Basin are described by Peers and Trendall (1968).

YILGARN BLOCK

The Yilgarn Block occupies a large part of the Western Australian Shield east of the Darling Fault. Two main subdivisions of the block adjoin the Perth Basin: the Southwestern Province (Williams, 1975) and the Murchison Province (de la Hunty, 1975). The boundary between these two provinces meets the Darling Fault at the Greenough River.

The Southwestern Province is made up predominantly of Archaean magmatic and migmatitic granitic rocks, with some small areas of metasediments and amphibolite. They are intruded by dolerite dykes of presumed Proterozoic age. The grade of metamorphism ranges from amphibolite to granulite facies. Structural trends are dominantly northwesterly. Gneisses in the province have been dated from 2 800 to 3 100 m.y., while the granites that intrude them give isotopic age datings from 2 600 to 2 700 m.y.

The Murchison Province which adjoins the northernmost part of the Perth Basin consists of north to northeast-trending Archaean greenstone belts separated by granite plutons and cut by ?Proterozoic dolerite dykes. The metamorphic grade is generally greenschist facies. The granitic rocks in the province have been dated as 2 600 m.y.

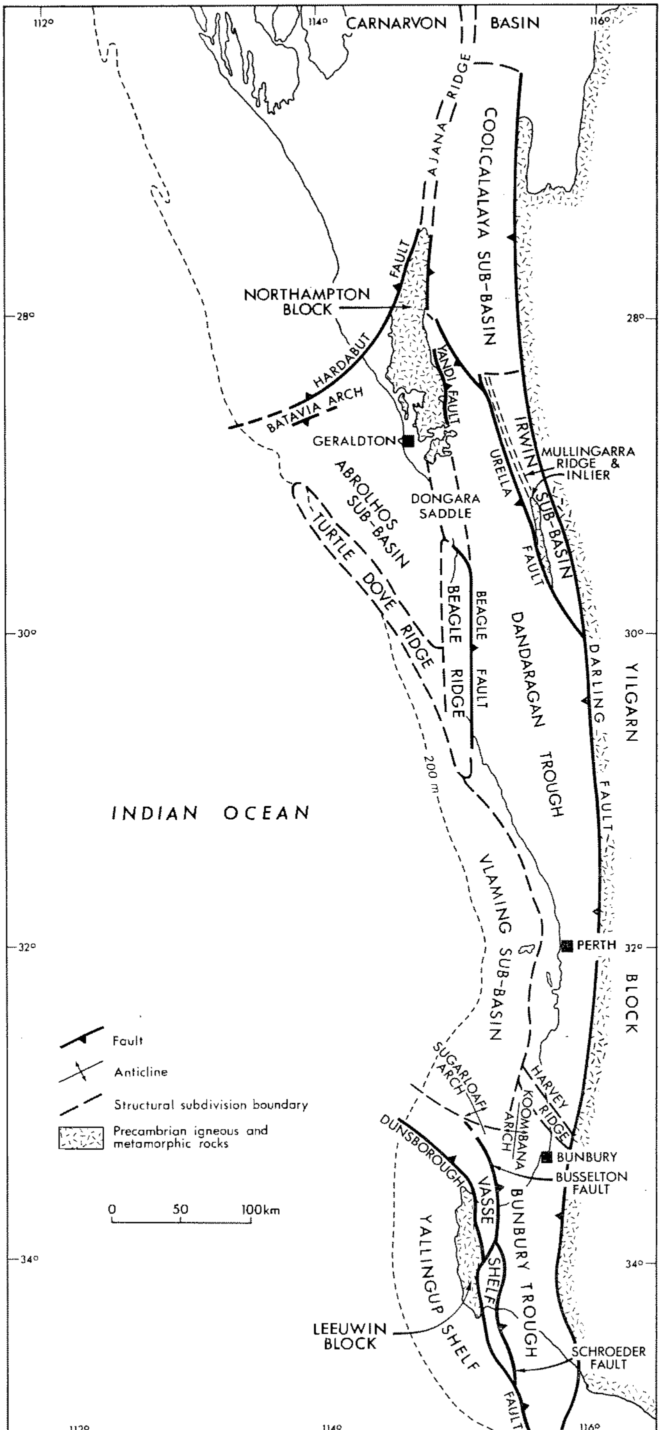


Figure 8. Structural subdivisions, Perth Basin.

Several areas of Proterozoic sedimentary rocks occur on the Yilgarn Block adjacent to the Perth Basin, belonging to the Badgeradda, Billeranga, Yandanooka, Moora, and Cardup Groups, the Wenmillia Formation, and the Nilling and Dudawa Beds.

The Yilgarn Block has been the source of much of the sedimentary section in the Perth Basin.

NORTHAMPTON BLOCK

The Northampton Block is a relatively small area of Proterozoic crystalline basement surrounded and onlapped by Phanerozoic sediments, near the northern end of the Perth Basin. The rocks of the Northampton Block consist of three broad units: granulite, granite, and migmatite. The granulites are of metasedimentary origin. They have been intruded by granite, with the development of migmatites along the boundaries. The granulites have been dated by Compston and Arriens (1968) as 1 040 ± 50 m.y.

The Northampton Block is cut by a dense swarm of dolerite dykes, which strike north-northeast and are usually steeply dipping. Lead, copper, zinc, and silver mineralizations have occurred along fractures parallel to the dolerite dykes, although some follow other fracture directions or gneissic banding (Blockley, 1971).

The block has been a positive feature throughout the Phanerozoic history of the Perth Basin. Its northwestern boundary is marked by the Hardabut Fault, but this has been inactive for most of its length since the Silurian. There are some smaller faults along other parts of the block margins, but in general the relationship with the Phanerozoic rocks is one of onlap. Outliers of Phanerozoic rocks (mainly of Mesozoic age) occur over basement in many parts of the block.

LEEUWIN BLOCK

The Leeuwin Block is a narrow belt of Proterozoic granulite and gneiss between Capes Leeuwin and Naturaliste. The granulites have been dated by Compston and Arriens (1968) as 670 ± 25 m.y.

The Leeuwin Block is thought to have been a positive feature throughout much of Phanerozoic time. The eastern boundary of the block is defined by the Dunsborough Fault, which has not operated since the Early Cretaceous. The western margin is probably marked by simple onlap rather than by faulting.

MULLINGARRA INLIER

The Mullingarra Inlier is a narrow belt of granitic gneiss east of the Urella Fault. It is overlapped to the east by Proterozoic sediments. A pegmatite in granitic rocks of the inlier has been dated as 1 120 m.y. (Wilson and others, 1960).

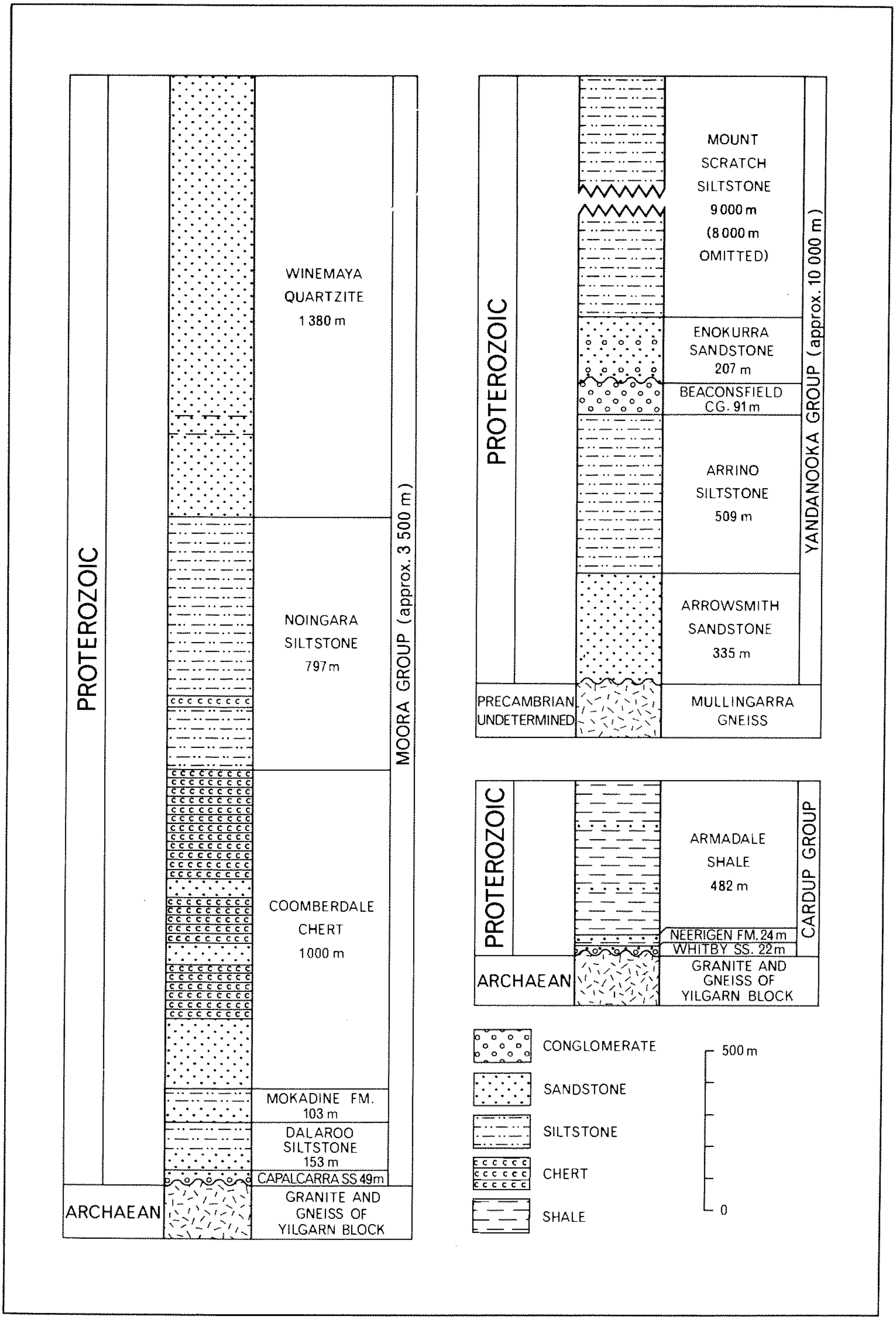


Figure 9. Proterozoic stratigraphic columns, Perth Basin.

STRATIGRAPHY

The stratigraphy of the Perth Basin is illustrated on Plate 4 and on Figures 9 and 10.

PROTEROZOIC

Sedimentary rocks of Proterozoic age are exposed at several localities in or adjoining the Perth Basin, in each case lying close to the Darling Fault. They consist mainly of siliciclastic rocks, in some cases containing a high proportion of volcanically derived material. Lava flows also occur at two localities. The Proterozoic sediments (apart from the Yandanooka Group) are cut by dolerite dykes.

The precise ages of the sequences are uncertain, but they probably range from Middle to Late Proterozoic. The total maximum thickness of the Proterozoic section probably exceeds 10 000 m.

SILURIAN

The Silurian is represented in the Perth Basin by a single formation, the Tumblagooda Sandstone. This unit probably exceeds 3 000 m in thickness. No diagnostic fossils have been found, but on stratigraphic grounds it is placed in the Silurian.

DEVONIAN

No Devonian rocks have been recognized either in outcrop or in the subsurface of the Perth Basin. However, remanié Devonian plant microfossils have been found in a Cretaceous unit in the northern part of the basin, and this suggests that Devonian strata were being eroded nearby in Cretaceous times.

PERMIAN

The Permian System is well represented in the Perth Basin, the total thickness of these rocks probably exceeding 2 600 m. In the northern part of the basin the section is mixed marine and continental, with a glacial unit at the base. The equivalent section in the south is entirely continental.

Permian rocks crop out in the valleys of the Murchison, Greenough, Irwin, Lockier, and Arrowsmith Rivers. Elsewhere in the basin they are known only from well sections.

TRIASSIC

The Triassic sequence in the Perth Basin may exceed 2 500 m in thickness. In the north it is marine in the lower part and grades upwards through paralic to continental, but in the south virtually the whole of the section is continental.

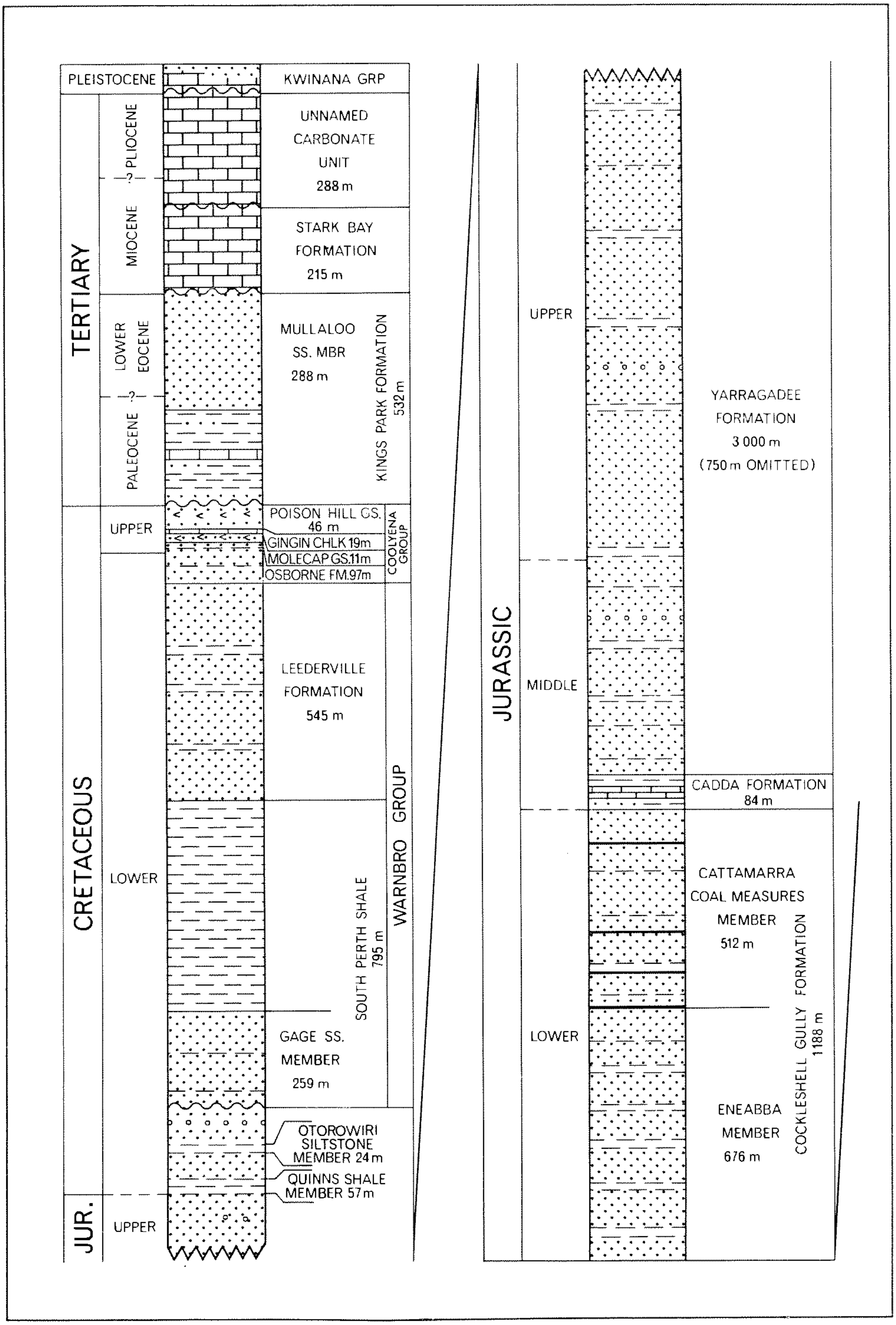
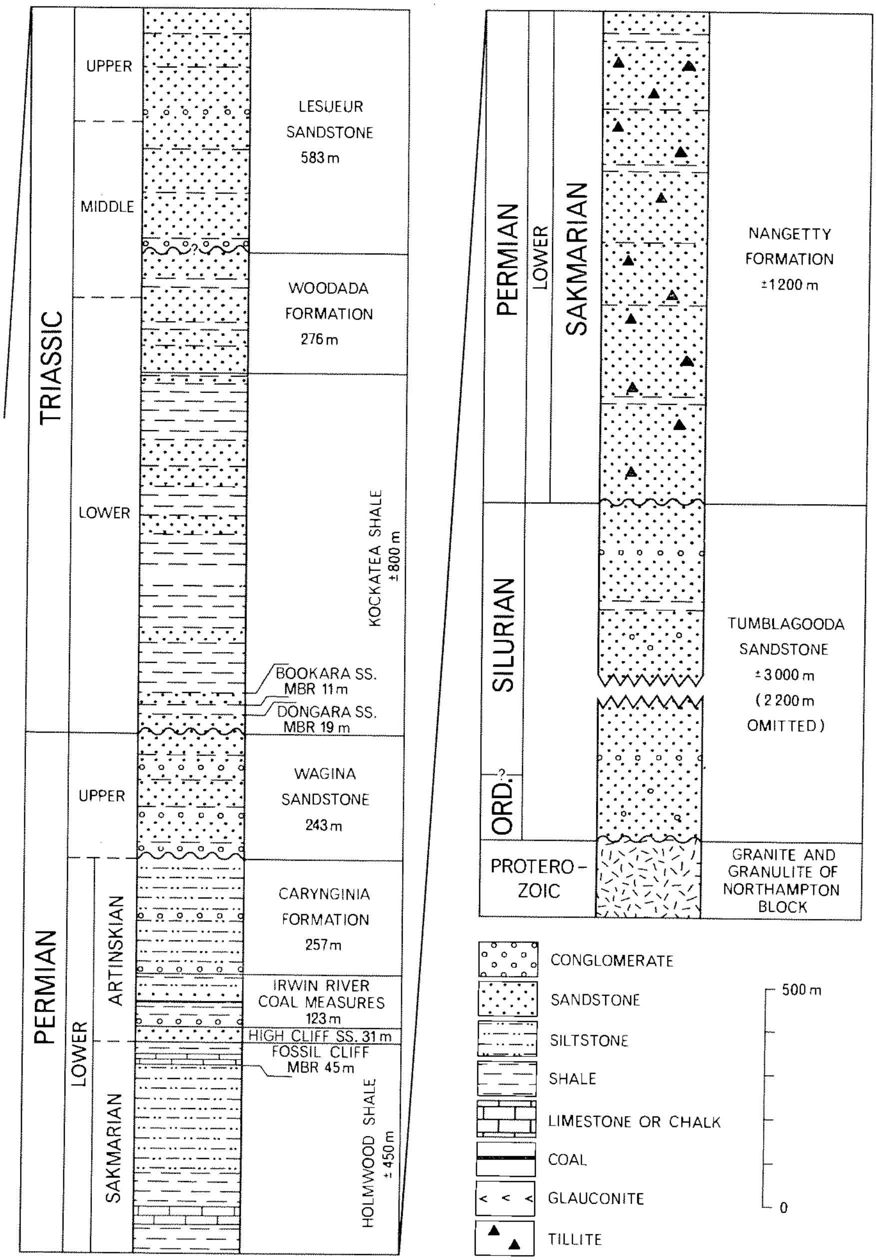


Figure 10 (above and opposite). Phanerozoic stratigraphic column, Perth Basin.


TRIASSIC
UPPER
MIDDLE
LOWER
LESUEUR SANDSTONE 583 m
WOODADA FORMATION 276 m
KOCKATEA SHALE ±800 m
BOOKARA SS. MBR 11 m
DONGARA SS. MBR 19 m
PERMIAN
UPPER
LOWER
ARTINSKIAN
SAKMARIAN
WAGINA SANDSTONE 243 m
CARYNGINIA FORMATION 257 m
IRWIN RIVER COAL MEASURES 123 m
HIGH CLIFF SS. 31 m
FOSSIL CLIFF MBR 45 m
HOLMWOOD SHALE ± 450 m
PERMIAN
LOWER
SAKMARIAN
NANGETTY FORMATION ±1200 m
SILURIAN
ORD.
?
TUMBLAGOODA SANDSTONE ±3 000 m (2 200 m OMITTED)
PROTERO-ZOIC
GRANITE AND GRANULITE OF NORTHAMPTON BLOCK
CONGLOMERATE
SANDSTONE
SILTSTONE
SHALE
LIMESTONE OR CHALK
COAL
GLAUCONITE
TILLITE
500 m
0

The only exposures of Triassic rocks in the basin are in the Geraldton and Hill River districts, but they occur in the subsurface throughout much of the basin.

Sedimentation in the Perth Basin seems to have been virtually continuous from Middle Triassic to Early Cretaceous (Neocomian) times, without any major changes in the type of sedimentation.

JURASSIC

Jurassic sediments are widespread throughout the Perth Basin, and are believed to be at least 4 200 m thick. The sequence is mainly continental, with a thin, discontinuous marine intercalation of Middle Jurassic age in the northern part of the basin. The best exposures are in the Geraldton and Hill River districts, but sporadic outcrops occur widely between these areas.

CRETACEOUS

Two important unconformities occur in the Cretaceous sequence of the Perth Basin. The oldest of these is within the Neocomian, separating a predominantly continental unit below from a mixed continental, paralic, and marine sequence above. A basalt flow was extruded on this Neocomian unconformity surface in the southern part of the basin. Another unconformity is developed within the Albian-Aptian and is overlain by an Albian to Upper Cretaceous marine sequence.

The total thickness of Cretaceous rocks in the Perth Basin may be as much as 12 000 m. The main exposures occur in the Gingin-Dandaragan area, and the thickest subsurface section is beneath the continental shelf west of Perth.

TERTIARY

Sedimentary rocks of undoubted Tertiary age are not known from outcrop in the Perth Basin. However, some thin continental sandstone units in the northern part of the basin are thought to be of this age, and at least part of the extensive laterite and associated sand is probably Tertiary. Marine Tertiary sediments occur in the subsurface of the Perth area and over much of the continental shelf. The sequence consists of shale, limestone, and dolomite, and is up to 600 m thick.

QUATERNARY

Quaternary deposits blanket most of the Perth Basin. They consist of Pleistocene coastal deposits (mainly dune limestone with a few thin shallow-marine bands near the coast, and podsolized dunes further inland), Holocene coastal dunes and associated beach deposits, Pleistocene and Holocene alluvium, and Pleistocene to Holocene laterite and associated sand.

STRUCTURE

The Perth Basin is a faulted trough filled with sediments, the dominant structural feature being the Darling Fault. This fault is nearly 1 000 km long, and its maximum throw may exceed 15 000 m. There is no single major bounding fault on the west side.

The basin is generally intensely faulted, most faults having north to northwest trends, with some of them throwing down to the west, others down to the east. There are also a number of moderately large cross faults (trending approximately east-west) in some areas. All the faults cutting Phanerozoic rocks seem to have normal displacements, and there is evidence that some are growth faults.

Simple compressional folding appears to be absent in the Phanerozoic sequence of the Perth Basin. Folds that do occur are generally strongly faulted, and some have probably developed in response to draping over fault blocks.

BASIN SUBDIVISIONS

A number of structurally controlled subdivisions of the Perth Basin are recognized (Fig. 8). The nomenclature of these units has evolved in recent years, the principal references being Thyer and Everingham (1956), Playford and Willmott (1958), Playford (1971), Cockbain and Lehmann (1971), Jones and Pearson (1972), and Playford and others (1975).

The divisions of the Precambrian basement in this area (the Yilgarn Block, Northampton Block, Leeuwin Block, and Mullingarra Inlier) have already been discussed in dealing with the Precambrian geology.

DANDARAGAN TROUGH

The Dandaragan Trough is the deepest part of the Perth Basin, possibly containing more than 15 000 m of Phanerozoic sediments. The trough is bounded on the east by the Darling and Urella Faults, and on the west by a series of faults including the Beagle Fault. The known section is primarily of Permian, Triassic, Jurassic, and Cretaceous age. However, some Tertiary occurs in the Perth area and offshore, and Silurian Tumblagooda Sandstone is present in the north.

BUNBURY TROUGH

The Bunbury Trough is a deep graben in the southern part of the Perth Basin. It occurs between the Darling Fault on the east and the Busselton and Schroeder Faults on the west. To the north it is bounded by the Harvey Ridge. The total thickness of Phanerozoic sediments in the trough is probably at least 10 000 m. They are known to be of Permian, Triassic, Jurassic, and Cretaceous age. Tertiary sediments are probably present offshore.

Two major positive structural features in the northern part of the trough near the boundary with the Vlaming Sub-basin have been referred to as the *Koombana* and *Sugarloaf Arches*.

COOLCALALAYA SUB-BASIN

The Coolcalalaya Sub-basin is the northernmost subdivision of the Perth Basin. It occurs between the Darling Fault and the Northampton Block or the Ajana Ridge, and adjoins the Irwin Sub-basin and the Dandaragan Trough. The section in the sub-basin may reach 5 000 m in thickness. It consists of the Silurian Tumblagooda Sandstone overlain by thin Permian sediments and a veneer of ?Tertiary deposits.

IRWIN SUB-BASIN

The Irwin Sub-basin occurs between the Mullingarra Ridge and the Darling Fault. It contains up to 1 500 m of Permian sediments overlying Silurian Tumblagooda Sandstone in the north and a very thick (more than 10 000 m) Proterozoic section in the south. The sub-basin has a synclinal shape, with its axis close to the Darling Fault.

ABROLHOS SUB-BASIN

The Abrolhos Sub-basin is that offshore part of the Perth Basin situated west of the Northampton Block, the Dandaragan Trough, and the Beagle Ridge. To the north it is separated from the Carnarvon Basin by the weakly developed *Batavia Arch*. It adjoins the Turtle Dove Ridge to the southwest. The sub-basin is believed to contain a very thick Tertiary, Mesozoic, and Palaeozoic section, possibly exceeding 6 000 m in thickness.

VLAMING SUB-BASIN

The Vlaming Sub-basin is a deep downwarp, partly fault bounded, and containing a very thick section of Tertiary, Mesozoic, and ?Palaeozoic sediments, totalling perhaps 15 000 m in thickness. It is especially characterized by a very thick (up to 11 000 m) Lower Cretaceous sequence. The boundary with the Bunbury and Dandaragan Troughs is not clearly defined.

VASSE SHELF

The Vasse Shelf is a structural unit having depths to basement intermediate between those of the adjoining Bunbury Trough and the Leeuwin Block. The section on the shelf is up to about 3 000 m thick, and is mainly of Permian age, overlain by thin Triassic, Jurassic, and Cretaceous sequences.

YALLINGUP SHELF

The Yallingup Shelf is the area west of the Leeuwin Block, extending to the continental slope. Geophysical evidence indicates that it contains a wedge of sediments up to 1 500 m thick, but the age and nature of these rocks is at present indefinite. They may be of Tertiary, Mesozoic, and Permian age.

BEAGLE RIDGE

The Beagle Ridge is a mid-basin ridge of relatively shallow basement between the Dandaragan Trough and the Abrolhos Sub-basin. Basement rocks come to within about 1 000 m of the surface at the shallowest part of the ridge. The eastern margin is marked by the Beagle Fault, and the other flank is also probably faulted. The ridge has been a positive feature since Permian times. It probably connects with the Northampton Block through the *Dongara Saddle.*

TURTLE DOVE RIDGE

The Turtle Dove Ridge is a shallow basement ridge along the edge of the continental shelf, marking the southwestern margin of the Abrolhos Sub-basin. Its boundaries are faulted, and basement rocks on the ridge are believed to occur as shallow as 1 200 m subsea.

AJANA RIDGE

The northwestern boundary between the Perth and Carnarvon Basins is marked by the Ajana Ridge. Basement depths along this ridge are believed to be relatively shallow, and it is essentially a subsurface extension of the Northampton Block. It may also link up with the Wandagee Ridge in the Carnarvon Basin.

HARVEY RIDGE

The Harvey Ridge separates the Dandaragan and Bunbury Troughs. It is probably fault bounded, and extends obliquely northwest from the Darling Fault. Basement is believed to occur as shallow as 5 000 m below the surface along this ridge.

MULLINGARRA RIDGE

The Mullingarra Ridge is a narrow basement ridge extending north from the Mullingarra Inlier of Precambrian crystalline rocks. It is overlain by Permian rocks which form an anticlinal nose plunging to the north. This has previously been referred to as the "Mullingarra Axis" (Woolnough and Somerville, 1924).

CHAPTER 4

Stratigraphy

PROTEROZOIC

The Proterozoic sedimentary sequence in and adjoining the Perth Basin is very thick, totalling at least 10 000 m. The relationships between the various units are uncertain, and there are few reliable isotopic age datings to assist in making correlations. The evidence is summarized by Low (1975).

The main units that have been recognized are the Yandanooka, Moora, Cardup, Billeranga, and Badgeradda Groups, Nilling and Dudawa Beds, and Wenmillia Formation. Sediments of the Billeranga Group, Badgeradda Group, and Nilling Beds have not been mapped by the Geological Survey, and they will not therefore be described in any detail in this publication. The Proterozoic section in the basin is illustrated on Figure 9.

YANDANOOKA GROUP

The Yandanooka Group is a very thick sequence of clastic sediments underlying the Permian rocks of the Irwin Sub-basin, and resting unconformably on the metamorphic complex of the Mullingarra Inlier. The group is exposed mainly in the area between Three Springs and Yandanooka (Plate 5).

The first geological study of these rocks was carried out by Campbell (1904) in connection with the Arrino copper deposits. Campbell (1910) conducted further work in the area as part of his regional survey of the country between Arrino and Northampton. The sequence was first named the "Yandanooka Beds" by Woolnough and Somerville (1924) after a reconnaissance study of the area. Johnson, de la Hunty, and Gleeson (1954) carried out the first systematic mapping of these sediments. They amended the name to Yandanooka Group, and also named several of the constituent formations. Baker (1951) examined a small area around Yandanooka in some detail.

Playford and Willmott (1958) mapped the Yandanooka Group as part of their regional survey of the Perth Basin. They recognized five formations in the group (the Arrowsmith Sandstone, Arrino Siltstone, Beaconsfield Conglomerate, Enokurra Sandstone, and Mount Scratch Siltstone) having an aggregate thickness of some 10 000 m.

No fossils have been found in the Yandanooka Group, and it is presumed to be of Middle or Late Proterozoic age, although an early Palaeozoic age cannot be entirely ruled out. Unlike other Proterozoic rocks in and adjoining the Perth Basin, the group is not intruded by basic dykes. However, the underlying Mullingarra Gneiss (dated as 1 120 m.y. old) seems also to be devoid of dykes.

The following is a description of the individual units of the Yandanooka Group.

ARROWSMITH SANDSTONE

Definition: The name Arrowsmith Sandstone was introduced by Playford and Willmott (*in* McWhae and others, 1958) for the sequence of feldspathic sandstone and arkose overlying granitic gneiss of the Mullingarra Inlier and underlying the Arrino Siltstone. It is named after the Arrowsmith River, which drains the area of outcrop of the unit around Arrino. The type section of the formation commences at lat. 29° 29′ 35″S, long. 115° 38′ 06″E (6 km south-southeast of Arrino) and continues to the east. The following is a description of this section (after Playford and Willmott, 1958):

Arrino Siltstone, contact not exposed, but conformably overlying—

Arrowsmith Sandstone (335 m)	Thickness (metres)
5. No exposure	43
4. Quartz sandstone, feldspathic, fine-grained grading into medium-grained; pinkish-grey, weathering pink, yellow, and orange; well-bedded, well-sorted, grains well-rounded. Outcrops in this interval are sporadic	134
3. Quartz sandstone, feldspathic, grading to arkose; alternating fine and medium-grained; pinkish-grey, well-bedded to thinly bedded, well-sorted, grains well-rounded, hard	141
2. No exposure	16
1. Quartz sandstone, feldspathic, grading to arkose; fine-grained, siliceous, grey, unbedded, well-sorted, grains rounded to subrounded	0.3

Unconformably overlying Mullingarra Gneiss.

Lithology: The Arrowsmith Sandstone consists of a rather uniform sequence of well-sorted, medium to thin-bedded, grey to pinkish-grey feldspathic sandstone and arkose. Lithic fragments, including volcanic rock and schist, are abundant in some parts of the formation. The feldspars consist of plagioclase (oligoclase to andesine), microcline, microperthite, and orthoclase (Glover, 1960).

The sandstone and arkose commonly weather yellow, pink, or orange. Sand grains range from subangular to well rounded, and are generally moderately well rounded.

Stratigraphic relationships: The contact between the Arrowsmith Sandstone and the Mullingarra Gneiss is believed to be an unconformity rather than a fault. The precise contact is not exposed, but the basal part of the formation is commonly conglomeratic, containing large fragments of the underlying basement rocks. The Arrino Siltstone overlies the Arrowsmith Sandstone with apparent conformity.

Distribution and thickness: The Arrowsmith Sandstone is exposed in a narrow strip from 15 km south to 0.8 km north of Arrino. In this belt the unit dips steeply (average about 50°) to the east. Outcrops are generally sporadic and the only complete section measured (335 m) is the type section.

The unconformity surface on top of the Mullingarra Gneiss apparently has considerable relief. The formation thins rapidly to the north against this surface, and it has pinched out about 3 km north of Arrino, where the Arrino Siltstone rests directly on the Mullingarra Gneiss.

Environment of deposition: The Arrowsmith Sandstone is a rather unusual unit, as it contains abundant fresh feldspar and lithic fragments, even though the grains are commonly well sorted and well rounded, indicating prolonged traction. Playford and Willmott (1958) and Glover (1960) suggest that these features are most consistent with deposition in a very shallow marine environment close to the strandline. Rounding of the sand grains is most likely to have resulted from wave action, although wind traction may also have contributed. The quartz and feldspar grains are probably derived almost entirely from a granitic source, presumed to be the Mullingarra Gneiss, while the volcanic clasts were derived separately from a lava-covered terrain.

Economic aspects: Some copper mineralization (malachite, azurite, and cuprite) is known from a few localities in the Arrowsmith Sandstone. There has been a little mining in the area of "Baxter's Copper Mine", about 4 km south of Arrino. Mineralization there is confined to the lower part of the formation. Production has amounted to only a few hundred tonnes of low-grade ore.

Low (1963) suggests that the mineralization is the result of concentration of copper from volcanic material in the unit by meteoric water. However, in view of the proximity of the ore to the unconformity with the underlying crystalline rocks it is also possible that the copper could be derived from these rocks, especially as they contain some copper mineralization in this area (Campbell, 1910).

Arrino Siltstone

Definition. The name "Arrino Tuff" was introduced by Johnson and others (1954) and was amended to Arrino Siltstone by Baker (1951) and Baker and others, *in* McWhae and others (1958).

The formation is named after Arrino Siding on the Midland (Perth-Geraldton) railway. The type section is 1.5 km east-southeast of Yandanooka, commencing at lat. 29° 19′ 05″S, long. 115° 34′ 45″E and continuing east along the road. The following is a description of this section (after Playford and Willmott, 1958):

Beaconsfield Conglomerate, conformably overlying—

Arrino Siltstone (509 m)	Thickness (metres)
3. Siltstone, lithic, dark-reddish-brown, micaceous, unbedded to well-bedded; often weathering spheroidally, outcrops discontinuous; rarely grades into silty, very fine-grained, dark-brown, lithic sandstone	482
2. Siltstone, lithic, dark-reddish-brown, micaceous, in part (particularly at the base) sandy and conglomeratic, with subrounded quartz and feldspar grains up to granule size; contains some large, rounded mica flakes	21
1. No exposure	6

Contact not exposed, but unconformably overlying Mullingarra Gneiss.

Lithology: The Arrino Siltstone is a monotonous sequence of dark-reddish-brown, micaceous, lithic siltstone, with some sandy beds (especially in the lower part). The unit varies from unbedded to well bedded, but bedding is generally only poorly developed. The rocks typically show spheroidal weathering.

Details of the petrography of the unit are given by Glover (1960). The siltstones and arenites are composed of quartz, mica, and lithic fragments in varying proportions, with minor feldspar. The lithic grains consist of volcanics and various basement rocks. There is no evidence of any tuffaceous beds, but the content of volcanically derived material is commonly high (up to about 15 per cent in specimens examined by Glover, 1960).

Stratigraphic relationships: The contact between the Arrino Siltstone and the underlying Arrowsmith Sandstone seems everywhere to be covered. However, the contact is believed to be conformable and fairly abrupt. In areas where the Arrowsmith Sandstone is absent, the Arrino Siltstone unconformably overlies the Mullingarra Gneiss.

The Arrino Siltstone is overlain with apparent conformity by the Beaconsfield Conglomerate, or disconformably by the Enokurra Sandstone.

Distribution and thickness: The Arrino Siltstone is exposed in a narrow belt from 18 km south to 21 km north of Arrino. Good exposures are largely restricted to creek beds. The best are those in the type section, 509 m thick. The unit is only about 60 m thick 5 km north-northeast of Yandanooka, where it overlies the Mullingarra Gneiss.

Environment of deposition: The Arrino Silstone is a water-laid deposit, made up of silt-grade particles of quartz, volcanic rocks, and other lithic material. There is no evidence to support the tuffaceous origin suggested by Campbell (1910) and Johnson and others (1954). It is believed to be a marine deposit composed of detritus eroded from volcanic and granitic sources.

Economic aspects: The formation shows some minor copper mineralization in the Arrino area, and small shafts and pits were put down early this century on some of the occurrences (Campbell, 1910), but there has been no significant economic production.

BEACONSFIELD CONGLOMERATE

Definition: The name Beaconsfield Conglomerate was proposed by Johnson and others (1954) for the unit of conglomerate lying between the Enokurra Sandstone and the Arrino Siltstone. It is named after Beaconsfield Creek (lat. 29° 17′ 03″S, long. 115° 35′ 45″E), where the type section is exposed. The following is a description of this section (after Playford and Willmott, 1958):

Enokurra Sandstone, contact not exposed, but disconformably overlying—

Beaconsfield Conglomerate (39 m)

1. Conglomerate, lithic, black with greenish tinge; pebbles and cobbles of volcanic rock with rare quartz pebbles, set in a matrix of greenish sandy silt; unbedded, contains rare lenses of lithic, feldspathic, medium-grained sandstone. Outcrops are discontinuous.

Contact not exposed, but conformably overlying Arrino Siltstone.

Lithology: The Beaconsfield Conglomerate is made up of black to dark-red and yellow-grey lithic conglomerate composed mainly of pebbles of volcanic rock (Fig. 11). The matrix is usually fine silt, but it sometimes consists of coarse-grained quartz sand. The clasts are up to cobble grade, and are generally well rounded. Bedding in the unit is generally poorly developed or absent.

The petrography of the clasts has been described by Glover (1958). He recognized six rock types: spilitic lava, quartz microdiorite, transitional volcanic rock, granitic rock, sandstone, and quartzite. Pebbles of volcanic rock (spilite and microdiorite) predominate. Many specimens are highly kankarized, apparently as a result of surface weathering. The microdiorite appears to be comagmatic with basic dyke rocks that Glover has examined from the nearby Yilgarn Block, but no equivalents of the spilitic lavas are known from that area.

Stratigraphic relationships: The Beaconsfield Conglomerate overlies the Arrino Siltstone conformably and is overlain disconformably by the Enokurra Sandstone.

Distribution and thickness: The Beaconsfield Conglomerate is known from a narrow belt from 17.5 km south to 18.5 km north of Arrino. Exposures are discontinuous, due both to outcrop conditions and to the erosional disconformity at the base of the Enokurra Sandstone, which has resulted in the complete removal of the Beaconsfield Conglomerate in some localities.

The formation ranges from zero to 90 m in thickness, the type section being 39 m thick. The greatest thickness is in the southern part of the outcrop area, where there has been less erosion at the base of the Enokurra Sandstone.

Environment of deposition: The Beaconsfield Conglomerate is a water-laid deposit, derived from a land area covered largely by spilitic and microdioritic lava flows. The volcanic fragments are commonly well rounded, indicating fairly prolonged traction, possibly by wave action near the shore.

Figure 11. Beaconsfield Conglomerate at the type locality beside Beaconsfield Creek. The conglomerate consists mainly of rounded pebbles and cobbles of volcanic rock.

ENOKURRA SANDSTONE

Definition: The Enokurra Sandstone was originally named the "Enokurra Grit" by Johnson and others (1954) and the name was amended by Playford and Willmott, *in* McWhae and others (1958). The unit is named after Enokurra Hill (also named "Granite Hill") at lat. 29° 29′ 21″S, long. 115° 35′ 40″E, where the type section is located. The following is a description of this section (after Playford and Willmott, 1958):

Enokurra Sandstone (75 m)

Top of formation not exposed.

1. Quartz sandstone, feldspathic, coarse to very coarse-grained, grading to granule conglomerate; yellow and grey; strongly cross-bedded, hard, massive; often pebbly and containing lenses of pebble conglomerate and some medium-grained sandstone; pebbles mainly of quartz and quartzite, subangular to subrounded, also occasional pebbles of acid gneiss and dark-brown silstone; quartz grains subangular, often showing crystalline quartz overgrowths.

Disconformably overlying Beaconsfield Conglomerate.

Playford and Willmott (1958) also selected a reference section, commencing at lat. 29° 16′ 24″S, long. 115° 35′ 15″E and continuing to the northeast for 0.8 km. The following is their description of this section, which is more complete than the type section:

Mount Scratch Siltstone, conformably overlying, with transitional contact—

Enokurra Sandstone (207 m)	Thickness (metres)
9. Sandstone and siltstone, interbedded; sandstone is feldspathic, coarse and medium grained, brownish grey, moderately well sorted, with subrounded quartz and feldspar; siltstone is micaceous, sandy, dark red, well bedded, grading into very fine-grained silty sandstone	4.9
8. Quartz sandstone, micaceous, fine-grained, pinkish-grey, well-sorted, well-bedded	0.15
7. Quartz sandstone, feldspathic, coarse and medium-grained, pink and grey, moderately well-sorted, grains subangular, grading into subrounded; contains thin beds of well-bedded red and yellow micaceous siltstone and fine to very fine-grained sandstone	16.0
6. Quartz sandstone, feldspathic, medium to coarse-grained, pink, contains lenses (up to 10 cm thick) of silty, micaceous, fine-grained sandstone and siltstone	1.2
5. Quartz sandstone, feldspathic, medium to very coarse-grained, grading to granule conglomerate; pink, weathering yellow, orange, and red; crudely bedded, grains subrounded, moderately well-sorted	15.0
4. No exposure	123.0
3. Quartz sandstone, feldspathic, coarse-grained, with conglomeratic bands; pink, yellow, and white; crudely bedded, large scale cross-bedding	32.0
2. No exposure	14.0
1. Quartz sandstone, feldspathic, conglomeratic, very coarse-grained, grading into granule conglomerate; red, grey, and white; contains subrounded pebbles of quartz, quartzite, and chocolate siltstone; unbedded	1.2

Contact not exposed, but disconformably overlying Arrino Siltstone.

Lithology: The Enokurra Sandstone consists of grey, yellow, brown, and pink, poorly sorted, very coarse to fine-grained feldspathic sandstone, and arkose. Beds in the unit are commonly conglomeratic, and grade into granule conglomerate. Pebbly horizons are common; the pebbles are rounded to subangular and consist of quartz, quartzite, basic volcanic rock, acid gneiss, and siltstone. Sorting ranges from moderate to poor, and sand grains are generally angular to subangular. The unit is characterized especially by large-scale cross-bedding (Fig. 12), and this suggests that the source lay to the northwest. Details of the petrography are given by Glover (1960).

Stratigraphic relationships: The Enokurra Sandstone disconformably overlies the Beaconsfield Conglomerate or the Arrino Siltstone, and is overlain conformably by the Mount Scratch Siltstone. The disconformity at the base shows a relief of more than 60 m.

The contact with the Mount Scratch Siltstone is transitional, interbeds of siltstone becoming progressively more abundant towards the top of the formation. The upper limit of the Enokurra Sandstone is taken to be the top of the highest bed of coarse-grained sandstone.

Figure 12. Cross-bedded sandstone and conglomerate of the Enokurra Sandstone at its type section on Enokurra Hill, near Yandanooka.

The Enokurra Sandstone shows a strong lithological resemblance to the Silurian Tumblagooda Sandstone, the nearest exposure of which is situated some 110 km to the north-northwest. However, apart from this similarity there is no evidence of a possible correlation between the two.

Distribution and thickness: The Enokurra Sandstone is exposed in a north-south belt from 17.5 km south to 23.5 km north of Arrino. It forms some conspicuous rugged outcrops, of which Enokurra Hill is the best-known example.

Only one complete section has been measured through the formation; this is the reference section, 207 m thick.

Environment of deposition: The advent of Enokurra Sandstone deposition marked a change in sedimentation within the Yandanooka Group. The underlying Beaconsfield Conglomerate and Arrino Siltstone were derived largely from volcanic sources, whereas the Enokurra Sandstone had, for the most part, a granitic provenance. The disconformity at the base of the unit probably reflected a pulse of tectonism associated with abrupt uplift of a granitic source area.

It is not clear whether the formation is of marine or continental origin.

MOUNT SCRATCH SILTSTONE

Definition: The name "Mount Scratch Beds" was introduced by Johnson and others (1954), and was amended to Mount Scratch Siltstone by Playford and Willmott, *in* McWhae and others (1958). Playford and Willmott also included the "Green Brook Volcanics" of Johnson and others (1954) in the unit. The name is taken from Mount Scratch in the Arrino area.

The type section commences 11 km east-northeast of Yandanooka (lat. 29° 17′ 07″S, long. 115° 40′ 30″E) and continues to the east along a creek for 0.8 km. The following is a description of this section (after Playford and Willmott, 1958):

Mount Scratch Siltstone (896 m+)	Thickness (metres)
Top of formation not exposed.	
6. Siltstone, dark-reddish-brown, grey-green, and grey, micaceous, well-bedded to fissile, cross-bedded, and ripple-marked (in part), hard; grades rarely into lithic, very fine to medium-grained, grey sandstone	558.0
5. Conglomerate, lithic, dark-greenish-brown, contains well-rounded volcanic pebbles and subordinate pebbles of granitic rocks, in a matrix of green sandy silt; weakly lithified	1.5
4. Siltstone, dark-reddish-brown to grey, micaceous, well-bedded to fissile, cross-bedded in part, hard	58.0
3. Conglomerate, lithic, greenish-brown; contains well-rounded volcanic pebbles in a matrix of sandy silt	0.3
2. Siltstone, reddish-brown and grey, micaceous, well-bedded to fissile, cross-bedded in part, hard	277.0
1. Conglomerate, lithic, greenish-brown; contains well-rounded pebbles of volcanic rock, quartzite, and acid gneiss in a matrix of sandy silt	1.5
Base of formation not exposed.	

Lithology: The Mount Scratch Siltstone is a thick, monotonous sequence of dark-reddish-brown, greenish-grey, and grey micaceous siltstone, with lesser thicknesses of shale, lithic conglomerate, and very fine to medium-grained lithic sandstone. The siltstones are well bedded to fissile, and often show well-developed cross-bedding and current ripple marks.

The petrography of the formation has been described by Glover (1960). Clasts of spilitic lava are abundant in the conglomerates. There are also clasts of various granitic and metasedimentary rocks. The pebbles and cobbles are generally well rounded. The sandstones contain a high percentage of volcanic fragments, and some could be tuffaceous. Glover suggests that the fine-grained rocks probably contain a mixture of epiclastic and pyroclastic volcanic material.

Stratigraphic relationships: The Mount Scratch Siltstone conformably overlies the Enokurra Sandstone and is overlain with strong angular unconformity by the Lower Permian Nangetty Formation.

Distribution and thickness: The Mount Scratch Siltstone occurs widely throughout the Yandanooka-Arrino area. Outcrops are generally very weathered, and the type section is by far the best exposure of the unit. This section is 896 m thick.

Dips in the formation are normally high, averaging about 50° east. The strike is generally constant at 160° to 170°. There is no evidence of any repetition of section by faulting, and none of the section is known to be overturned;

the well-developed cross-bedding everywhere indicates that the strata are right-way-up. The total exposed thickness of the formation is estimated to be between 7 500 and 9 000 m. These thicknesses were calculated from two sections across the formation using all available dip-and-strike data.

Environment of deposition: The Mount Scratch Siltstone was deposited during a period of rapid subsidence associated with continuing volcanism on the adjoining landmass. The section appears to be entirely water laid (probably marine), and most of the volcanic particles appear to be epiclastic. However, it seems likely that there is also a pyroclastic component. The area of provenance also included granitic and metasedimentary rocks.

Economic aspects: Small copper shows have been observed at a number of localities in the Mount Scratch Siltstone, and Campbell (1910) reported that several shafts were sunk at various localities near Mount Scratch. However, none of these occurrences have proved to be economic.

MOORA GROUP

The Moora Group is a thick sequence of chert, siltstone, sandstone, and arkose overlying the Archaean granitic rocks in a belt up to 14 km wide east of the Darling Fault between Moora and Carnamah. The group was first named by Logan and Chase (*in* McWhae and others, 1958), and is described by Logan and Chase (1956, 1961). These rocks were mapped during the present investigation by Low (1969).

Sediments of the Moora Group are cut by numerous normal faults, some of which parallel the Darling Fault, while others trend obliquely northeast to east-northeast. The rocks are also cut by many dolerite dykes. No fossils other than stromatolities and some problematica of uncertain affinites are known from the group, but it is believed to be of Proterozoic, possibly Middle or Late Proterozoic, age.

The Moora Group as defined by Logan and Chase embraces four conformable formations; these are (from the base upwards) the Capalcarra Sandstone, Dalaroo Siltstone, Mokadine Formation, and Coomberdale Chert. Two additional formations are recognized by Low (1975) in the northern part of the area: the Noingara Siltstone (which probably overlies the Coomberdale Chert) and the Winemaya Quartzite. The total exposed thickness of the group probably exceeds 3 500 m.

CAPALCARRA SANDSTONE

Definition: The Capalcarra Sandstone was named by Logan and Chase (*in* McWhae and others, 1958) after Capalcarra Farm, near Moora. It is a poorly exposed unit of sandstone and conglomerate overlying the Archaean rocks and overlain by the Dalaroo Siltstone.

The type section is situated east of Mokadine Spring near Moora (lat. 30° 38′S, long. 116° 03′E). The following description of this poorly exposed section is slightly modified from that given by Logan and Chase (1961):

Dalaroo Siltstone, overlying, with apparent conformity—

Capalcarra Sandstone (49 m)	Thickness (metres)
4. Arkose, very fine-grained, grey-green, slightly metamorphosed by nearby dolerite instrusion; no solid outcrop, only rare cobble-sized fragments in soil	8
3. Metasomatized rock; original nature not apparent, metasomatism is due to adjacent dolerite intrusion; no solid outcrop, only rare cobble-sized fragments in soil	17
2. Orthoquartzite, coarse-grained, white to grey, orange when weathered, well-sorted; cemented by microcrystalline quartz; rare kaolinized feldspar grains present; no solid outcrop, only rare cobble-sized fragments in soil	12
1. Arkose, conglomeratic, medium to coarse-grained, pink, poorly sorted; contains angular pebbles of acid crystalline rock, quartz, and feldspar	12

Unconformably overlying Archaean granitic gneiss.

Lithology: The Capalcarra Sandstone is composed mainly of conglomeratic arkose, with some beds of orthoquartzite and conglomerate. The colour of the rocks is variable, and includes, white, grey, orange, brown, green, and pink.

Stratigraphic relationships: The Capalcarra Sandstone rests unconformably on Archaean metamorphic rocks, and is overlain conformably, with a transitional contact, by the Dalaroo Siltstone.

Distribution and thickness: The Capalcarra Sandstone is a thin, poorly exposed unit at the base of the Moora Group, and has been traced between Moora and Watheroo. The thickest section that has been measured is the type section, 49 m thick. At Watheroo the thickness is only 9 m.

Fossils and age: No fossils have been found in the Capalcarra Sandstone, but it is believed to be of Proterozoic age.

Environment of deposition: The Capalcarra Sandstone is composed of granitic debris, and it may have resulted from the reworking of the soil mantle covering a granitic terrain by a transgressing sea.

DALAROO SILTSTONE

Definition: The name Dalaroo Siltstone was introduced by Logan and Chase (*in* McWhae and others, 1958) for the sequence of siltstone, claystone, arkose, and chert which rests conformably on the Capalcarra Sandstone or unconformably on Archaean rocks and is overlain conformably by the Mokadine Formation.

The type section is situated 0.8 km east of Mokadine Spring, after which the unit is named (lat. 30° 38′S, long. 116° 03′E). The following is a description of this section (slightly modified from that given by Logan and Chase, 1961):

Mokadine Formation, conformably overlying—

Dalaroo Siltstone (153 m)	Thickness (metres)
13. Siltstone, sandy, tuffaceous, well-bedded; sand grains are feldspar and devitrified volcanic glass; interbedded thin beds of arkose and one lens of pink chert	3
12. Claystone, silty and sandy, yellow and dark-red, tuffaceous; shows fine graded bedding; exposures consist of angular blocks in soil	21
11. Claystone, interbedded with siltstone, yellow and red, fissile; some ripple marks present	11
10. Claystone, yellow, grey, and purple, fissile with fracture and slaty cleavage; interbedded with red, fissile siltstone	6
9. Siltstone, purple to grey, fissile; shows evidence of micro-slumping; no solid outcrop, only cobble-sized fragments in soil	3
8. Chert, white, drusy, saccharoidal appearance, banded in part; cropping out prominently	2
7. Claystone, white with pink banding, kaolinized; no solid outcrop	15
6. Arkose, medium to coarse-grained, greyish-pink, poorly sorted, massive; poorly exposed	16
5. Claystone, silty, greyish-red, bedded; and fine, weathered conglomerate, with subrounded quartz granules; both rock types are only poorly exposed	21
4. Sandstone, silty, greyish-red, friable, with some mud-balls; poorly exposed	7
3. Claystone, silty, greyish-red, weathering yellow and orange, well-bedded to fissile; poorly exposed	22
2. Arkose, fine-grained, red to light-brown; largely kaolinized, partly cemented by authigenic quartz; poorly exposed	10
1. Claystone, silty, green-grey, fissile, jointed; the green colouration is due to chlorite (probably associated with a nearby dolerite intrusion); poorly exposed	16

Conformably overlying Capalcarra Sandstone.

Lithology: Siltstone and claystone are the dominant rock types in the formation. They are typically coloured dark red (due to the presence of finely divided hematite), but yellow, purple, greenish grey, and light grey also occur. The rocks are generally well bedded, ranging from thin bedded to fissile. Cross-bedding and current ripple marks are developed at some localities.

Logan and Chase (1961) recognized three end-member types in the siltstones: arkosic siltstone, calcareous siltstone, and tuffaceous siltstone. The tuffaceous siltstone contains both devitrified volcanic glass and small fragments of fine-grained volcanic rocks. It also contains some detrital calcareous material.

Thin beds of arkose occur in the formation. They resemble those found in the Capalcarra Sandstone, and are usually silicified. There are also a few thin beds of white chert, and these are believed to represent silicified limestone and dolomitic limestone.

Stratigraphic relationships: The Dalaroo Siltstone conformably overlies the Capalcarra Sandstone and is overlain conformably by either the Mokadine Formation or the Coomberdale Chert.

Distribution and thickness: Logan and Chase (1961) state that the Dalaroo Siltstone ranges in thickness from 153 m near Moora to 113 m near Watheroo. Low (1969) suggests that the maximum thickness of the unit may be as much as 400 m.

Fossils and age: No fossils have been found in the formation, but it is believed to be of Proterozoic age.

Environment of deposition: The Dalaroo Siltstone contains volcanic and granitic debris. It is probably a shallow-water marine deposit, laid down during a period of volcanism on the neighbouring landmass.

Mokadine Formation

Definition: The Mokadine Formation was originally named the "Mokadine Arkose" by Logan and Chase (*in* McWhae and others, 1958), and the name was amended by Logan and Chase (1961). It is a terrigenous clastic sequence with minor chert, which overlies the Dalaroo Siltstone and underlies the Coomberdale Chert. The name is taken from Mokadine Spring near Moora, and the type section is located nearby (lat. 30° 38′S, long. 116° 02′E). The following is a description of this section, slightly modified from that given by Logan and Chase (1961):

Coomberdale Chert, conformably overlying—

Mokadine Formation (103 m)	Thickness (metres)
10. Siltstone, medium-grained, banded grey and greyish-purple, laminated, flaggy, dense	4.5
9. Claystone, silty, greyish-red, massive, weathered; contains mud-balls; and feldspathic, conglomeratic, pale-red-purple sandstone, weathered white and orange, cemented by microcrystalline quartz; pebbles are of chert; the quartz cement often contains small inclusions of calcite; exposed as isolated boulders and cobbles in the soil	17.0
8. Chert, banded, white to grey	3.0
7. Siltstone, shaly, calcareous, greyish-red, well-bedded; bedding planes are micaceous	32.0
6. Arkose, greyish-red to light-brown, fissile to massive; siliceous cement	15.0
5. Siltstone, tuffaceous, greyish-red to dark-red, laminated; some beds of claystone and sandy siltstone	8.5
4. Sandstone, feldspathic, medium-grained, dark-orange-yellow to light-grey, silicified, well-sorted; quartz and feldspar grains are rounded	11.0
3. Arkose, fine to medium-grained, light-brown, flaggy, friable, siliceous cement	4.0
2. Arkose, fine-grained, light-red-purple, thinly bedded to fissile, dense	3.4
1. Arkose, medium-grained, pale-red, weathered brown, cross-bedded; siliceous cement; quartz and feldspar grains are rounded	4.9

Conformably overlying Dalaroo Siltstone.

Lithology: The Mokadine Formation is an interbedded sequence of arkose and feldspathic sandstone, with subordinate siltstone and claystone and some thin beds of chert. The siltstones are typically dark grey to red in colour, and in places they are tuffaceous. They resemble siltstones of the Dalaroo Siltstone. The arkose and feldspathic sandstone is coloured red, grey, yellow, and brown, and is well bedded to massive. The sand grains are subrounded to rounded.

Stratigraphic relationships: The Mokadine Formation conformably overlies the Dalaroo Siltstone and is overlain conformably by the Coomberdale Chert.

Distribution and thickness: The Mokadine Formation is a lenticular unit, being found only in the Moora-Coomberdale area. It is absent at Watheroo, where the Coomberdale Chert rests conformably on the Dalaroo Siltstone. The type section is 103 m thick, and Low (1969) states that the maximum thickness may be as much as 240 m.

Fossils and age: The only fossils known from the formation are trace fossils of the Fodinichnia ("feeding burrow") group. The unit is thought to be of Proterozoic age.

Environment of deposition: Logan and Chase (1961) interpret the Mokadine Formation as a shallow-water marine deposit. They suggest that deposition was associated with movement along faults in the Archaean granitic terrain, and that some contemporaneous volcanism also occurred.

COOMBERDALE CHERT

Definition: The Coomberdale Chert was named by Logan and Chase (*in* McWhae and others, 1958) after the small railway siding of Coomberdale. They defined it as the sequence of chert and quartzite overlying the Mokadine Formation or the Dalaroo Siltstone.

The type section is located in a series of fault blocks south of Coomberdale (lat. 30° 25′S, long. 116° 03′E). It is a composite section, and correlations from one block to another are very uncertain. The following is a slightly modified description of the section measured by Logan and Chase (1961):

Coomberdale Chert (1 006 m+)	Thickness (metres)
Top of formation not exposed.	
22. Chert, and intraformational slump breccia; contains stromatolite structures; strongly jointed	335+
21. Orthoquartzite, fine to medium-grained, with chert breccias and conglomerates; also rare beds of brown siltstone. Current ripple marks are present in some parts of the section	49
20. Chert breccia, intraformational; contains some stromatolites	146
19. Quartz orthoquartzite, fine to medium-grained, red, brown, and white, often shows current ripple marks; contains chert breccias at the base, and thick lenses of chert	116
18. Chert as for Unit 22	168
17. Orthcquartzite, white, fine-grained, strong chert cement; composed largely of a problematical colonial fossil, with some *Collenia*	20
16. Orthoquartzite, medium to coarse-grained, white, massively bedded	24

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15.	Orthoquartzite, medium to coarse-grained, white, massively bedded	22
14.	Orthoquartzite, mottled brown and white, strongly current-bedded, poorly sorted, chert cement	3
13.	No outcrop	3
12.	Chert, white, opaque, massive	4.5
11.	Orthoquartzite, medium-grained, white, massively bedded, chert cement	11
10.	Chert, white, thinly bedded, with detrital quartz grains in thin laminae; a palimpsest oolitic structure is visible in the chert	12
9.	Orthoquartzite, fine to medium-grained, pink, current bedded, chert cement	26
8.	Orthoquartzite, fine-grained, light-grey, cross-bedded	0.3
7.	Orthoquartzite, pink, fine to medium-grained, with well-developed current bedding, poorly sorted	1.5
6.	Orthoquartzite, medium-grained, white and pink, well-sorted, contains problematical colonial fossils at the base; chert occurs as a cement, and as thin beds	9
5.	No outcrop	26
4.	Orthoquartzite, coarse-grained, white, well-sorted, crudely bedded	1
3.	Orthoquartzite, medium-grained, white, massive, with colonies of a silicified problematical organism in biostromal development, and thin beds of chert	12
2.	Orthoquartzite, medium-grained, white, well-sorted, massive	6
1.	Orthoquartzite, fine to medium-grained, red to white, cross-bedded, with rare current ripple marks; thin-sections show that it has a chert cement, and contains silicified oolites	11

Conformably overlying Mokadine Formation.

Logan and Chase (1961) recognize several members in the formation (Noondine Member, Kiaka Sandstone Member, Koolera Sandstone Member), but we were unable to map them satisfactorily.

Lithology: The Coomberdale Chert is a sequence of chert, quartzite, chert breccia, and partly silicified (commonly dolomitic) limestone and dolomite. The cherts are white to light grey or yellow grey in colour, and are thinly bedded to massive. Intraformational chert breccias are common, and they are often associated with slump structures. The quartzites are white to light-grey and red-brown rocks, composed of fine to coarse-grained quartz sand in a cherty matrix.

Partly silicified dolomitic limestone containing stromatolites occurs in the Coomberdale Chert at Coorow Cave and near Mokadine Spring. Erratics of the same lithology also occur commonly in Permian glacial deposits (Nangetty Formation) in the Perth Basin (Fig. 13). The cherty limestones are grey rocks with irregular silicified areas.

The chert which makes up the major part of the formation is believed to be the end-product of silicification of dolomitic limestone. Relict dolomite rhombs, oolitic textures, and other features of the original carbonate rock have been observed in the chert.

Stratigraphic relationships: The Coomberdale Chert conformably overlies the Mokadine Formation or the Dalaroo Siltstone. The upper limit of the formation is not exposed, but it is thought to be overlain by the Noingara Siltstone.

Distribution and thickness: The Coomberdale Chert is the most widespread unit in the Moora Group. It occurs in a belt of resistant outcrops, 3 to 4 km wide, extending from near Coorow to Moora.

Two sections of the formation were measured by Logan and Chase (1956). Their type section is some 1 000 m thick, while another section near Watheroo is 565 m thick. Low (1969) believes that the maximum thickness of the formation may be more than 1 800 m.

Fossils and age: Algal stromatolites are common in some parts of the Coomberdale Chert (Fig. 13). They were first described by Fairbridge (1950) from Gunyidi and Moora, as belonging to the genus *Collenia*. Logan and Chase (1961) recognized three forms in the formation, *Collenia undosa, C. columnaris,* and *Cryptozoon frequens.*

Logan and Chase also found a "fossilum problematicum" in the formation. This consists of radiating polygonal tubes and was identified by Öpik and Tomlinson (1955) as a tabulate coral, possibly belonging to the Ordovician genus *Tetradium*. D. Hill (written comm. to Wapet, 1956) believed that the forms could either be tabulate corals, or stromatoporoids belonging to the family Labechiidae. On the other hand, Logan and Chase (1961) state that the tubes

Figure 13. Coomberdale Chert containing abundant stromatolites, occurring as an erratic boulder in the Lower Permian Nangetty Formation, at Beckett Gully near Mingenew.

appear to have an agglutinated wall structure and that as a result they cannot be corals or stromatoporoids. They favour affinities with the algae or worms, and are of the opinion that the Moora Group is of Proterozoic rather than Palaeozoic age, especially as it is intruded by dolerite dykes.

We agree that the fossils in the Coomberdale Chert are not necessarily inconsistent with a Proterozoic age. The affinities of the "fossilum problematicum" are very doubtful, and indeed they may not be organic.

Environment of deposition: The Coomberdale Chert is believed to have been laid down originally as a shallow-marine limestone, probably as a lime mud. Algal stromatolites grew prolifically in certain areas, and extensive slumping and brecciation took place in some of the weakly consolidated limestones. Partial dolomitization of the limestone occurred, either penecontemporaneously or early in its diagenetic history. Later again the dolomitic limestones were extensively silicified, most of the section being completely altered to chert. The source of so much silica and the precise mechanism of chertification are unknown.

Economic aspects: There has been some prospecting for talc in the Coomberdale Chert. A commercial talc deposit occurs in the Dudawa Beds (thought to correlate with the Coomberdale Chert) near Three Springs. It is believed to have originated by metasomatic alteration of dolomite associated with intrusion of the dolerite dykes that adjoin the deposit. As a result, prospecting for talc in the Coomberdale Chert has concentrated on the areas near dolerite intrusions.

NOINGARA SILTSTONE

Definition: The name Noingara Siltstone was proposed by Low (1975) for the sequence of siltstone and chert which probably overlies the Coomberdale Chert and is overlain conformably by the Winemaya Quartzite. The name is taken from Noingara Well, which is situated 3.2 km north-northwest of the type section (lat. 30° 14′S, long. 116° 00′E). This is a discontinuous composite section, which commences 1.8 km west-southwest of Longreach homestead and extends east to near the homestead. The following is a description of this section:

Winemaya Quartzite, conformably overlying—

	Thickness (metres)
Noingara Siltstone (790 m)	
9. Siltstone, predominantly red-brown, also light-grey to white and pale-yellow; mostly massive, with some thin beds; micaceous and highly ferruginous; strongly sheared in places; much of the exposure consists of small flat chips or flaggy rubble in soil. Cut by a dolerite dyke about 215 m above the base of the unit	581
8. Chert, ferruginous, with irregular patches of coarse quartz sand, banded white and dark-grey, some fine contorted bedding; exposed as scattered boulders	5

7.	Siltstone, ferruginous, poorly exposed as chips and flaggy rubble; predominantly red-brown, also pale-brown and yellow, cream, and orange on weathered surfaces; micaceous, mostly massive but with some thin bedding; some light-grey, fine-grained sandstone lenses; some dolerite and orthoquartzite rubble present	132
6.	Chert, ferruginous, white and dark-grey, bedded; brecciated in places, poorly exposed	2
5.	No outcrop	6
4.	Chert, as for unit 6; also boulders of light-grey, medium to very coarse-grained orthoquartzite, containing pebbles of light-grey to white chert	7
3.	Siltstone, red-brown, exposed as small flat chips in the soil	25
2.	Chert, as for unit 6	1
1.	Siltstone, as for unit 3	31

Base not exposed, but thought to conformably overlie Coomberdale Chert.

Lithology: The Noingara Siltstone consists mainly of massive to thin-bedded, red-brown, light-grey, white, and pale-yellow siltstone. It contains thin interbeds of white and grey chert, and some orthoquartzite.

Stratigraphic relationships: The lower limit of the Noingara Siltstone is not exposed, but stratigraphic evidence suggests that the formation overlies the Coomberdale Chert. It is overlain conformably by the Winemaya Quartzite.

Distribution and thickness: The Noingara Siltstone is known only in the area extending from 8 km northwest of Watheroo to just west of Coorow. The type section, 790 m thick, is the only section that has been measured through the formation.

Fossils and age: No fossils have been found in the unit, but it is believed to be of Proterozoic age.

Environment of deposition: The Noingara Siltstone is probably a shallow-marine deposit.

WINEMAYA QUARTZITE

Definition: The name Winemaya Quartzite was proposed by Low (1975) for the uppermost unit of the Moora Group. It is named after Winemaya Spring, 10.5 km north of the type section (lat. 30° 14′S, long. 115° 59′E). The formation is a sequence of orthoquartzite, with minor siltstone and chert, overlying the Noingara Siltstone.

The following is a description of the type section, which commences about 4 km west of Longreach homestead and extends for some 2.2 km to the east-northeast:

Winemaya Quartzite (1 365 m)

		Thickness (metres)
	Top of formation not exposed.	
13.	Orthoquartzite, light-grey to white, medium-grained, well sorted, subrounded to well-rounded grains, strongly cemented by chert; contains chert patches and bands; strongly jointed	135
12.	No outcrop	455
11.	Orthoquartzite, light-grey to medium-grey, fine to medium-grained, well-bedded, with occasional thin, coarse-grained beds containing pebbles of chert and orthoquartzite; some thin sheared beds of white and brown siltstone	155
10.	No outcrop	25
9.	Orthoquartzite, light-grey to medium-grey, mostly fine-grained and finely bedded, with occasional beds of coarse-grained orthoquartzite and sheared brown siltstone; contains thin bed of banded light and dark-grey chert at top	160
8.	No outcrop	75
7.	Siltstone, red-brown, micaceous, exposed as tabular chips and slabs	5
6.	Orthoquartzite, light-grey, fine-grained, finely bedded; some interbeds of medium to coarse-grained orthoquartzite; chert cement	30
5.	Siltstone, light-brown, sandy, micaceous, finely bedded	10
4.	Orthoquartzite, light-grey, coarse-grained; well-rounded, well-sorted grains; some potash feldspar grains; massive with chert cement	25
3.	Orthoquartzite, light-brown to brown, fine to medium-grained; minor light-brown siltstone; massive at the base, becoming thinly bedded towards the top	20
2.	Orthoquartzite, light-brown to brown, fine to medium-grained; massive to thinly bedded	25
1.	Orthoquartzite, light-grey, coarse-grained, well-sorted, well-bedded towards the top; occasional thin beds of pebble conglomerate with rounded quartz and chert clasts	245
	Conformably overlying Noingara Siltstone.	

Lithology: The Winemaya Quartzite consists predominantly of orthoquartzite, with occasional thin interbeds of chert, siltstone, and pebble conglomerate. The orthoquartzite is white to medium grey, and is composed of fine to coarse-grained quartz sand, cemented by silica. The siltstone is white to red brown; it is micaceous and is commonly slightly sheared. Clasts in the thin-bedded conglomerate consist of pebbles of light-grey chert and orthoquartzite which are generally fairly well rounded (but are sometimes angular) and are set in a quartz-sand matrix.

Stratigraphic relationships: The Winemaya Quartzite rests with apparent conformity on the Noingara Siltstone. The top of the formation is not exposed.

Distribution and thickness: The Winemaya Quartzite occurs as scattered exposures over a belt 5 km wide lying east of the Darling Fault and extending from 9 km northwest of Watheroo to 13 km northwest of Marchagee.

The formation is 1 365 m thick at the type section, the only section that has been measured. The top is not exposed, and it is possible that a considerable additional thickness occurs between the outcrop area and the Darling Fault.

Fossils and age: No fossils have so far been found in the Winemaya Quartzite. However, the unit is believed to be of Proterozoic age.

Environment of deposition: The Winemaya Quartzite was probably laid down under shallow-marine conditions.

CARDUP GROUP

The Cardup Group is a sequence of shale, sandstone, and minor conglomerate overlying the Archaean rocks east of the Darling Fault in a narrow strip (up to 0.7 km wide) between Maddington and Serpentine. The sequence dips steeply (average 50-60°) to the west.

The group was originally referred to as the "Cardup-Armadale Shale" by Esson (1927). This was amended to "Cardup Series" by Prider (1941), and further to "Cardup Shale" by McWhae and others (1958). However, subsequent work by Wapet geologists F. B. Williams and M. G. McKellar, and by Singh (1958), and Low and others (1970) has shown that the "Cardup Shale" can now be raised to group status.

The age of the Cardup Group is uncertain, but isotopic evidence suggests that it is probably Late Proterozoic. The sediments are older than the dolerite dykes that intrude them. These dykes are part of a suite cutting the nearby Archaean rocks, that has been dated as 560-590 m.y. old (Compston and Arriens, 1968). The sediments show only slight dynamic metamorphism and are younger than a period of regional metamorphism and pegmatization in the Archaean rocks dated as 700-750 m.y. old a few tens of kilometres to the north (Compston and Arriens, 1968). Hence the age of the Cardup Group sediments appears to fall in the range from 700-750 m.y. to 560-590 m.y. A Late Proterozoic dating for the group therefore seems most probable.

Three formations have been mapped by Low and others (1970) in the Cardup Group. They are (from the base upwards) the Whitby Sandstone, Neerigen Formation, and Armadale Shale.

WHITBY SANDSTONE

Definition: The name Whitby Sandstone was first used by Singh (1958) for the sequence of orthoquartzite, boulder conglomerate, and silty sandstone, which rests unconformably on Archaean rocks and is overlain by the Neerigen Formation. The name was taken from Whitby Falls on Manjedal Creek. The type section is in the Mundijong railway cutting (lat. 32° 18′ 20″S, long. 116° 00′ 40″E), and is described below:

Neerigen Formation, conformably overlying—

Whitby Sandstone (21.8 m)	Thickness (metres)
3. Sandstone, white and red-brown, fine-grained, with lenticular interbeds of coarse to very coarse-grained subrounded sandstone	9.0
2. Quartz sandstone, white to reddish-brown, fine to coarse-grained, with coarse-grained to conglomeratic lenses and beds; clasts rarely up to 20 cm in diameter; finely cross-bedded; well-bedded; well-jointed in part	12.3
1. Conglomerate, white to reddish-yellow, with clay matrix containing subrounded quartz grains; clasts are subrounded, up to 15 cm in diameter, and include granite and quartzite	0.5

Unconformably overlying Precambrian granite gneiss.

Lithology: The basal part of the Whitby Sandstone commonly consists of pebble to boulder conglomerate, with some clasts up to 75 cm in diameter of various Archaean rocks. This grades upwards into fine to coarse-grained sandstone or orthoquartzite. The sand grains are generally subrounded to well rounded.

Stratigraphic relationships: The Whitby Sandstone is a lenticular unit which rests unconformably on Archaean rocks and is overlain conformably, with a transitional contact, by the Neerigen Formation.

Distribution and thickness: The Whitby Sandstone is a thin, lenticular formation at the base of the Cardup Group. It is discontinuously exposed between Mundijong and Gosnells and ranges up to about 40 m in thickness.

Fossils and age: No fossils have been found in the formation, but it is thought to be of Proterozoic age.

Environment of deposition: The Whitby Sandstone is considered to be the basal unit of a marine transgressive sequence.

NEERIGEN FORMATION

Definition: The name Neerigen Formation was proposed by Playford and Willmott (1958) for the unit of sandstone and shale overlying the Whitby Sandstone. It is named after Neerigen Brook, which flows past the type section of the unit 300 m north of the "Olde Narrogin Inne" at Armadale (lat. 32° 08′ 45″S, long. 116° 01′ 05″E). This exposure is in a road cutting and the section, described below, was measured by F. B. Williams and M. G. McKellar:

Armadale Shale, conformably overlying—

Neerigen Formation (23.6 m)	Thickness (metres)
2. Sandstone, fine-grained, pinkish-white, weathering yellow-brown, thinly bedded; contains rare medium to coarse-grained quartz grains, which are subangular to subrounded; moderately hard to friable; contains some thin beds of white to reddish-brown micaceous shale, particularly in the upper part	16.0

1.	Shale, white and reddish-brown, soft, micaceous, ripple-marked; with thin beds of white and reddish-brown siltstone, and white, thinly bedded, fine-grained, partly silicified sandstone	7.6

Conformably overlying Whitby Sandstone.

Lithology: The Neerigen Formation is a unit of interbedded sandstone and shale. The sandstone is fine to medium grained, micaceous, poorly sorted, thin to medium bedded, and cross bedded in places. It is usually white to light grey in colour, but is sometimes purple to red brown. Silicification is common, and the matrix is usually silty. The shale beds are similar to the sandstone in colour. They are fissile, in part sandy and silty, and contain some ripple marks.

Stratigraphic relationships: The Neerigen Formation rests conformably on the Whitby Sandstone or unconformably on Archaean rocks, and is overlain conformably by the Armadale Shale. The formation is cut by dolerite dykes.

Distribution and thickness: The Neerigen Formation has been mapped in the area between Maddington and Serpentine. The formation is 23.6 m thick in the type section.

Fossils and age: No fossils are known from the Neerigen Formation, but it is believed to be of Late Proterozoic age.

Environment of deposition: The Neerigen Formation is thought to be a marine unit, although this cannot be proved owing to the lack of fossils.

ARMADALE SHALE

Definition: The name Armadale Shale was introduced by Playford and Willmott (1958) for the sequence of black and white shale overlying the Neerigen Formation and overlain by Quaternary piedmont deposits. The type section is in the Cardup Quarry (lat. 32° 14′ 35″S, long. 116° 00′ 55″E). The following is a description of this section as measured by F. B. Williams and M. G. McKellar:

Armadale Shale (483 m)	Thickness (metres)
Top not exposed, overlain by Quaternary deposits.	
6. Shale, white to cream and light-grey, soft, laminated, jointed and sheared	144.0
5. Orthoquartzite, white, very hard	4.6
4. Shale, white to cream, soft, laminated, very poorly exposed	151.0
3. Orthoquartzite, white, very hard	4.5
2. Shale, white to cream, thinly bedded	145.0
1. Shale, black, jointed, hard	34.0

Conformably overlying Neerigen Formation.

Lithology: The Armadale Shale consists of black and white shale with minor sandstone and orthoquartzite. The shales are purple and red brown in places, and are micaceous, laminated, moderately hard to friable, and contain sparse fine sand grains. Most sandstone beds are thin and they are commonly strongly silicified to form orthoquartzites. They are generally white and fine to medium grained. Symmetrical ripple marks and graded bedding have been observed.

Stratigraphic relationships: The Armadale Shale rests conformably on the Neerigen Formation, and is overlain unconformably by Quaternary alluvial deposits.

The Darling Fault is situated west of the exposures of Armadale Shale. It is parallel to the strike of the formation.

Distribution and thickness: The Armadale Shale has been mapped in a narrow strip from near Kelmscott to the Serpentine area. Outcrops are generally poor and sporadic owing to widespread Quaternary cover.

The type section is the thickest section of the formation that has been measured (483 m). However, the total thickness of the formation may be considerably greater than this as the section between the Darling Fault and the outcrop area is covered by soil.

Fossils and age: No definite fossils have been found in the Armadale Shale. Some *Collenia*-like forms were reported from an orthoquartzite or chert in the formation at the Armadale Quarry by Fairbridge (1953), but it is not certain that the structures observed are indeed organic. As discussed earlier, it seems likely that the units of the Cardup Group are of Late Proterozoic age.

Environment of deposition: The Armadale Shale is thought to be a marine deposit. The presence of symmetrical ripple marks suggests that at least part of the unit was laid down above wave base.

Economic aspects: The Armadale Shale is used extensively for brick manufacture. Quarries have been opened at various localities between Armadale and Mundijong for this purpose.

WENMILLIA FORMATION

Definition: The Wenmillia Formation is a unit of siltstone, shale, phyllite, and basic lava exposed in a narrow strip along Wenmillia Creek and the Wooderarrung River immediately west of the Darling Fault. The name was introduced by Playford and Willmott (1958), and the unit was later studied in more detail by Ranford and Shaw (1960). The type section extends along the Wooderarrung River, commencing near the Darling Fault (lat. 28° 29′ 25″S, long. 115° 28′ 05″E). The following is a description of this section as measured by Playford and Willmott (1958):

Nangetty Formation, unconformably overlying—

	Thickness (metres)
Wenmillia Formation (290 m)	
7. Lava, spilitic, fine-grained, dark-green, massive, contains thin irregular veins of quartz	52.0
6. Shale, greenish-grey, partly slaty, thinly bedded, soft	7.6

5.	Lava, spilitic, fine-grained, dark-green, massive, strongly jointed. Some thin beds showing crude bedding are present, and these may represent weathered tuffaceous horizons	58.0
4.	Shale, greenish-grey to dark-grey, partly slaty, undulating dip, contains some thin veins of quartz	47.0
3.	Lava, spilitic, dark-green, mainly fine-grained, but with some medium to coarse-grained; a thin bed of fine-grained ?tuffaceous material at the base	17.0
2.	Shale, yellow-green, fissile, showing some small drag folds	4.5
1.	Shale, slaty, partly phyllitic, black to dark-greenish-grey, fissile, contains sporadic quartz veins up to 0.5 m thick, some bands show well-developed drag folds; severely contorted at the base; adjacent to the fault contact with the Archaean rocks. A little malachite has been introduced into the base of the formation, perhaps in association with a quartz vein	104.0

Darling Fault: strike 180°, dip 85° west, against Archaean sheared granitic rock.

Lithology: The Wenmillia Formation is a sequence of alternating greenish-grey to black shale and dark-green spilitic lava flows. Tuffaceous beds may also occur. The sequence is cut by at least one dolerite dyke, and quartz-albite and quartz veins are also present.

Some of the shales of the formation are carbonaceous, and they are partly altered to phyllites near the Darling Fault. In this area they also contain a little copper mineralization (malachite). The interbedded spilitic lavas are fine to coarse-grained, and are generally very weathered.

Stratigraphic relationships: The Wenmillia Formation is faulted against the Archaean adamellites of the Yilgarn Block. The fault dips steeply to the west and appears to be part of the Darling Fault System. The formation is overlain with strong angular unconformity by the Nangetty Formation along the Wooderarrung River, but it seems that on Wenmillia Creek the two are separated by a small fault.

Distribution and thickness: The Wenmillia Formation is known only from the steeply west-dipping exposures between the Wooderarrung River and Wenmillia Creek, over a distance of some 1.5 km. The only thickness measured is that of the type section, 290 m.

Fossils and age: No fossils have been found in the Wenmillia Formation, and it is presumed to be of Proterozoic age.

Environment of deposition: The Wenmillia Formation is a mixed sedimentary and volcanic unit. The sediments are fine-grained clastic deposits which were probably laid down under marine conditions, with periodic extrusion of lava on the sea floor.

BILLERANGA GROUP

The Billeranga Group is a sequence of gently dipping sandstone, siltstone, chert, and trachytic to andesitic lava overlying the Archaean basement complex in the Billeranga Hills area, about 14 km east of the Darling Fault. They were originally named the "Billeranga Beds" by Playford and Willmott (*in* McWhae and others, 1958). Arriens and Lalor (1959), in an unpublished thesis, raised the unit to group status and named four constituent formations: The *Neereno Sandstone, Morawa Lavas, Oxley Chert,* and *Campbell Sandstone*. These names were formalized by Low (1975).

The total exposed thickness of the Billeranga Group is about 75 m. The sediments are intruded by dolerite dykes, and the Morawa Lavas have been dated as 1 400 m.y. (Compston and Arriens, 1968). The group is overlain, probably disconformably, by the Dudawa Beds. The Billeranga Group and the Dudawa Beds may be of similar age, and could be approximately correlative with the Moora Group.

The Billeranga Group has not been mapped during the present investigation, and accordingly will not be discussed further in this publication.

DUDAWA BEDS

Definition: The Dudawa Beds were named by Arriens and Lalor (1959) and the name was first published by Low (1975). The name is derived from the Dudawa Estate on the Morawa-Arrino road about 16 km southwest of the Billeranga Hills. The type area lies just east of this estate (lat. 29° 23′S, long. 115° 46′E), but no type section has been designated because of the poorness of exposures. The unit is defined as the sequence of chert and orthoquartzite overlying the Billeranga Group.

Lithology: The Dudawa Beds consist predominantly of chert and orthoquartzite with minor dolomite, and a thin basal unit of sandstone. The basal sandstone is slightly friable, and is mottled pale red to greyish red. The overlying chert and orthoquartzite are bedded and are white to dark grey in colour. The Dudawa Beds are cut by dolerite dykes in some areas.

Stratigraphic relationships: The disconformable relationship of the Dudawa Beds with the underlying Billeranga Group is inferred from the presence in the basal unit of the Dudawa Beds of pebbles of black flint thought to have been derived from the underlying Campbell Sandstone (the highest unit of the group). The top of the Dudawa Beds is not exposed—the beds are everywhere covered by laterite or soil.

The Dudawa Beds show a marked lithological resemblance to the Coomberdale Chert of the Moora Group, and they are tentatively correlated. On the other hand, it is possible that the beds correlate with the Winemaya Quartzite.

Distribution and thickness: Exposures of the Dudawa Beds have been recognized from just west of the Billeranga Hills to near the Darling Fault, and as far south as the Coodawa talc deposit, 9 km east-northeast of Three Springs.

The exposed thickness of the Dudawa Beds is unknown, because outcrops are poor and discontinuous and no accurate sections have been measured. Arriens and Lalor (1959) conservatively estimated that the beds are at least 150 m thick.

Fossils and age: The only fossils known from the Dudawa Beds are algal stromatolites of *Collenia* type. A Middle or Late Proterozoic age for the unit seems probable.

Environment of deposition: The Dudawa Beds are interpreted as shallow-water marine deposits.

Economic aspects: High-quality talc is being mined from the Dudawa Beds at Coodawa, 9 km east-northeast of Three Springs. The talc contains well-preserved stromatolites and the deposit is thought to have formed by metasomatism of dolomite in the Dudawa Beds, associated with intrusion of adjoining dolerite dykes.

NILLING BEDS

The Nilling Beds were named by Perry and Dickins (1960). The beds consist of a poorly exposed sequence of quartz greywacke and thin-bedded coarse-grained sandstone, which is exposed in small areas south of the Woodrarrung Range, a few kilometres east of the Darling Fault. They rest unconformably on Archaean schist and granitic gneiss, and are overlain, probably unconformably, by the Bililly Formation, the lowest unit of the Badgeradda Group.

The thickness of the beds is unknown because of the poorness of outcrop and structural complexities. The beds were not mapped during the present investigation, and therefore they will not be discussed in further detail in this publication.

BADGERADDA GROUP

The Badgeradda Group is a sequence of sandstone and siltstone exposed in the Badgeradda Range, Woodrarrung Range, and Errabiddy Hills areas, a few kilometres east of the Darling Fault near the northern end of the Perth Basin. The group overlies the Nilling Beds, probably with angular unconformity.

The Badgeradda Group was originally named the "Badgeradda Beds" by Konecki and others (1958), and it was raised to group status by Perry and Dickins (1960). They recognized four formations in the group; these are, from the base up: the *Bililly Formation, Woodrarrung Sandstone, Coomberarie Formation,* and *Yarrawolya Formation.* The total aggregate thickness of the group is more than 3 000 m.

The Badgeradda Group was not mapped during the present survey. It is believed to be of Proterozoic age, and shows a strong facies resemblance to parts of the Bangemall Group (about 1 000 m.y. old), 250 km to the northeast. Its relationship to other Proterozoic units to the south is unknown.

SILURIAN

One unit in the Perth Basin, the Tumblagooda Sandstone, is believed to be of Silurian age, although this has not been proved conclusively as it does not contain any diagnostic fossils.

TUMBLAGOODA SANDSTONE

Definition: The Tumblagooda Sandstone is a thick unit of sandstone which overlies Precambrian rocks and is overlain by Permian or younger deposits in the Perth Basin. The unit was named by Clarke and Teichert (1948) after Tumblagooda Hill, near the mouth of the Murchison River (in the southern Carnarvon Basin). The type section designated by Johnstone and Playford (*in* McWhae and others, 1958) extends for some 70 km along the Murchison River from 3 km west of Hardabut Pool (lat. 27° 52′ 00″S, long. 114° 33′ 30″E) to Second Gully Point (lat. 27° 36′ 30″S, long. 114° 08′ 30″E). Although this section is in the Carnarvon Basin, it is also quite typical of the formation as it occurs in the Perth Basin. A description of this section (as measured by Johnstone and Playford, 1955) is as follows:

Birdrong Sandstone (Lower Cretaceous), overlying, with angular unconformity—

Tumblagooda Sandstone (1 070 m+)	Thickness (metres)
6. Sandstone, fine and medium-grained, brown, red, and yellow, cross-bedded; with silty, very fine and fine-grained sandstone, grading into dark-red, thin-bedded to laminated siltstone; some invertebrate tracks and burrows present	95
5. Sandstone, feldspathic (in part), coarse-grained, red, yellow, brown, and grey; grading into fine conglomerate; pebbles are of quartz, quartzite, and siliceous sandstone; strongly cross-bedded, shows well-developed jointing	215
4. Sandstone, fine-grained, white, grey, and red, thinly bedded to laminated	30
3. Sandstone, coarse to medium-grained, grey, yellow, and white hard; grades in places into fine quartz conglomerate; feldspathic in the basal 20 m	75
2. Sandstone, silty, fine and very fine-grained, some harder medium-grained beds, white, yellow, and red; tracks, trails, and burrows found, particularly in the fine-grained beds	185
1. Sandstone, feldspathic (in part), coarse-grained, red, yellow, and grey; conglomeratic in part, sometimes grading into strongly cross-bedded, jointed, fine conglomerate	470

Reverse fault (Hardabut Fault), small throw, against dolerite dykes and Precambrian metamorphic rocks.

The uppermost unit of those in the type section (unit 6) was named the *Yalthoo Member* by Johnstone and Playford (1955), but this member has not definitely been recognized in the Perth Basin exposures.

Lithology: The Tumblagooda Sandstone is a sequence of very fine to coarse-grained sandstone, which is commonly conglomeratic and contains some thin beds of conglomerate and siltstone. The sandstones are coloured red, grey, yellow, and white, red being the most characteristic. They often show well-developed large-scale cross-bedding, while current ripple marks and intraformational conglomerates are often present. Feldspathic sandstone is very common, and in places it grades into arkose. The arenites are often very porous and permeable, and make excellent aquifers and potential petroleum reservoirs.

Conglomerate and conglomeratic sandstone in the unit contain rounded to subrounded granules, pebbles, and rarer cobbles of quartz and quartzite.

Siltstone is not often observed in outcrops of the formation in the Perth Basin. It is typically dark red, micaceous, sandy, and thinly bedded to massive. In the Carnarvon Basin siltstone is common in parts of the Yalthoo Member and in bores, where red micaceous siltstone grading to shale may make up an important part of the section.

The Tumblagooda Sandstone is usually strongly lithified, and it forms conspicuous outcrops. Jointing is often well developed, and in some areas (particularly in the Carnarvon Basin) major joints control the drainage pattern to a marked degree.

Stratigraphic relationships: The Tumblagooda Sandstone unconformably overlies, or is faulted against, Precambrian crystalline rocks of the Northampton Block. In the Perth Basin the unit is overlain with sharp angular unconformity by Permian, Triassic, or Jurassic sediments. In the valley of the Murchison River east of the Northampton Block the formation is overlain by the Lower Permian Nangetty Formation; in the area north of Northern Gully it is overlain by Jurassic sediments or by the Permian Holmwood Shale; and north of Geraldton it is overlain by the Lower Triassic Kockatea Shale.

Distribution and thickness: In the Perth Basin the Tumblagooda Sandstone is exposed in the valley of the Murchison River (Figs. 14 and 15) and in the Northern Gully-Nolba area. The southernmost outcrop occurs 5.5 km southeast of Northern Gully.

The Tumblagooda Sandstone may exceed 4 000 m in thickness. Johnstone and Playford measured a section along the Murchison River east of the Northampton Block that is over 3 500 m thick. This is discontinuous and faulted, but the faults are not believed to have caused any major repetition of section. The top of the unit is not exposed, and isolated exposures continue down dip beyond the top of the measured section for several kilometres.

Fossils and age: The only fossils that have been found in established Tumblagooda Sandstone in outcrop are invertebrate tracks, trails, and burrows (Fig. 15). The best examples occur in the section west of the Northampton Block, and some have been described by Öpik (1959) as belonging to the forms *Protichnites*, *Diplocraterion*, and *Scolithus*. Öpik concluded that these tracks indicate that the formation is of Palaeozoic age, and he favoured a Cambrian or Ordovician dating.

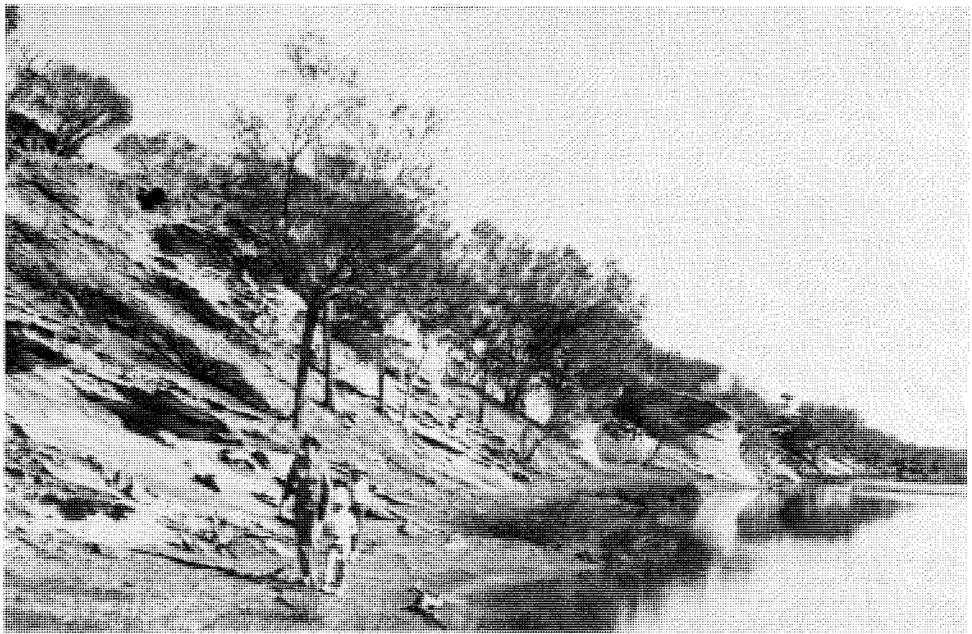

Figure 14. Tumblagooda Sandstone, dipping to the east, at Pencell Pool on the Murchison River.

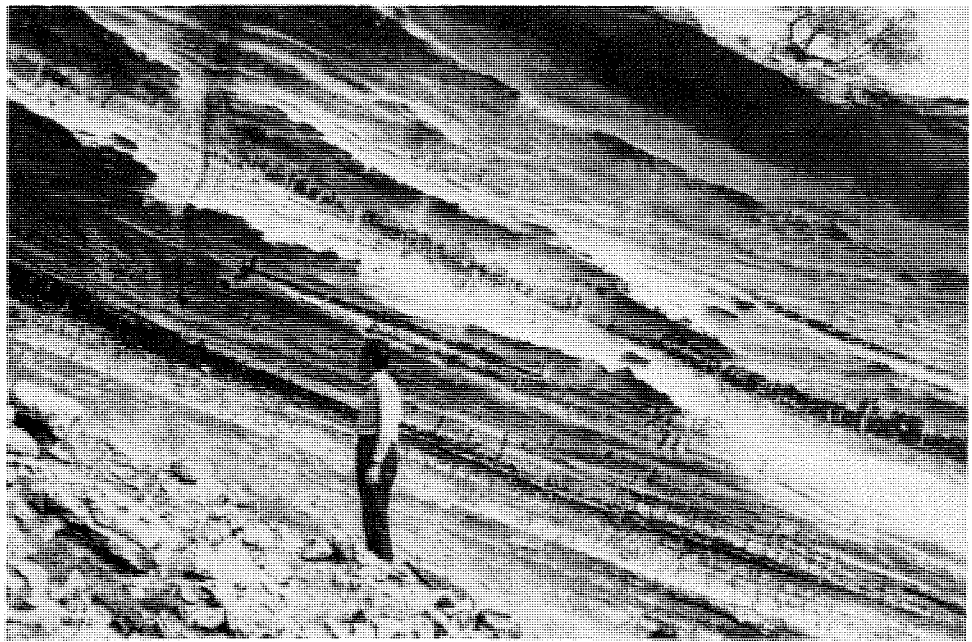

Figure 15. Tumblagooda Sandstone showing abundant invertebrate burrows, at Pencell Pool on the Murchison River.

Poorly preserved moulds of shells occur in a ferruginous sandstone which may belong to the Tumblagooda Sandstone near Coolcalalaya, but they cannot be identified with confidence (Öpik, 1959; Cockbain, 1973a). It is possible that these shells actually occur in the Nangetty Formation or even in the Dirk Hartog Formation, although the latter unit is not known to occur outside the Carnarvon Basin.

Simple microplankton associated with trilete spores in a sample from the upper part of the Tumblagooda Sandstone in Wandagee No. 1 well (in the Carnarvon Basin) was reported by Balme (*in* Pudovskis, 1962). Balme originally regarded the assemblage as being of Ordovician or Early Silurian age, but recent re-examination (Balme, B. E., pers. comm., 1973) suggests that it may be no older than Late Silurian. Furthermore, the contact between the Tumblagooda Sandstone and the overlying Ludlovian Dirk Hartog Formation is transitional in a number of well sections in the Carnarvon Basin. Accordingly we regard the Tumblagooda Sandstone as being Silurian in age. However, there remains the possibility (as it is such a thick unit) that the oldest part of the unit could be Late Ordovician.

Environment of deposition: The red coloration of the Tumblagooda Sandstone is one of the most distinctive features of the formation, and it may be considered as a "red-bed" type of deposit. Sediments of this type are generally believed to have been laid down under oxidizing conditions. Such conditions are most common in continental fluviatile environments, although red marine deposits do occur, and a marine or paralic environment of deposition for parts of the unit cannot be ruled out, especially as the trace fossils have marine affinities (Öpik, 1959).

Strong contemporaneous tectonism (presumably block faulting) must have accompanied deposition of the formation. The source area was granitic, as is indicated by the arkosic nature of the arenites. It seems probable that the unit was laid down as a fluviatile to shallow-marine deposit during an active period of faulting, possibly along the Darling Fault and faults bounding the Northampton Block.

DEVONIAN

Sediments of Devonian age have not yet been identified in the Perth Basin, either in outcrop or in the subsurface. However, Ingram (1967b) reported the presence of remanié Late Devonian spores in the Lower Cretaceous Otorowiri Siltstone Member of the Yarragadee Formation in the Arrowsmith River bores, west of Arrino. This Devonian spore assemblage has only been found previously in the Gneudna Formation, some 500 km north in the Carnarvon Basin. Its presence in the Otorowiri Siltstone Member suggests strongly that Devonian sediments were being eroded nearby during deposition of the member. A likely source area is the nearby Urella Fault Zone, which was strongly active during the Early Cretaceous.

It is concluded that Devonian sediments probably occur in the Perth Basin; they may eventually be found in the subsurface through drilling.

PERMIAN

Permian sedimentary rocks are known to crop out only in the northern part of the Perth Basin. The most extensive exposures are in the Irwin River—Lockier River area (Plate 6, Fig. 51), but scattered outcrops also occur in the valleys of the Greenough and Murchison Rivers. Permian rocks are widespread in the subsurface of the basin, and the total thickness of the sequence probably exceeds 2 600 m.

Drilling has shown that the Permian section is mixed marine and continental in the northern part of the basin, whereas in the southern part it is continental. The northern sequence commences with the glacigene Nangetty Formation and is followed successively by the Holmwood Shale, High Cliff Sandstone, Irwin River Coal Measures, Carynginia Formation, and Wagina Sandstone. Another

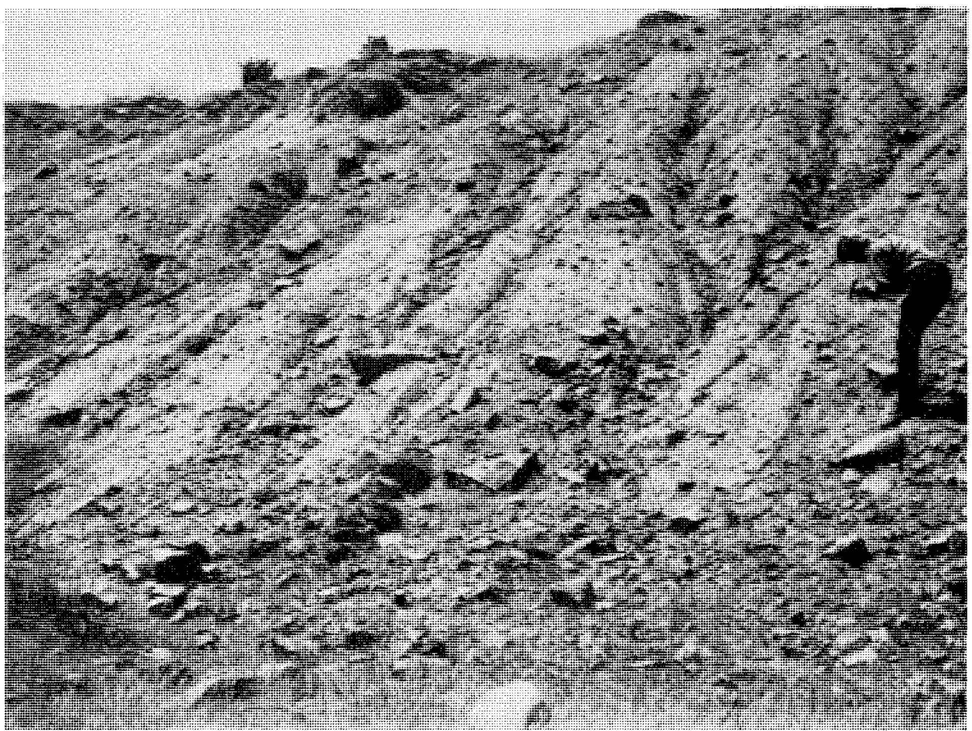

Figure 16. Tillite of the Nangetty Formation exposed on the bank of the Greenough River near Bindoo Spring. The erratics consist of a wide variety of Precambrian rock types, including those derived from every formation of the Yandanooka Group and several of the Moora Group. The Silurian Tumblagooda Sandstone is also represented.

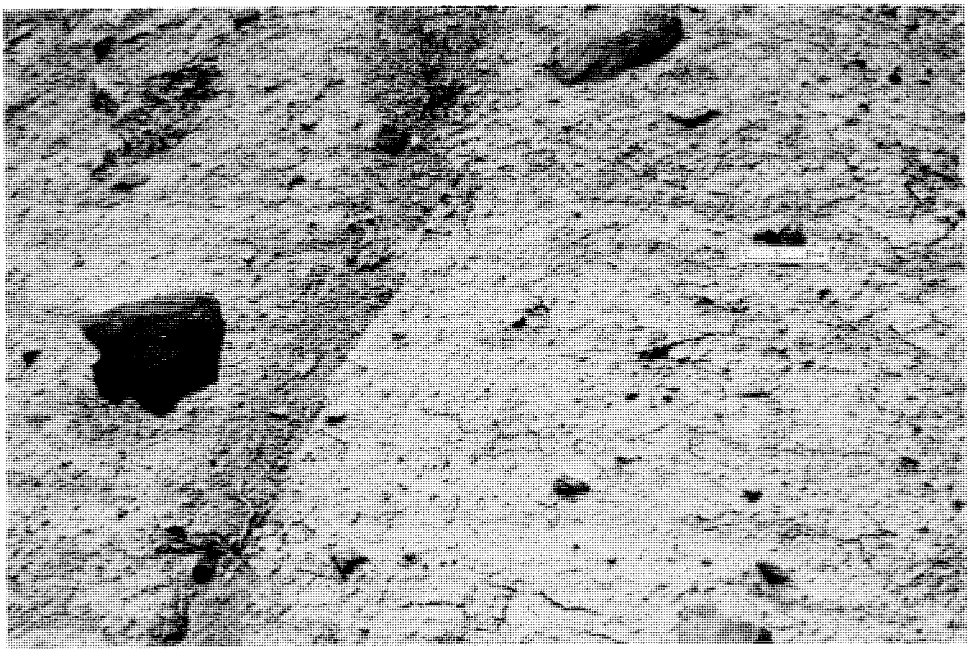

Figure 17. Close-up view of tillite exposed on the bank of the Greenough River near Bindoo Spring. Erratic cobbles and pebbles of Precambrian rocks are scattered in an unsorted matrix of sandy, silty clay. The deposit is crudely bedded, and it may be marine, the glacial debris having been dropped from melting icebergs.

unit, the Mingenew Formation, is probably equivalent to part of the Carynginia Formation. In the south the Permian sequence consists of the continental Sue Coal Measures at the base and the Sabina Sandstone (which also extends into the Triassic) above.

NANGETTY FORMATION

Definition: The Nangetty Formation is a glacigene unit at the base of the Permian sequence in the northern Perth Basin. It was first named the "Nangetty Glacial Formation" by Clarke and others (1951), and this was amended to Nangetty Formation by Playford and Willmott (*in* McWhae and others, 1958).

The type area is the Nangetty Hills (lat. 29° 00′ 00″S, long. 115° 26′ 30″E). Exposures are poor and discontinuous in this area, and no specific type section has been designated.

Lithology: The Nangetty Formation is a sequence of tillite, shale, sandstone, and conglomerate. The tillites are unsorted boulder clays with erratic boulders, cobbles, and pebbles up to 6 m across set in a matrix of sandy, silty clay (Figs. 16 and 17). Some show stratification (Fig. 17) and are thought to be subaqueous deposits, the glacial debris having apparently been dropped from melting icebergs. The boulders, cobbles, and pebbles in these deposits are mostly highly angular, and some show well-developed facets and striations (Fig. 18).

Shales in the Nangetty Formation superficially resemble those of the overlying Holmwood Shale. However, closer examination shows that the Nangetty Formation shales are sandy, unlike those of the Holmwood Shale. They also contain scattered dropstone erratics and "cannon-ball" limestone concretions.

Sandstones in the Nangetty Formation are generally white and are poorly sorted, with a clayey and silty matrix. Many are conglomeratic, and they frequently show strong penecontemporaneous contortion, possibly resulting from the grounding of icebergs or ice flows (Fig. 19). Thin beds of conglomerate containing rounded cobbles and pebbles of various Precambrian rocks are interbedded with the sandstone in some areas. The best exposures of these sandstones and the associated conglomerates occur in the valley of the Wooderarrung River and its tributaries.

An excellent exposure of varved shale and siltstone in the Nangetty Formation is exposed on the bank of the Wooderarrung River near Mullewa (Fig. 20). The varves are coloured reddish brown, yellow, and grey, each cycle being some 2 to 3 mm thick. The thicker varves show well-developed slumping. The varved unit

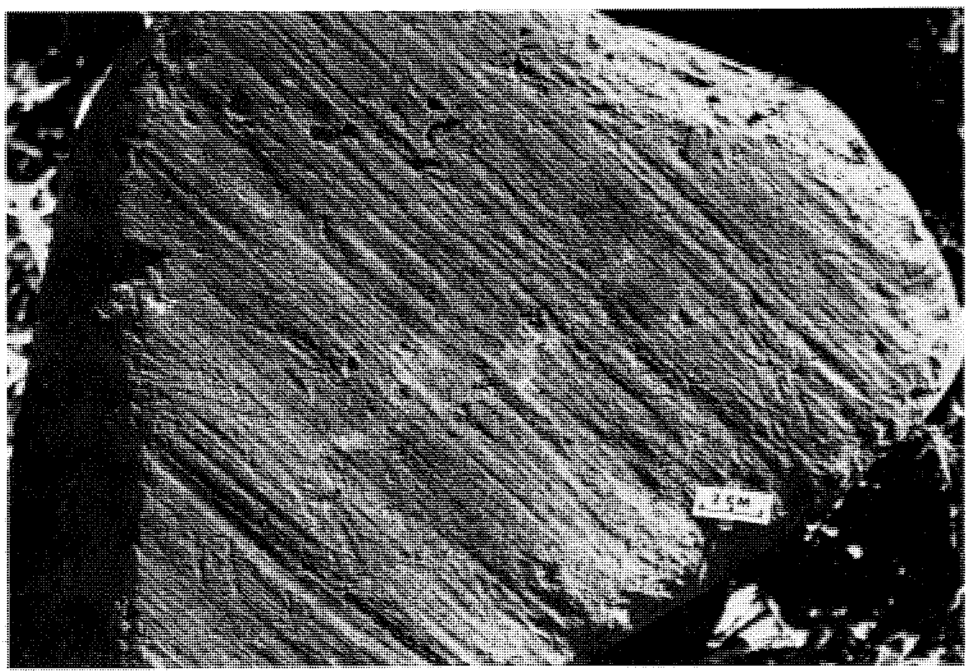

Figure 18. Striated and faceted boulder of dolerite from tillite in the Nangetty Formation at Mungaterra Hill.

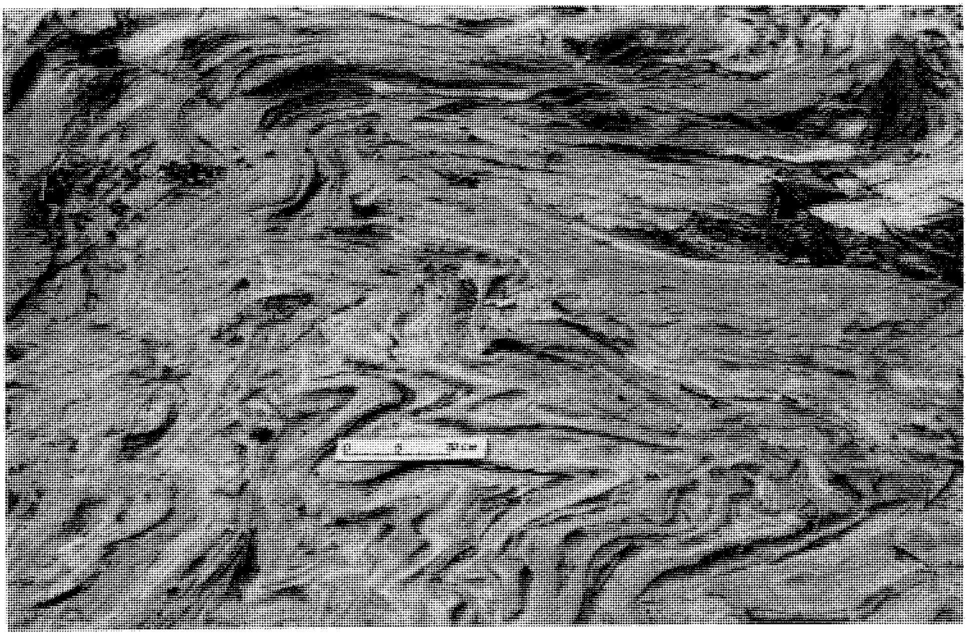

Figure 19. Strongly contorted silty sandstone of the Nangetty Formation exposed on the bank of the Wooderarrung River. The folding may have resulted from the grounding of an iceberg or ice flow on unconsolidated sediments.

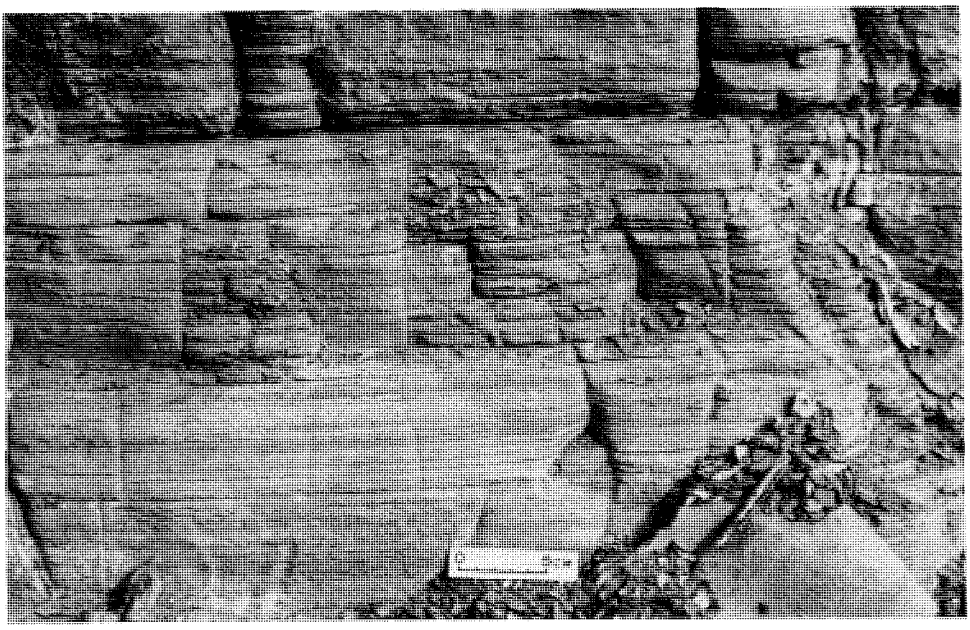

Figure 20. Varved shale and siltstone in the Nangetty Formation exposed on the bank of the Wooderarrung River.

overlies a conglomerate containing rounded clasts of Precambrian rocks. The varves were studied by Ranford and Shaw (1960), who estimated that approximately 40 000 years are represented by the outcrop.

Erratics in the Nangetty Formation include many pre-Permian rock types. In addition to the various metamorphic, granitic, and sedimentary Archaean rocks represented, there are also various types of Proterozoic sediments. Clasts of Tumblagooda Sandstone and of every formation of the Yandanooka Group and several of the Moora Group can be recognized in a spectacular cliff exposure of boulder clay near Bindoo Spring (Figs. 16 and 17). Proterozoic sediments of the Moora and Yandanooka Groups crop out 100 to 250 km south-southeast of Bindoo Spring, and this suggests that the direction of ice movement during the Permian was towards the present north-northwest. Among the most conspicuous erratics in the formation over a wide area are blocks of chert and siliceous limestone derived from the Coomberdale Chert (Fig. 13). A well-known example is the "White Horse" erratic near Mungaterra homestead.

Stratigraphic relationships: The Nangetty Formation unconformably overlies the Tumblagooda Sandstone, Yandanooka Group, Wenmillia Formation, or Precambrian crystalline rocks in different parts of the Perth Basin. The upper contact with the Holmwood Shale is conformable and is commonly transitional.

In areas of poor exposure the top of the Nangetty Formation is mapped immediately above the top boulder bed. In other areas where exposures are better the boundary is placed at the change from sandy shale of the upper Nangetty Formation to typical non-sandy shales of the Holmwood Shale.

Distribution and thickness: The main exposures of Nangetty Formation occur in the drainage areas of the Lockier, Irwin, Greenough, Wooderarrung, and Murchison Rivers, extending from 9.5 km north-northwest of Carnamah to the Murchison River. Outcrops of the formation are generally poor, frequently consisting only of erratic boulders in the soil. No outcrop sections that have been measured are more than 130 m thick, although the total exposed thickness is probably at least 600 m.

The Nangetty Formation is known from drilling in the northern part of the Dandaragan Trough and is more than 1 500 m thick adjacent to the Urella Fault, east of Eradu. It possibly occurs throughout the trough, but over most of the area it is too deep to be penetrated in wells drilled to date. The formation pinches out against the Northampton Block and the Beagle Ridge. An isopach map of the Nangetty Formation and Holmwood Shale (combined) is given as Figure 21.

Fossils and age: The only fossils recorded from the Nangetty Formation are plant microfossils and arenaceous foraminifers.

Spores and pollen (Segroves, 1969, 1970, 1971)

Acanthotriletes tereteangulatus Balme and Hennelly
Apiculatisporis cornutus (Balme and Hennelly)
Cycadopites cymbatus (Balme and Hennelly)
Deltoidospora directa (Balme and Hennelly)

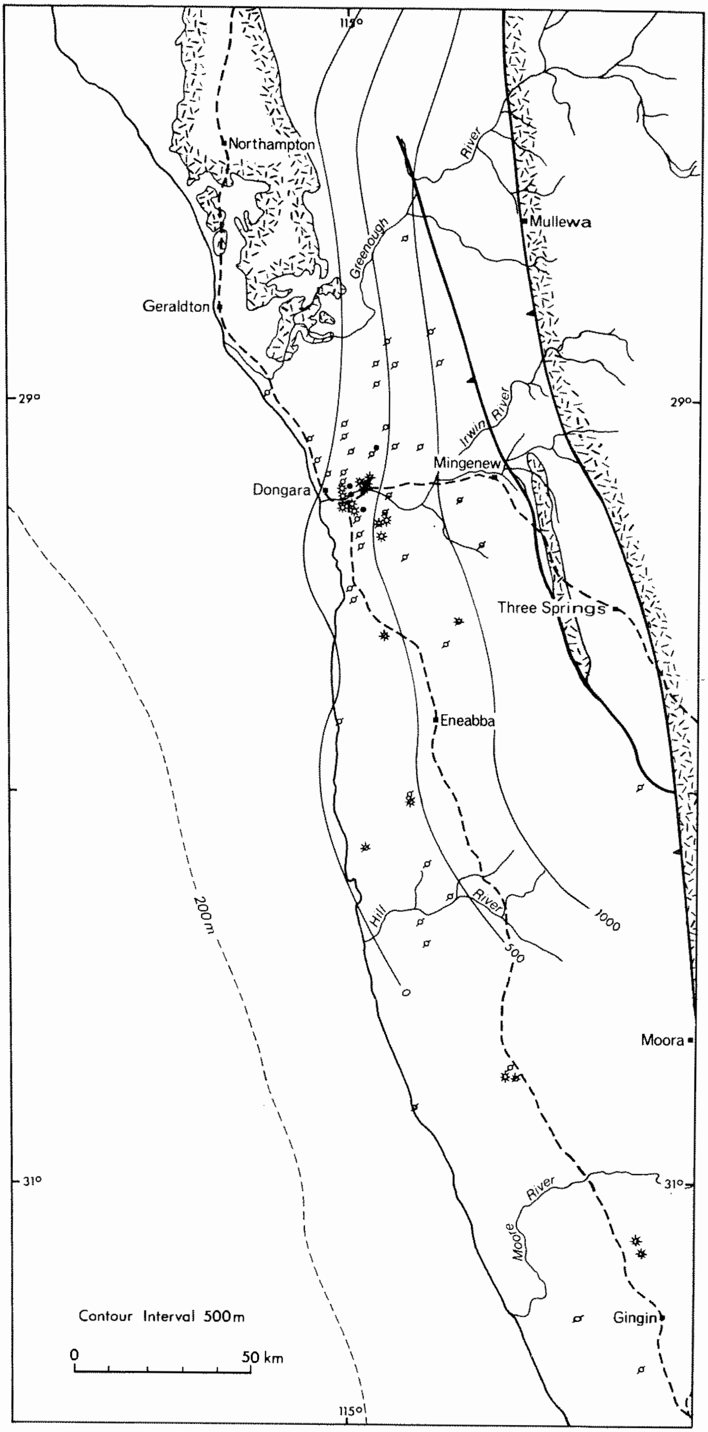

Figure 21. Isopach map, Nangetty Formation and Holmwood Shale (Sakmarian).

Densoisporites solidus Segroves
Densosporites rotundidentatus Segroves
Horriditriletes ramosus (Balme and Hennelly)
Kraeuselisporites enormis Segroves
Limitisporites moersensis (Grebe)
L. sp. cf. *L. rectus* Leschik
Lophotriletes scotinus Segroves
Marsupipollenites triradiatus forma *striatus* Balme and Hennelly
Microbaculispora tentula Tiwari
Parasaccites sp. cf. Virkkipollenites mehtae Lele
Protohaploxypinus limpidus (Balme and Hennelly)
Punctatisporites gretenis (Balme and Hennelly)
Striatoabietites multistriatus (Balme and Hennelly)
Sulcatisporites ovatus (Balme and Hennelly)

Chlorophyta (Segroves, 1971)
Botryococcus sp.

Foraminiferida (Crespin, 1958)
Hemigordius schlumbergi (Howchin)
Hyperammina elegantissima Plummer

According to Balme (*in* McWhae and others, 1958) the spores and pollen indicate a Sakmarian age for the formation. The presence of foraminifers suggests that at least part of the Nangetty Formation is marine.

Environment of deposition: The Nangetty Formation is a glacigene unit which probably includes both marine and continental deposits.

Tillite and shale in the upper part of the formation are probably marine, as the shales are similar to those in the overlying Holmwood Shale, which contains a marine fauna. Most of the coarser sediment (sand to boulder size) in this part of the section is thought to have been dropped from melting icebergs. Other parts of the formation may include continental moraine deposits, and Crowell and Frakes (1971) suggested that much of the formation originated from the mass movement of till. On the other hand, the poorly sorted sandstone and rounded conglomerate elsewhere in the section are thought to have been deposited by torrential streams issuing from melting glaciers. The varves that have been observed at a few localities were probably laid down in glacial lakes, as were some other finely bedded clays and silts containing dropstones.

HOLMWOOD SHALE

Definition: The name Holmwood Shale was introduced by Clarke and others (1951) for the black shale overlying the Nangetty Formation and underlying the "Fossil Cliff Formation". Johnson and others (1954) redefined the "Holmwood Shale Formation" to include the "Fossil Cliff Formation", as they maintained that the latter unit was not sufficiently distinct to warrant formation status. McWhae and others (1958) and Playford and Willmott (1958) did not adopt this usage, although Playford and Willmott observed that there was some merit in Johnson and others' proposal. They agreed that the "Fossil Cliff Formation" could justifiably be regarded as an upper, more calcareous facies of the Holmwood Shale. Nevertheless they felt that the name "Fossil Cliff Formation" was so firmly entrenched in the literature that it would be advisable to continue recognizing it as a separate formation.

However, we now feel that this reason is not sufficient to justify retaining the unit as a formation. Our work has shown that the unit is difficult to map satisfactorily, as it only differs from normal Holmwood Shale in that it contains thin, lenticular beds of fossiliferous limestone, and it can be recognized only in the small area between the North Branch of the Irwin River and 6.5 km south of Beckett Gully. Our conclusion is that it is best considered as a member of the Holmwood Shale, that is, as the Fossil Cliff Member.

The type section of the Holmwood Shale nominated by Playford and Willmott (*in* McWhae and others, 1958) is along Beckett Gully (lat. 29° 01′ 12″S, long. 115° 31′ 17″E). This section is faulted and is for the most part poorly exposed, so that the total thickness as measured is not reliable. However, it does illustrate the range of rock types developed in the formation. A description of the section (as measured by Playford and Willmott, 1958) is as follows:

High Cliff Sandstone, conformably overlying—

	Thickness (metres)
Holmwood Shale (566 m)	
17. *Fossil Cliff Member:* Siltstone, clayey, black with yellow (jarositic) bands, thin-bedded to fissile; containing subordinate thin beds of richly fossiliferous, silty, grey and red, tough and hard limestone; some limestone beds partly replaced by hematite	45
16. Siltstone, sandy, clayey, grey to black, micaceous, well-bedded, partly gypseous and jarositic; with some thin (0.3-0.5 m) beds and lenses of silty, grey to yellow, partly gypseous, hard limestone which is mainly unfossiliferous, but with some beds containing a few small bivalves and crinoid stems; some large limestone concretions present	60
15. No exposure	30
14. Siltstone, sandy, clayey, grey to black, micaceous, well-bedded to thinly bedded, partly gypseous and jarositic, intermittently exposed; with thin (0.3-0.5 m) beds and lenses of silty, sandy, grey to yellow, hard, massive limestone	174
13. No exposure	29
12. Shale, grey to greenish-grey; with thin (0.3 m) beds and lenses of grey to yellow-grey, massive, hard limestone; a few beds show cone-in-cone structure	19
11. Siltstone, with thin beds of limestone, as for unit 12	25
10. Shale, green-grey to dark-brownish-grey	4.6
9. *Beckett Member*: Shale, green-grey to dark-brownish-grey; with prominent beds of clayey, grey, hard, massive, partly phosphatic limestone, weathering brown, some showing cone-in-cone structure; one concretionary bed contains the goniatite *Juresanites jacksoni*	11
8. Shale, grey-green to dark-brownish-grey; with lesser thin beds of grey, hard, massive limestone, weathering yellow, showing cone-in-cone structure	21
7. No exposure	43

6. Shale, light blue-grey, weathering yellowish-green; with thin beds of grey, hard, massive limestone, weathering yellow, showing cone-in-cone structure	62
5. Shale with thin beds of limestone, as for unit 6	1
4. No exposure	14
3. Shale, blue-grey to green, with a thin (15 cm) bed of grey to blue-grey limestone, weathering light brown, showing cone-in-cone structure	7
2. No exposure	20
1. Shale, blue-green, weathering olive-green	0.3

Base of formation concealed, but conformably overlying Nangetty Formation.

The type section of the formation described above also includes the type section of the *Beckett Member*. The type section of the *Fossil Cliff Member* on the other hand is at Fossil Cliff (lat. 28° 56′ 35″S, long. 115° 32′ 35″E). The following is a description of this section (modified from Playford and Willmott, 1958):

High Cliff Sandstone, conformably overlying—

Fossil Cliff Member of Holmwood Shale (27 m)	Thickness (metres)
26. Siltstone, black with yellow bands, jarositic, carbonaceous, thinly bedded; contains abundant impressions of *Fenestella*	0.3
25. Sandstone, grey, silty, fine-grained, soft, friable	0.15
24. Siltstone, black with yellow jarositic bands, clayey, micaceous, thinly bedded	1.0
23. No exposure	6.7
22. Siltstone, red, clayey, sandy, strongly ferruginous, massive, probably represents replaced limestone	0.15
21. No exposure	0.3
20. Siltstone, as for unit 25	0.15
19. Sandstone, fine-grained, silty, white and brown, friable	0.3
18. Siltstone, as for unit 25, with thin beds of fine-grained, silty, white and brown, friable sandstone	0.3
17. Siltstone, sandy, light-grey to yellow and black, jarositic, slightly micaceous, thinly bedded	0.6
16. Claystone, silty, black and grey, jarositic, thinly bedded with thin beds of ironstone (replaced limestone), fossiliferous, hard; and fine-grained, silty, yellow, soft, and friable sandstone	1.2
15. Claystone, unfossiliferous, grey to black, with yellow, weathered, irregular patches	1.2
14. Sandstone, fine-grained, with silty and clayey bands, yellow and white, friable, thinly bedded; interbedded with black siltstone and claystone; a few beds of ironstone (replaced limestone); richly fossiliferous at about 0.3 m intervals	1.0
13. Siltstone, sandy, clayey, grey to yellow, very calcareous, thinly bedded, with abundant fossils throughout	0.3
12. Siltstone, sandy, calcareous, grey to yellow-brown, fossiliferous, soft	0.5
11. Limestone, silty, clayey, grey and red, massive, tough and hard, partly replaced by hematite, fossiliferous	0.3

10.	Siltstone, yellow to reddish-grey, calcareous, thinly bedded	1.8
9.	Siltstone, jarositic, grey, thinly bedded, with a few fossils; a thin band of gypsum is present	0.6
8.	Siltstone, grey and yellow, clayey, very calcareous, richly fossiliferous, with thin beds of ironstone at the base	1.8
7.	Limestone, grey, silty, hard, with 5 cm bed of richly fossiliferous ironstone at the top	0.3
6.	Siltstone, calcareous, richly fossiliferous, with fossils generally thin-shelled and small	0.7
5.	Siltstone, clayey, black, micaceous, jarositic, with bands of *Fenestella,* but otherwise unfossiliferous; contains occasional gypsum bands	4.8
4.	Limestone, yellow, massive, weathered, richly fossiliferous	0.6
3.	Siltstone, grey and yellow, calcareous, with beds of gypsum; grades laterally into grey limestone with abundant fossils	0.8
2.	Limestone, grey, massive, hard, with gypsum veins, lenticular, poorly fossiliferous to richly fossiliferous	0.3
1.	Siltstone, clayey, grey and yellow, calcareous, fossiliferous, with a few thin bands of limestone as in unit 5	1.0

Lithology: In the type area the lower part of the Holmwood Shale is made up of grey-green shale, weathering yellow green, with thin beds of cone-in-cone clayey limestone. The Beckett Member occurs within this lower shaly section. It consists of alternating beds of shale and brown limestone, and includes a conspicuous horizon of yellow-brown phosphatic limestone concretions containing the goniatite *Juresanites jacksoni.* Playford and Willmott (1958) note that the apical angle of the cones in the cone-in-cone limestones increases progressively moving up the section. Such limestones are only present in the lower (shaly) part of the formation.

The upper part of the unit consists dominantly of grey to black, micaceous, jarositic, and gypseous, well-bedded clayey siltstone. This part of the section contains thin limestone beds, especially at the top where they characterize the Fossil Cliff Member. A conspicuous richly fossiliferous limestone bed lower in the section has been named the *Woolaga Limestone Member* by G. Playford (1959). This member has been mapped only in the Woolaga Creek area.

The Fossil Cliff Member consists of interbedded dark siltstone, sandy siltstone, shale, and richly fossiliferous limestone. The beds of limestone, which characterize the member, are thin and markedly lenticular. They are mainly bioclastic calcarenites. The siltstones are commonly calcareous and are sparsely fossiliferous. The limestones become distintly more sandy as the Darling Fault is approached. This is especially marked in Carynginia Gully, where exposures of ferruginous limestone in the member near the fault contain abundant quartz and feldspar grains, up to granule size.

In the northern part of the basin two unnamed sandstone members have been recognized in well sections (Johnstone and Willmott, 1966). They probably crop out at Tenindewa.

Rare glacial erratics occur in the Holmwood Shale, especially near the base of the formation.

Stratigraphic relationships: The Holmwood Shale rests conformably on the Nangetty Formation, and is overlain with apparent conformity by the High Cliff Sandstone or unconformably by younger deposits. In some areas the formation rests unconformably on the Tumblagooda Sandstone or on Precambrian rocks.

Distribution and thickness: The northernmost exposures of the Holmwood Shale are probably in the valley of the Murchison River, 13 to 25 km south of Bompas Hill. They consist of white, red, yellow, and purple claystones overlying glacigene deposits of the Nangetty Formation and overlain by the ?Tertiary Victoria Plateau Sandstone.

The main exposures of Holmwood Shale are found in the valleys of the Irwin and Lockier Rivers. Outcrops are generally poor, being restricted to the watercourses. The only section that has been measured through the whole of the formation is the type section. Although this section, as measured by Playford and Willmott (1958), is 566 m thick, it includes some repetition of section by faulting, and the true thickness may be of the order of 450 m.

The formation crops out poorly in the Yuna area, the best exposures being in dam excavations. Most outcrops in this area are highly weathered.

The Fossil Cliff Member is exposed only in the small area from the North Branch of the Irwin River to 6.5 m south of Beckett Gully. It may also occur north of the Irwin River, although the characteristic limestones that define the member have not been seen in this area. Correlatives of the member have been reported from a number of wells drilled in the basin, extending as far south as Cadda No. 1. The thickest section that has been measured is in Beckett Gully (45 m). The member is 27 m thick in its type section at Fossil Cliff.

In the subsurface the Holmwood Shale occurs in the Dandaragan Trough at least as far south as Cadda No. 1 well. It reaches its maximum thickness of about 450 m in the type area between the Urella and Darling Faults, and thins westward. Figure 21 is an isopach map of the Holmwood Shale and Nangetty Formation.

Fossils and age: Plant microfossils and foraminifers have been recorded from the shales of the formation, but macrofossils are virtually confined to the carbonate members. The following fossils either occur throughout the Holmwood Shale or they cannot be assigned to a particular member.

Spores and pollen (B. E. Balme *in* G. Playford, 1959; Segroves, 1969, 1970, 1971)

Acanthotriletes tereteangulatus Balme and Hennelly
Alisporites gracilis Segroves
A. indarraensis Segroves
Apiculatisporis cornutus (Balme and Hennelly)
A. levis (Balme and Hennelly)
Calamospora diversiformis Balme and Hennelly
C. sp. cf. *C. microrugosa* (Ibrahim)
Corisaccites alutas Venkatachala and Kar
Cycadopites cymbatus (Balme and Hennelly)
Deltoidospora directa (Balme and Hennelly)
Densoisporites solidus Segroves
Densosporites rotundidentatus Segroves

Diatomozonotriletes townrowii Segroves
Entylissa sp. cf. *E. cymbatus* Balme and Hennelly
Grandispora sp.
Granulatisporites micronodosus Balme and Hennelly
G. sp.
Horriditriletes ramosus (Balme and Hennelly)
Hymenozonotriletes spp.
cf. *Illinites* sp.
Kraeuselisporites enormis Segroves
K. splendens (Balme and Hennelly)
K. sp.
Latosporites colliensis (Balme and Hennelly)
Limitisporites moersensis (Grebe)
L. sp. cf. *L. rectus* Leschik
Lophotriletes scotinus Segroves
Lundbladispora sp.
Marsupipollenites triradiatus forma *striatus* Balme and Hennelly
Microbaculispora tentula Tiwari
Nuskoisporites sp.
Parasaccites bilateralis Tiwari
P. gondwanensis (Balme and Hennelly)
P. sp. cf. *Virkkipollenites mehtae* Lele
Potoniesporites balmei (Hart)
Protohaploxypinus amplus (Balme and Hennelly)
P. limpidus (Balme and Hennelly)
Punctatisporites gretensis Balme and Hennelly
cf. *Reinchospora* sp.
cf. *Sahnites* sp.
?*S.* sp.
Striatoabietites multistriatus (Balme and Hennelly)
Sulcatisporites ovatus (Balme and Hennelly)
S. sp. cf. *Pityosporites potoniei* Lakhanpal, Sah, and Dube
S. splendens Leschik
Verrucosisporites naumovae Hart
V. pseudoreticulatus Balme and Hennelly
Vestigisporites sp. cf. *V. rudis* Balme and Hennelly
Vittalina sp.

Acritarchs (B. E. Balme *in* G. Playford, 1959)
spinose hystrichosphaerids

Incertae sedis (Segroves, 1967)
Quadrisporites sp. cf. *Q. horridus* Hennelly

Chlorophyta (Segroves, 1971)
Botryococcus sp.

Foraminiferida (Crespin, 1958)
Ammodiscus nitidus Parr
Glomospirella nyei Crespin
Hyperammina callytharraensis Crespin
H. hadzeli Crespin
H. sp.
Pelosina ampulla Crespin
Psammosphaera pusilla Parr
Thurammina phialaeformis Crespin
Thuramminoides sphaeroidalis Plummer
Trochammina subobtusa Parr

Scyphozoa (Clarke and others, 1951)
Conularia sp.

Bryozoa (Clarke and others, 1951)
Fenestella sp.

Brachiopoda (Clarke and others, 1951)
Linoproductus cora foordi (Etheridge Jr.)
Neochonetes pratti (Davidson)

Bivalvia (Clarke and others, 1951; Dickins, 1963)
Conocardium
"Solemya" holmwoodensis Dickins

Gastropoda (Clarke and others, 1951; Dickins, 1963)
Baylea perthensis Dickins
Bellerophon sp.
Soleniscus sp.

Annelida (Clarke and others, 1951)
serpulids

The faunas of the named members are as follows:

1. Beckett Member

Nautiloidea (Clarke and others, 1951)
orthoceroid

Ammonoidea (Etheridge Jr., 1907b; Glenister and Furnish, 1961)
Juresanites jacksoni (Etheridge Jr.)

Crinoidea (Clarke and others, 1951)
crinoid stem fragment

2. Woolaga Limestone Member (see G. Playford, 1959 for a general survey of the fauna)

Scyphozoa (Dickins, 1957)
conularid sp. indet.

Brachiopoda (Dickins, 1957)
"Dielasma" sp. indet.
Neochonetes pratti (Davidson)

Bivalvia (Dickins, 1957)
"Sanguinolites" sp.

Gastropoda (G. Playford, 1959)
unidentified

Nautiloidea (G. Playford, 1959)
unidentified

Ammonoidea (Teichert and Glenister, 1952; G. Playford, 1959; Glenister and Furnish, 1961; Glenister and others, 1973)
Juresanites jacksoni (Etheridge Jr.)
Uraloceras irwinensis Teichert and Glenister

Annelida (G. Playford, 1959)
serpulids

Crinoidea (Dickins, 1957)
crinoid columnals

3. Fossil Cliff Member

Acritarchs (Segroves, 1967)
Maculatisporites amplus Segroves

Foraminiferida (Etheridge Jr., 1907b; Campbell, 1910; Crespin, 1947, 1958)
Ammodiscus nitidus Parr
A. woolnoughi Crespin and Parr
Calcitornella elongata Cushman and Waters
C. stephensi (Howchin)
Endothyra sp. cf. *E. media* Waters
Frondicularia woodwardi Howchin
Geinitzina triangularis Chapman and Howchin
Hemigordius schlumbergi (Howchin)
Hyperammina callytharraensis Crespin
H. sp. cf. *H. elegans* (Cushman and Waters)
H. hadzeli Crespin
Nodosaria irwinensis Howchin

N. tereta Crespin
N. sp.
Proteonina arenosa Crespin
Reophax n. sp.
Stacheia dickinsi Crespin
Thuramminoides sphaeroidalis Plummer
Trepeilopsis australiensis Crespin
Trochammina subobtusa Parr

Rugosa (Hinde, 1890; Etheridge Jr., 1907b; Campbell, 1910; Hill, 1937, 1942)
"*Amplexus*" sp.
Euryphyllum trizonatum Hill
Gerthia sulcata (Hinde)
Plerophyllum australe Hinde

Bryozoa (Foord, 1890; Chapman, 1904b; Etheridge Jr., 1907b; Campbell, 1910; Clarke and others, 1951)
Fenestella sp.
Hexagonella sp.
Polypora sp.
Rhombopora sp.
Stenopora leichardti Nicholson and Etheridge Jr.

Brachiopoda (Foord, 1890; Chapman, 1904b; Etheridge Jr., 1907b; Campbell, 1910; Hosking, 1933; Prendergast, 1935, 1943; Clarke and others, 1951; Coleman, 1957; Dickins and Thomas, 1957)
Aulosteges baracoodensis Etheridge Jr.
A. spinosus Hosking
Cancrinella cancriniformis (Tschernyschew)
C. lyoni (Prendergast)
Cleiothyridina macleayana (Etheridge Jr.)
Costiferina callytharensis (Prendergast)
C. magnus (Coleman)
Linoproductus cora foordi (Etheridge Jr.)
"*Martiniopsis*" sp. indet.
Neochonetes pratti (Davidson)
N. fasciger (Keyserling)
Phricidothyris lineata (Martin)
Pseudosyrinx? sp.
Seminulina globulina Phillips
Spirifer sp. cf. *S. curzoni* Diener
Spiriferella australasica (Etheridge Jr.)
Spiriferellina? sp.
Streptorhynchus sp.
Strophalosia (Heteralosia) etheridgei Prendergast
S. (H.) irwinensis Coleman
S. (H.) prendergastae Coleman
S. (H.) tenuispina Waagen
Taeniothaerus coolkiliensis Coleman
T. irwinensis Coleman
T. sp. aff. *T. miniliensis* Coleman

Bivalvia (Foord, 1890; Chapman, 1904b; Etheridge Jr., 1907b, Campbell, 1910; Dickins and Thomas, 1957; Dickins, 1963)
Acanthopecten? sp.
Anthraconeilo n. sp.
Astartella obliqua Dickins
Astartila? tumida Dickins
Atomodesma mytiloides Beyrich
Aviculopecten sp. cf. *A. subquinquelineata* (M'Coy)
A. tenuicollis (Dana)
Chaenomya sp.
Conocardium sp.
Cypricardinia? elegantula Dickins
Edmondia prichardi Dickins
Girtypecten ovalis Dickins
Modiolus koneckii Dickins

Myonia subarbitrata Dickins
M. n. sp.
Nuculopsis (Nuculopsis) darlingensis Dickins
N. (Nuculanella) bangarraensis Dickins
Pachymyonia sp. cf. *P. occidentalis* Dickins
Palaeocosmomya sp.
Palaeolima n. sp.
Palaeosolen? badgeraensis Dickins
Parallelodon bimodoliratus Dickins
Phestia lyonsensis (Dickins)
Plagiostoma? n. sp.
Praeundulomya subelongata Dickins
Quadratonucula australiensis Dickins
Schizodus sandimanensis Dickins
Streblopteria sp.
Strutchburia hoskingae Dickins

Gastropoda (Foord, 1890; Etheridge Jr., 1907b; Campbell, 1910; Dickins and Thomas, 1957; Dickins, 1963)
Baylea perthensis Dickins
Bellerophon sp. cf. *B. formani* Dickins
B. n. sp.
Macrochilina winensis Dickins
Mourlonia? obscura Dickins
M. (Pseudobaylea) freneyensis Dickins
M. (Woolnoughia) angulata Dickins
Naticopsis? sp.
Peruvispira sp. cf. *P. umariensis* (Reed)
Platyceras sp. cf. *P. abundans* (Wanner)
Ptychomphalina talboti Dickins
"Retispira" clarkei Dickins
R. irwinensis Dickins
Stachella crucilirata Dickins
Straparollus (Leptomphalus) n. sp.
Warthia sp.

Nautiloidea (Foord, 1890; Campbell, 1910; Clarke and others, 1951)
Domatoceras sp.
Euloxoceras sp.
Pseudorthoceras sp.
Stearoceras sp.

Ammonoidea (Chapman, 1904b; Glenister and Furnish, 1961; Glenister and others, 1973)
Metalegoceras kayi Glenister, Windle, and Furnish

Trilobita (Stubblefield *in* Teichert, 1944)
Ditomopyge sp.

Ostracoda (Clarke and others, 1951; Dickins and Thomas, 1957)
cf. *Amphissites* sp.
Bairdia sp.
Healdia sp.

Crinoidea (Chapman, 1904b; Campbell, 1910; Glauert, 1910b; Teichert, 1949)
Actinocrinus? sp.
Calceolispongia digitata Teichert
Platycrinus sp.

The fauna of the Fossil Cliff Member has long been known for its richness and variety, although not all groups have been studied in detail. If Newton (1892) is correct in considering the type specimen of *Neochonetes pratti*, described by Davidson in 1859, to have come from the Irwin River district, then this is the first fossil species to have been described from Western Australia. The ammonoids are the most important fossils for establishing the age of the Holmwood Shale. According to Glenister and Furnish (1961) the joint occurrence of *Juresanites* and *Uraloceras* indicates a late Sakmarian age and they suggest that the Fossil Cliff Member is equivalent to the Sterlitamakian, the uppermost subdivision of the Sakmarian. The Irwin River area is one of the few places in the world where beds with the *Glossopteris* flora (Irwin River Coal Measures) occur in the same stratigraphic sequence as marine strata containing ammonoids (Holmwood Shale).

Environment of deposition: The Holmwood Shale is a marine deposit, laid down under cold-water conditions. Sporadic glacial erratics in the formation testify to occasional icebergs which dropped material onto the sea floor as they melted.

The dark colour of the shale and lack of benthonic fauna in most of the section indicate a reducing environment on the sea floor during most of the time of deposition of the formation. Woolnough (1937) suggested that this may have resulted from the Holmwood Shale being deposited in some form of barred basin. However, drilling has now shown the extensive distribution of the Holmwood Shale in the Perth Basin, and clearly the formation was not laid down in a local barred basin.

The presence of fossiliferous limestones in the upper part of the formation (Woolaga Limestone Member and Fossil Cliff Member) show that there were periods when the bottom was well aerated, allowing a benthonic fauna to flourish for relatively short periods.

HIGH CLIFF SANDSTONE

Definition: The name High Cliff Sandstone was introduced by Clarke and others (1951) for the unit of sandstone lying between the Irwin River Coal Measures and the "Fossil Cliff Formation". The type section is at High Cliff (lat. 28° 56′ 40″S, long. 115° 32′ 45″E) on the North Branch of the Irwin River (Fig. 23). The following is a description of this section (from Playford and Willmott, 1958):

Irwin River Coal Measures, conformably overlying—

	Thickness (metres)
High Cliff Sandstone (24 m)	
5. Sandstone, fine-grained, silty, clayey, white, grey, pink, and yellow, feldspathic, crudely bedded; with bands of fine-grained, clayey, brown and yellow, jarositic, sandstone, with burrows, a few slump structures, and a few thin carbonaceous bands; pebbles and boulders of granite, gneiss, and quartzite occur in a band near the top of the unit	17
4. Sandstone, very fine-grained, silty and clayey, black, carbonaceous, jarositic	0.3
3. Sandstone, coarse-grained, red, brown, yellow, and grey, strongly cross-bedded, massive, well-sorted, grains rounded to subrounded	2.1
2. Sandstone, very fine-grained, strongly silty and clayey, black, jarositic, crudely bedded, friable	1
1. Sandstone, fine-grained, silty, clayey in part, grey, black, yellow, and brown, crudely bedded, slightly carbonaceous, with some ferruginous bands, friable, grains subangular to subrounded; strong bioturbation	3.7

Overlying, with apparent conformity, Fossil Cliff Member of Holmwood Shale.

(4)—53419

Lithology: The High Cliff Sandstone consists of white, yellow, brown, and black fine-grained quartz sandstone, which is in part silty, and containing lesser thicknesses of coarse-grained cross-bedded sandstone, and thin beds of white siltstone. The sandstone is generally massive, and forms some conspicuous exposures. Thin beds of boulder and pebble conglomerate, with clasts of granite, quartzite, and chert, have been observed in a number of areas, particularly at Beckett Gully and Woolaga Creek. A bed of fossiliferous ferruginous sandstone occurs in the lower part of the formation in the Woolaga Creek area.

There is some evidence that the coarseness of the sandstone increases as the Darling Fault is approached, and in places much of the unit becomes conglomeratic, with well-rounded quartz pebbles, as in the area just south of Badgerra Pool. Similarly there are suggestions of increasing coarseness approaching the Urella Fault. Probably these faults were slightly active during Early Permian times, being marked by weak scarps.

Stratigraphic relationships: The High Cliff Sandstone overlies the Holmwood Shale. There is no field evidence to suggest that this contact is other than conformable, although it is usually abrupt, and it is possible that a brief break in sedimentation occurred prior to deposition of the High Cliff Sandstone.

The High Cliff Sandstone is overlain conformably by the Irwin River Coal Measures.

Distribution and thickness: The High Cliff Sandstone is discontinuously exposed from the Greenough River valley, 13 km north of Bindoo Hill, to Woolaga Creek, a distance of some 130 km. The main exposures are in the Irwin River-Lockier River drainage area. The formation also occurs in a number of exploratory wells, but it is difficult to distinguish from the Irwin River Coal Measures in the subsurface (Johnstone and Willmott, 1966). An isopach map of the High Cliff Sandstone and Irwin River Coal Measures (combined) is shown as Figure 22.

The High Cliff Sandstone ranges in thickness from 24 m at High Cliff to 42 m at Woolaga Creek.

Fossils and age: Outcrops of the High Cliff Sandstone are generally unfossiliferous, the main exception being the basal unit of the formation in the Woolaga Creek area (G. Playford, 1959).

In the subsurface, the formation cannot be satisfactorily separated from the Irwin River Coal Measures and therefore any spores and pollen grains occurring in the formation are listed with those from the Irwin River Coal Measures. The following fossils have been recorded from the High Cliff Sandstone:

Bryozoa (Dickins, 1957)
 fenestrate bryozoans

Brachiopoda (Dickins, 1957; G. Playford, 1959; Campbell, 1965)
 Aulosteges sp. cf. *A. ingens* Hosking
 A. sp. indet.
 Cancrinella sp. cf. *C. lyoni* (Prendergast)
 C. sp.
 C. sp. indet.

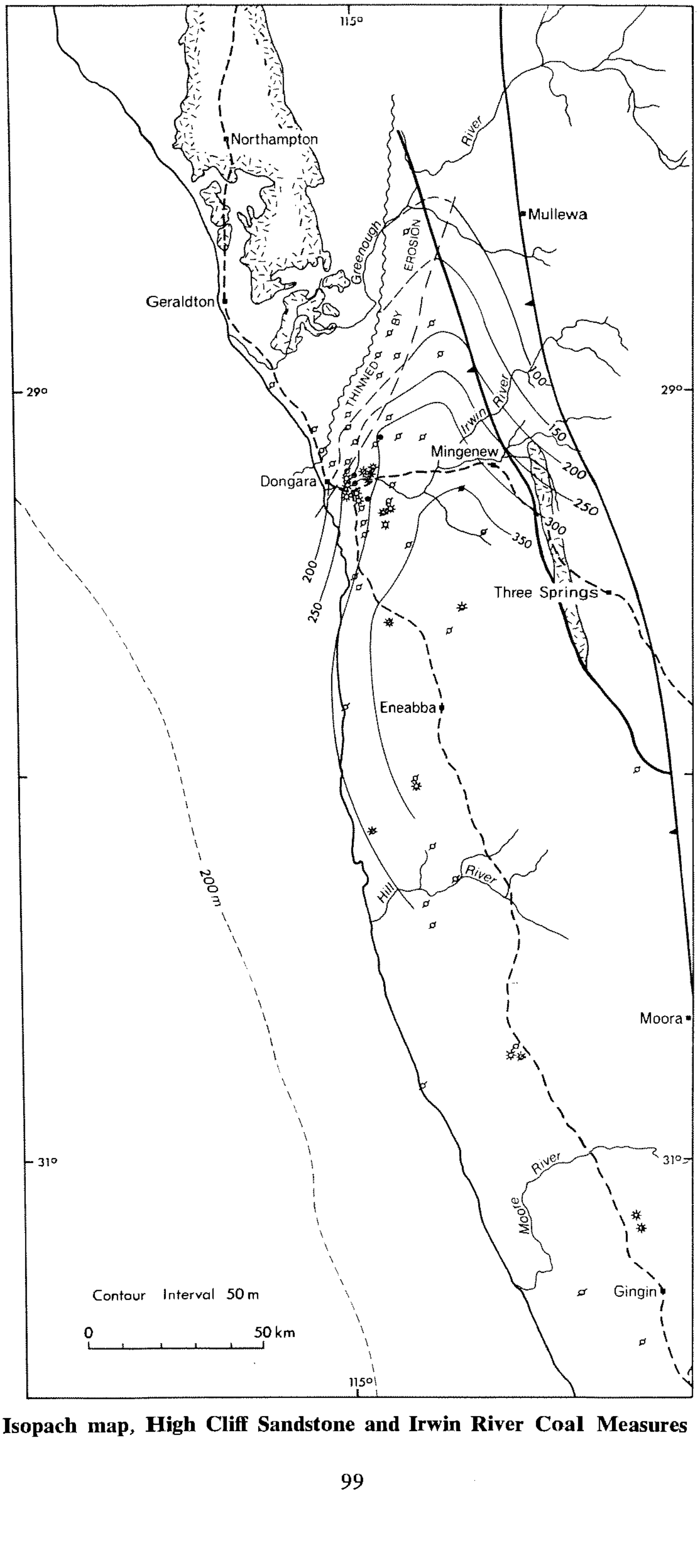

Figure 22. Isopach map, High Cliff Sandstone and Irwin River Coal Measures (Artinskian).

Cleiothyridina sp.
C. sp. indet.
Gilledia woolagensis Campbell
"*Martiniopsis*" sp. A. Dickins
Neochonetes sp.
Neospirifer n. sp. A. Dickins
N. n. sp. B. Dickins
N. sp. indet.
Phricidothyris? sp.
spiriferid n. sp.

Bivalvia (Dickins, 1957, 1963; G. Playford, 1959)
Astartila? sp.
Atomodesma sp. cf. *A. mytiloides* Beyrich
Aviculopecten sp. cf. *A. tenuicollis* (Dana)
Cypricardinia? sp.
Edmondia sp.
Oriocrassatella sp.
Palaeosolen? sp.
Parallelodon sp. cf. *P. bimodoliratus* Dickins
Schizodus sp. cf. *S. fitzroyensis* Dickins
Streblopteria sp.
Stutchburia sp. cf. *S. variabilis* Dickins

Gastropoda (Dickins, 1957, 1963; G. Playford, 1959)
Bellerophon sp. cf. *B. formani* Dickins
Mourlonia (Pseudobaylea) sp. cf. *M. (P.) freneyensis* Dickins
Naticopsis? sp.

The High Cliff Sandstone is considered to be of Artinskian age. Its shelly fauna is distinct from that of the Sakmarian Fossil Cliff Member, and Dickins (1957) considers the fauna to be intermediate in age between those of the Callytharra Formation (which equates with the Fossil Cliff Member) and the Madeline Formation of the Carnarvon Basin.

Environment of deposition: The High Cliff Sandstone is a shallow-marine deposit. It was probably laid down mainly in shallow subtidal conditions, although some parts of the unit could represent beach deposits.

IRWIN RIVER COAL MEASURES

Definition: The name Irwin River Coal Measures was introduced by Clarke and others (1951) for the coal-measures sequence lying between the High Cliff Sandstone and the Caryngina Formation. The type section extends along the North Branch of the Irwin River, commencing at High Cliff (lat. 28° 56′ 40″S, long. 115° 32′ 45″E). The following is a description of this section (from Playford and Willmott, 1958):

Caryngina Formation, conformably overlying—

	Thickness (metres)
Irwin River Coal Measures (63 m)	
48. Sandstone, fine to medium-grained, yellow to white, poorly sorted, friable; with thin beds of carbonaceous siltstone and claystone	5.5
47. Conglomerate, fine, grading into very coarse-grained, grey, poorly sorted, feldspathic sandstone	0.3
46. Siltstone and shale, sandy, dark-grey and purple, intermittently exposed, containing plant fossils	0.6

45.	Coal, clayey, lenticular, grading into black, carbonaceous claystone containing plant fossils	0.6
44.	Claystone, black, very carbonaceous	1.8
43.	Ironstone, red, massive, hard, silty and sandy	0.3
42.	Sandstone, medium to fine-grained, silty, yellow, feldspathic, crudely bedded to cross-bedded, poorly sorted	3.0
41.	Sandstone, very fine-grained, silty, with numerous thin beds of black, carbonaceous claystone	0.5
40.	Claystone, black, very carbonaceous, grading laterally into coal	0.1
39.	Sandstone, conglomeratic, coarse to very coarse-grained, poorly sorted	0.3
38.	Coal, sub-bituminous, clayey	1.2
37.	Sandstone, fine-grained, white and yellow, silty; contains thin carbonaceous and micaceous bands	0.3
36.	Sandstone, fine-grained, yellow, clayey, unbedded, friable, micaceous	0.3
35.	Siltstone, black, carbonaceous micaceous, thinly bedded; with minor beds of white fine-grained sandstone	0.3
34.	Sandstone, fine-grained, yellow to white, thinly bedded and cross-bedded, with a few thin carbonaceous beds	2.1
33.	Sandstone, fine-grained, silty, yellow, friable, cross-bedded, interbedded with silty, black, carbonaceous claystone	2.1
32.	Claystone silty, black, carbonaceous, micaceous, well-bedded, grades into fine-grained, silty, yellow sandstone	1.8
31.	Sandstone, fine-grained, silty, yellow, friable, thinly bedded, and finely cross-bedded, with thin beds of silty, carbonaceous, black claystone	7.3
30.	Coal, clayey, black, grades into carbonaceous claystone	1.8
29.	Sandstone, very coarse-grained, grey, grading into fine, feldspathic, massive conglomerate	0.5
28.	Siltstone, sandy, grey to yellow, cross-bedded, and thinly bedded	0.5
27.	Sandstone, fine-grained, yellow, well-sorted	0.3
26.	Sandstone, fine-grained, yellow, unbedded, friable	0.3
25.	Siltstone, clayey, grey	0.3
24.	Sandstone, fine-grained, silty, yellow, with thin bands of carbonaceous siltstone	1.0
23.	Sandstone, fine-grained, grey to white, friable, crudely bedded	0.3
22.	Sandstone, fine-grained, silty, bedded, grading into sandy siltstone; with some brown carbonaceous beds containing plant fossils	1.0
21.	Sandstone, conglomeratic, fine-grained, grey, fairly well-bedded, feldspathic	0.6
20.	Claystone, silty, brown, carbonaceous, thinly bedded	0.3
19.	Sandstone, fine-grained, pink, cross-bedded, friable, grading into sandy, micaceous, carbonaceous siltstone	0.3
18.	Sandstone, coarse-grained, partly conglomeratic, silty, red, cross-bedded, slumped	0.3
17.	Sandstone, very fine-grained, silty, grey-brown, carbonaceous, well-bedded, contains abundant leaf impressions	0.6
16.	Sandstone, coarse-grained, conglomeratic, yellow, crudely bedded, friable, with some hard beds, poorly sorted	2.7
15.	Coal, sub-bituminous, clayey, black	3.7
14.	Claystone, sandy and silty, dark-grey, thinly bedded; contains plant fossils	1.2
13.	Coal, sub-bituminous, clayey, black	0.3
12.	Sandstone, fine to medium-grained, white to grey, friable, moderately sorted, poorly bedded, with traces of jarosite	0.5
11.	Sandstone, very fine-grained, black and grey, thinly bedded; interbedded with black, thinly bedded siltstone and claystone	1.0

10.	Sandstone, fine-grained, white, friable, thinly bedded, interbedded with clayey, black, micaceous, carbonaceous siltstone	0.8
9.	Sandstone, fine-grained, white, friable, with rare carbonaceous beds	0.3
8.	Claystone and siltstone, black, carbonaceous, micaceous, thinly bedded to laminated, containing fossil leaves; with thin beds of fine to very fine-grained, white, friable sandstone	8.2
7.	Sandstone, coarse to fine-grained, conglomeratic, red, strongly cross-bedded, poorly sorted	3.7
6.	Siltstone, clayey, dark-grey to white, grading into very fine-grained, silty and clayey; grey to black sandstone, jarositic in part	0.7
5.	Sandstone, medium-grained, light-red and yellow, poorly sorted	0.6
4.	Sandstone, very fine-grained, silty, yellow and grey	0.6
3.	Sandstone, conglomeratic, fine to coarse-grained, yellow, crudely bedded	1.2
2.	Siltstone, dark-grey, carbonaceous, with thin beds of fine-grained sand, crudely bedded	0.6
1.	Sandstone, coarse-grained, partly conglomeratic, yellow and grey, poorly sorted, partly jarositic, partly ferruginous	0.5

Conformably overlying High Cliff Sandstone.

Lithology: The Irwin River Coal Measures are an alternating sequence of very coarse to very fine-grained sandstone, siltstone, and claystone, with lenticular beds of sub-bituminous coal (Fig. 24). The sandstones are often strongly cross-bedded, in places show current ripple marks, and are coloured red, yellow, brown, or white. They are conglomeratic in places. The siltstone, shale, and claystone are frequently carbonaceous and dark coloured. Otherwise they generally vary from reddish brown to yellow and white in colour. Ferruginous beds are present in some horizons.

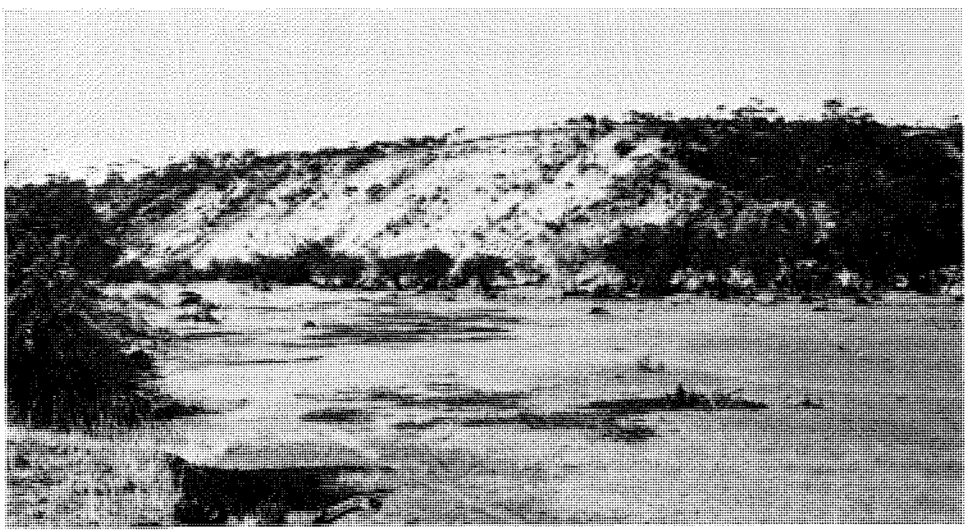

Figure 23. High Cliff, on the North Branch of the Irwin River. Exposures on the cliff consist of Holmwood Shale, High Cliff Sandstone, Irwin River Coal Measures, and Victoria Plateau Sandstone, capped by duricrust.

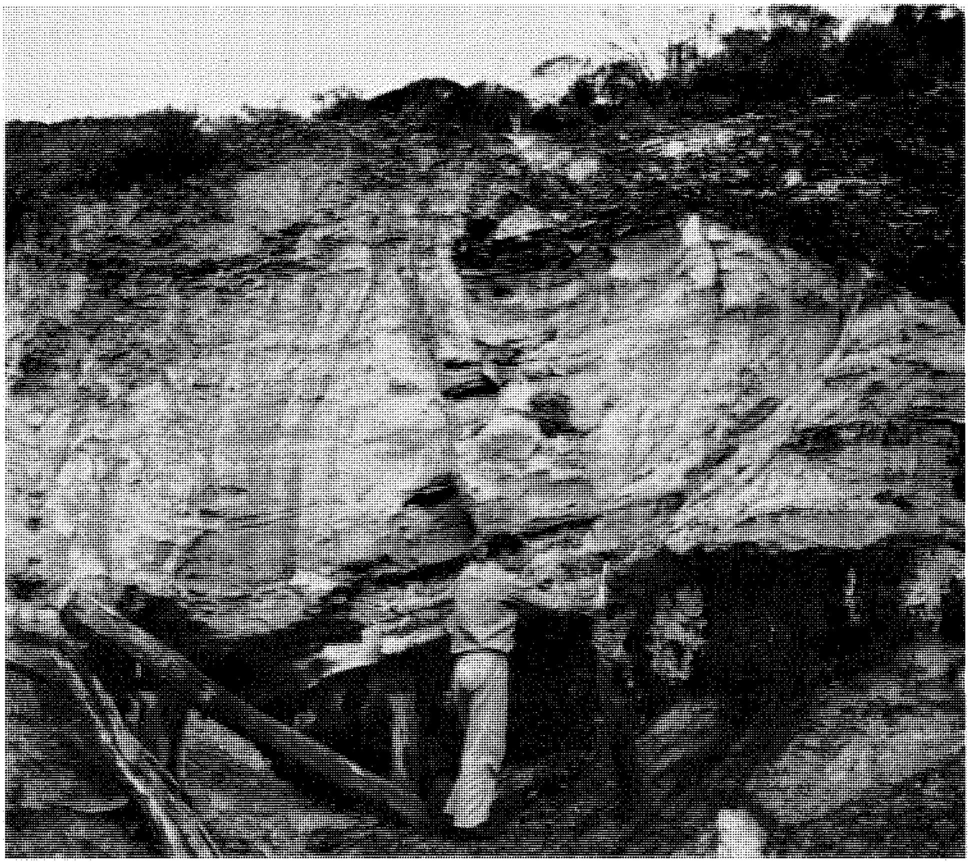

Figure 24. Adit driven along a coal seam in the Irwin River Coal Measures on the North Branch of the Irwin River.

Strata are distinctly lenticular in the lower part of the Irwin River Coal Measures, and they show rapidly alternating rock types. The lithological characteristics are more uniform in the upper part, which consists of yellow to grey, fine to medium-grained, massively bedded sandstone with common small-scale current-bedding and slump structures.

The coal seams are low-grade sub-bituminous types with a high ash content. They are markedly lenticular. Five thin seams crop out along the North Branch of the Irwin River, three are known from the South Branch, and several occur at Caryngnia Gully. No coal is known at Woolaga Creek, although there are several beds of highly carbonaceous claystone.

Occasional granite, quartzite, and chert boulders occur in the Irwin River Coal Measures. They may have been rafted by floating vegetation rather than by ice.

Stratigraphic relationships: The Irwin River Coal Measures rest conformably on the High Cliff Sandstone, and are overlain conformably by the Caryngina Formation. In each case the contact is transitional.

The lower contact is placed so as to include the main carbonaceous shale and siltstone beds below the lowest coal seam in the coal measures. The upper boundary is placed at the base of the jarositic micaceous siltstone which characterizes much of the Caryngina Formation. Johnson and others (1954) had included the Caryngina Formation in the Irwin River Coal Measures. However, our work has shown that the two units can be mapped as separate formations, although the differences between them are less well marked in the Woolaga Creek area than in the Irwin River area.

Distribution and thickness: The Irwin River Coal Measures are known to crop out from the Greenough River, east of the Northampton Block, to Woolaga Creek. Exposures are very poor in the Greenough River area, where the unit is known mainly from bores.

The formation occurs in the subsurface through much of the northern Perth Basin, but it is commonly difficult to distinguish from the High Cliff Sandstone in well sections. Johnstone and Willmott (1966) note that the combined thickness of these two units is generally about 300 m in wells drilled in the northern Perth Basin. An isopach map of the combined Irwin River Coal Measures and High Cliff Sandstone is shown as Figure 22.

In outcrop the formation ranges in thickness from 63 m on the North Branch of the Irwin River to 123 m at Woolaga Creek.

Fossils and age: The Irwin River Coal Measures contain a rich *Glossopteris* flora which has recently been monographed by Rigby (1966). The formation also yields abundant spores and pollen. As indicated previously, the High Cliff Sandstone cannot easily be separated from the Irwin River Coal Measures in the subsurface and hence some of the spores and pollen in the following list may have come from the High Cliff Sandstone.

Spores and pollen (Balme and Hennelly, 1955, 1956a, 1956b; Segroves, 1969, 1970, 1971)

Acanthotriletes tereteangulatus Balme and Hennelly
Alisporites gracilis Segroves
A. indarraensis Segroves
A. sp. cf. *A. plicatus* Jizba
Apiculatisporis cornutus (Balme and Hennelly)
A. levis (Balme and Hennelly)
Barakarites rotatus (Balme and Hennelly)
Calamospora diversiformis Balme and Hennelly
C. sp. cf. *C. microrugosa* (Ibrahim)
Corisaccites alutas Vankatachala
Cycadopites cymbatus (Balme and Hennelly)
Deltoidospora directa (Balme and Hennelly)
Densipollenites indicus Bharadwaj and Salujha
Densoisporites solidus Segroves
Densosporites rotundidentatus Segroves
Florinites eremus Balme and Hennelly
Gnetaceaepollenites sinuosus (Balme and Hennelly)
Grandispora sp.

Granulatisporites micronodosus Balme and Hennelly
G. quadruplex Segroves
G. trisinus Balme and Hennelly
G. sp.
Hamiapollenites dettmannae Segroves
Horriditriletes ramosus (Balme and Hennelly)
Hymenozonotriletes sp.
Kraeuselisporites enormis Segroves
K. niger Segroves
K. splendens (Balme and Hennelly)
K. sp.
Laevigatosporites flexus Segroves
L. scissus Balme and Hennelly
Latosporites colliensis (Balme and Hennelly)
Leschikisporis cestus Segroves
Limitisporites moersensis (Grebe)
L. sp. cf. *L. rectus* Leschik
Lophotriletes scotinus Segroves
L. sp. cf. *L. rarus* Bharadwaj and Salujha
Lueckisporites fusus Balme and Hennelly
Lundbladispora sp.
Marsupipollenites triradiatus forma *striatus* Balme and Hennelly
M. triradiatus forma *triradiatus* Balme and Hennelly
Microbaculispora tentula Tiwari
Parasaccites bilateralis Tiwari
P. gondwanensis (Balme and Hennelly)
P. sp. cf. *Virkkipollenites mehtae* Lele
Platysaccus sp. cf. *P. leschiki* Hart
Potoniesporites balmei (Hart)
Protohaploxypinus amplus (Balme and Hennelly)
P. limpidus (Balme and Hennelly)
P. rugatus Segroves
Punctatisporites gretensis Balme and Hennelly
Striatoabietites multistriatus (Balme and Hennelly)
Striatopodocarpites raniganjensis (Bharadwaj)
S. sp. cf. *S. cancellatus* (Balme and Hennelly)
S. sp.
Sulcatisporites ovatus (Balme and Hennelly)
S. splendens Leschik
S. sp. cf. *Pityosporites potoniei* Lakhanpal, Sah, and Dube
Tuberculatosporites modicus Balme and Hennelly
Verrucosisporites naumovae Hart
V. pseudoreticulatus Balme and Hennelly
Vittatina sp.

Acritarchs (Segroves, 1967)
Spongocystia eraduica Segroves

Chlorophyta (Segroves, 1971)
Botryococcus sp.

Plant macrofossils (Glauert, 1923b; Teichert, 1943; Clarke and others, 1951; Rigby, 1966)

Cladophlebis roylei Arber
?conifer cone
Cordaicladus sp.
Cyclodendron leslii (Seward)
Gangamopteris obovata (Carruthers)
Glossopteris ampla Dana
G. balmei Rigby
G. browniana Brongniart
G. sp. cf. *G. communis* Feistmantel
G. indica Schimper
G. spathulato-cordata Feistmantel
gymnosperm stem
lycopod leaves
Noeggerathiopsis hislopi (Bunbury)

Paracalamites australis Rigby
P. levis Rigby
?*Pseudoctenis* sp.
Rhabdotaenia? *waginae* Rigby
scale leaf
seed
Sphenophyllum rhodesii Rigby
?*S.* sp.
Sphenopteris lobifolia Morris
Vertebraria indica (Royle)

On the basis of the contained spores and pollen, Balme (*in* McWhae and others, 1958) considers the Irwin River Coal Measures to be of Artinskian age. The plant macrofossils are typical of the Lower Gondwana *Glossopteris* flora (Rigby, 1966). The presence of northern taxa (for example, *Sphenophyllum*) in this flora was first noted by Teichert (1958). More recent systematic palaeontology by Rigby (1966) has reduced the number of these northern taxa, but Chaloner and Lacey (1973) still label the northern Perth Basin on their maps as an area with a ?mixed *Glossopteris*/Euramerican flora.

Environment of deposition: The Irwin River Coal Measures are, for the most part, continental deposits, as is indicated by the lenticular nature of individual beds, rapid alternations in lithology, abundance of fossil plants, lack of marine fossils, and presence of coal seams through most of the section. The sediments exhibiting these features are believed to be of fluvial and paludal to lacustrine origin. However, the upper part of the unit, where it grades into the marine Caryngìnia Formation, is probably paralic.

Economic aspects: The possible economic potential of coal seams in the Irwin River Coal Measures has been investigated at various times since their discovery in 1846 (Gregory and Gregory, 1884). However, each investigation has concluded that the coal is uneconomic, the most recent being by Johnson and others (1954). Exploration for coal in the formation has also been carried out in the Beagle Ridge area. Further details are given in the economic geology chapter of this bulletin.

CARYNGINIA FORMATION

Definition: The Carynginia Formation was originally named the "Carynginia Shale", and this was modified to Carynginia Formation by Playford and Willmott (*in* McWhae and others, 1958) as it consists predominantly of interbedded siltstone and sandstone with only minor shale. The unit overlies the Irwin River Coal Measures and is overlain by the Wagina Sandstone.

The type locality of the formation is in Carynginia Gully, but no detailed section has been measured there as the exposures are very discontinuous. Playford and Willmott (1958) designated the main reference section as that exposed along Woolaga Creek (lat. 29° 11′ 20″S, long. 115° 39′ 30″E). The following is a description of this section, slightly modified from that given by G. Playford (1959):

Wagina Sandstone, disconformably overlying—

Caryngina Formation (257 m)	Thickness (metres)
7. Siltstone, dark-brown to black, weathering pale-grey, jarositic, thin-bedded; with thin beds (up to 0.3 m thick) of medium-grained, white and grey, silty sandstone, and intercalations of yellow-brown, ferruginous siltstone	26
6. No outcrop	37
5. Interbedded siltstone, grey and dark-brown to black, weathering pale grey, clayey, micaceous, thin-bedded to massive; and siltstone grading to very fine and fine-grained sandstone, yellow and red-brown, ferruginous, micaceous, commonly fissile, and locally cross-bedded; minor beds of coarse-grained conglomeratic sandstone	51
4. Siltstone, grey and brown, jarositic, micaceous, clayey, thin-bedded; minor intercalations of red-brown ferruginous siltstone and thin beds of medium to coarse-grained, pale-brown and yellow sandstone	130
3. Sandstone, fine to very coarse-grained, silty, brown, light-grey, and red, well-sorted; with thin intercalations of red and yellow-brown, ferruginous, resistant siltstone, and minor lenses of medium to coarse-grained, red and yellow sandstone	2.7
2. Shale, dark-brown to black, weathering grey, jarositic, carbonaceous, micaceous, silty; with intercalations of red and yellow-brown, ferruginous, resistant siltstone, and minor lenses of medium to coarse-grained, red and yellow sandstone	8.5
1. Interbedded siltstone, clayey, dark-brown to black, jarositic, carbonaceous, micaceous; and medium to fine-grained, yellow-brown sandstone; scattered pebbles, cobbles, and boulders of granitic gneiss, quartzite, and dolerite occur in the unit	1.5

Overlying Irwin River Coal Measures with a transitional, conformable contact.

Lithology: The Caryngina Formation consists predominantly of black, grey, brown, or yellow, jarositic, micaceous siltstone, and yellow and grey to dark-brown quartz sandstone, with thin beds of fine conglomerate. The proportion of sandstone in the formation seems to be greater in the Woolaga Creek section than along Caryngina Gully.

Erratic blocks up to boulder size occur in the lower part of the Caryngina Formation. They consist mainly of granitic gneiss and quartzite, and are generally rounded to subrounded. It is not sure whether they are glacially derived, but this seems possible.

Stratigraphic relationships: The Caryngina Formation rests conformably on the Irwin River Coal Measures and is overlain disconformably or with a slightly angular unconformity by the Wagina Sandstone. The contact with the Wagina Sandstone had been regarded as conformable by Playford and Willmott (*in* McWhae and others, 1958) and by G. Playford (1959), but Swarbrick (1964) and Johnstone and Willmott (1966) have shown that regionally the contact is unconformable, with a slightly angular relationship.

It seems probable that the Mingenew Formation is laterally equivalent to part of the Caryngina Formation, although this has not been proved.

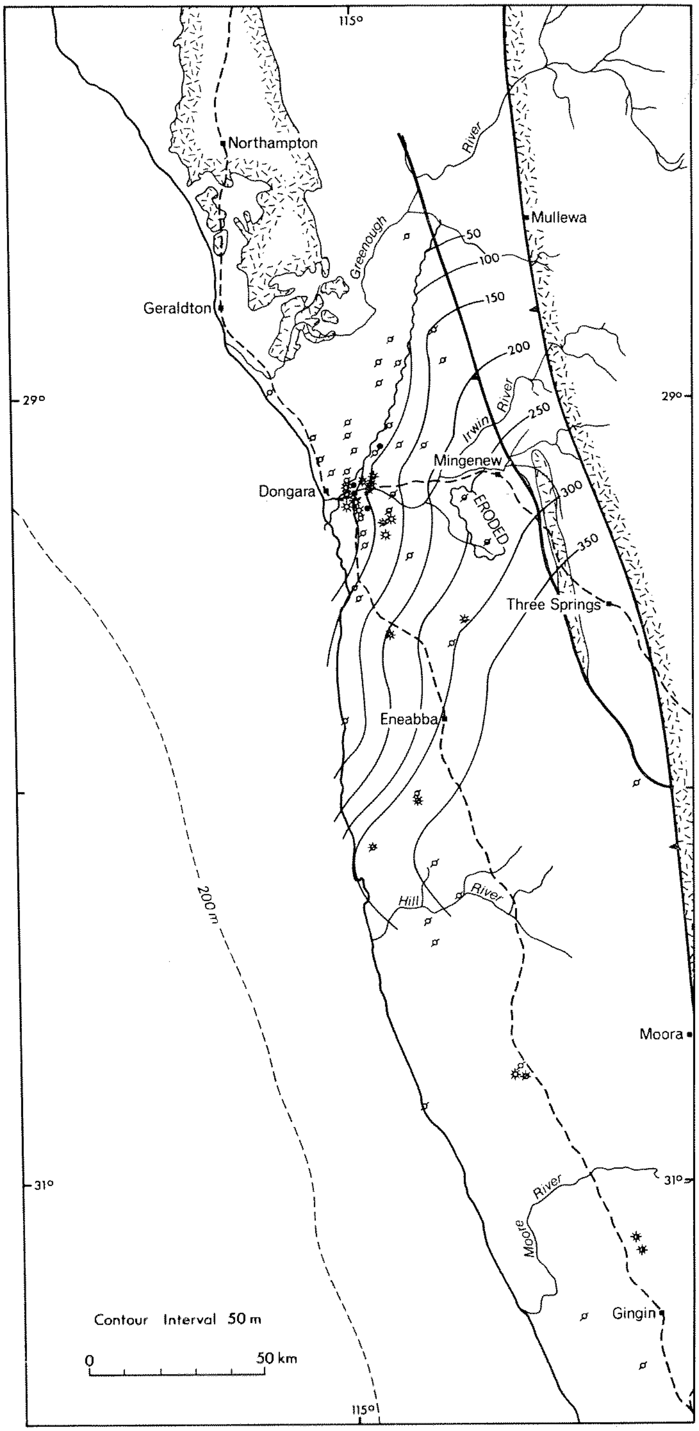

Figure 25. Isopach map, Carynginia Formation (Artinskian).

Distribution and thickness: The Carynginia Formation crops out in the Irwin River and Woolaga Creek areas. The best exposures are along Woolaga Creek and Carynginia Gully. According to Clarke and others (1951) the unit is 244 m thick along Carynginia Gully, while the section at Woolaga Creek is 257 m thick.

The formation is recognized in the subsurface over a wide area of the northern Perth Basin, from Wicherina No. 1 well in the north to Cadda No. 1 well in the south. The thickest known section is that in Cadda No. 1 well (349 m), although the top of the formation there is truncated by the Triassic unconformity. An isopach map of the formation is shown as Figure 25.

Fossils and age: Microfossils, particularly spores and pollen, are common in the Carynginia Formation. No macrofossils are known from outcrops of the formation; those recorded from Carynginia Gully by Clarke and others (1951) are now considered to come from the Fossil Cliff Member of the Holmwood Shale. However, a few macrofossils have been identified from the Carynginia Formation in B.M.R. No. 10 bore (Dickins *in* McTavish, 1965).

Spores and pollen (Segroves, 1969, 1970, 1971)

Acanthotriletes tereteangulatus Balme and Hennelly
Alisporites gracilis Segroves
A. indarraensis Segroves
A. sp. cf. *A. plicatus* Jizba
Apiculatisporis cornutus (Balme and Hennelly)
A. levis (Balme and Hennelly)
Barakarites rotatus (Balme and Hennelly)
Calamospora diversiformis Balme and Hennelly
C. sp. cf. *C. microrugosa* (Ibrahim)
Corisaccites alutas Venkatachala
Cycadopites cymbatus (Balme and Hennelly)
Deltoidospora directa (Balme and Hennelly)
Densipollenites indicus Bharadwaj and Salujha
Densoisporites solidus Segroves
Densosporites rotundidentatus Segroves
Diatomozonotriletes townrowii Segroves
Dictyotriletes sp. cf. *D. bireticulatus* (Ibrahim)
Dulhuntyispora inornata Segroves
Florinites eremus Balme and Hennelly
Gnetaceaepollenites sinuosus (Balme and Hennelly)
Gondisporites imbricatus Segroves
Grandispora sp.
Granulatisporites micronodosus Balme and Hennelly
G. trisinus Balme and Hennelly
G. sp.
Hamiapollenites dettmannae Segroves
Horriditriletes ramosus (Balme and Hennelly)
Hymenozonotriletes sp.
Klausipollenites sp.
Kraeuselisporites enormis Segroves
K. niger Segroves
K. splendens (Balme and Hennelly)
K. sp.
Laevigatosporites flexus Segroves
L. sp.
Latosporites colliensis (Balme and Hennelly)
Leschikisporis cestus Segroves
Limitisporites moersensis (Grebe)
L. sp. cf. *L. rectus* Leschik

Lophotriletes scotinus Segroves
L. sp. cf. *L. rarus* Bharadwaj and Salujha
Lundbladispora sp.
Marsupipollenites triradiatus forma *striatus* Balme and Hennelly
M. triradiatus forma *triradiatus* Balme and Hennelly
Microbaculispora tentula Tiwari
Parasaccites bilateralis Tiwari
P. gondwanensis (Balme and Hennelly)
P. sp. cf. *Virkkipollenites mehtae* Lele
Platysaccus sp. cf. *P. leschiki* Hart
Potoniesporites balmei (Hart)
Protohaploxypinus amplus (Balme and Hennelly)
P. limpidus (Balme and Hennelly)
P. rugatus Segroves
Punctatisporites gretensis Balme and Hennelly
Striatoabietites multistriatus (Balme and Hennelly)
Striatopodocarpites raniganjensis (Bharadwaj)
S. sp. cf. *S. cancellatus* (Balme and Hennelly)
S. sp.
Sulcatisporites ovatus (Balme and Hennelly)
S. splendens Leschik
S. sp. cf. *Pityosporites potoniei* Lakhanpal, Sah, and Dube
Tuberculatosporites modicus Balme and Hennelly
Verrucosisporites naumovae Hart
V. pseudoreticulatus Balme and Hennelly
Vittatina sp.

Chlorophyta (Segroves, 1971)
Botryococcus sp.

Foraminiferida (Crespin, 1958)
Ammodiscus nitidus Parr
Hippocrepinella n. sp.
Hyperammina sp. cf. *H. callytharraensis* Crespin
H. sp. cf. *H. elegans* (Cushman and Waters)
H. expansa (Plummer)
H. fusta Crespin
H. n. sp.
Proteonina arenosa Crespin
Spiroplectammina carnarvonensis Crespin
Thuramminoides sphaeroidalis Plummer

Scyphozoa (Dickins *in* McTavish, 1965)
conularid

Brachiopoda (Dickins *in* McTavish, 1965)
"*Neochonetes*" sp.
Neospirifer sp.
"*Permorthotetes*" sp.
Strophalosia sp. A. Dickins

The presence of hystrichosphaerids has been reported by Balme (*in* McWhae and others, 1958). Dickins (*in* McTavish, 1965) considers that the macrofossils are similar to those occurring in the Mingenew Formation and in the Madeline Formation (of the Carnarvon Basin), and Crespin (1958) has pointed out that the foraminifers of the Carynginia and Madeline Formations are similar. The Carynginia Formation is of Artinskian age.

Environment of deposition: The Carynginia Formation is a marine unit, much of the section having been laid down under conditions of restricted circulation.

WAGINA SANDSTONE

Definition: The Wagina Sandstone was named by Clarke and others (1951) after Wagina Well, on the South Branch of the Irwin River, where the type section is located (lat. 28° 59′ 30″S, long. 115° 35′ 00″E). However, exposures are rather poor in this area, and Playford and Willmott (*in* McWhae and others, 1958) proposed that the main reference section for the unit be located near Woolaga Creek, commencing at Red Hill (lat. 29° 11′ 01″S, long. 115° 40′ 00″E) and continuing east to the axis of the syncline adjoining the Darling Fault. The following is a description of this section (after Playford and Willmott, 1958):

Wagina Sandstone (251 m)	Thickness (metres)
Upper limit of formation not exposed. Top of exposure separated from Darling Fault by a belt of no outcrop.	
8. Sandstone, fine and medium-grained, clayey, light-brown and yellow-brown, bedded, moderately sorted; with interbedded coarse-grained, clayey, brown, poorly sorted, cross-bedded and partly ferruginous sandstone; and white, micaceous, clayey, bedded to thinly bedded siltstone	29
7. As for unit 8, with interbedded pebble conglomerate having a coarse-grained sandstone matrix	4
6. Conglomerate, pebble and cobble, with silty, clayey, sand matrix, bedded, contains pebbles and cobbles of quartz, quartzite, and granite, which are subangular to subrounded and poorly sorted	2.7
5. Sandstone, coarse-grained, clayey, brown, poorly sorted, cross-bedded and ferruginous in some beds; interbedded with fine-grained, red, ferruginous, moderately sorted, thinly bedded sandstone, and clayey, white, micaceous, bedded to thinly bedded siltstone	9.1
4. Sandstone, fine to medium-grained, brown and yellow-brown, bedded, poorly sorted; with interbedded clayey, white, micaceous, bedded to thinly bedded siltstone	22
3. Sandstone, fine to medium-grained, yellow-brown to brown, poorly sorted, cross-bedded; with thin lenses of white siltstone	8
2. Sandstone, fine-grained, clayey, red at base, becoming pink and white upwards, well-cemented, crudely bedded to unbedded; containing a few thin lenses of coarse-grained, clayey, white, poorly sorted sandstone, with some clayey and silty lenses	175
1. Sandstone, fine and medium-grained, silty and clayey, red, ferruginous, unbedded	1.2
Disconformably overlying Caryngina Formation.	

The name *Yardarino Sandstone Member* has been proposed by R. G. McKellar of Wapet (written comm., 1972) for the unit of quartz sandstone developed at the top of the Wagina Sandstone in the Yardarino-Dongara area. The name "Yardarino Sandstone" had previously been applied to this unit by Playford and Low (1972), who believed that it was of Early Triassic age. The unit had been included in the "Basal Triassic Sandstone" by Hosemann (1971) and was referred to as "Unit A" of the Wagina Sandstone by Pearson (1964). Palynological work by Wapet has now shown that much of the "Basal Triassic

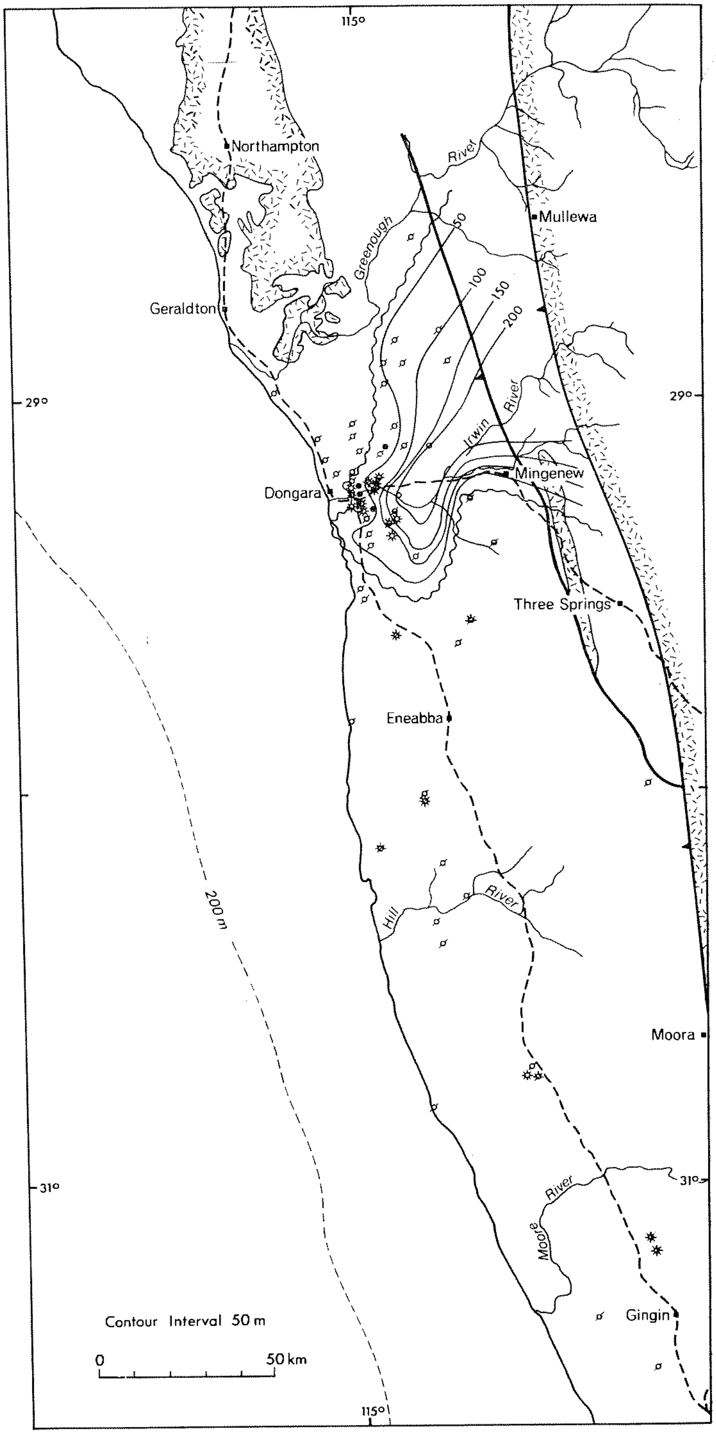

Figure 26. Isopach map, Wagina Sandstone (Upper Permian).

Sandstone" is of Late Permian age, and McKellar proposed that this part should be regarded as a member of the Wagina Sandstone. The type section of the Yardarino Sandstone Member is in Yardarino No. 1 well, from 2 284 to 2 307 m.

Lithology: The Wagina Sandstone consists of white, fine to medium-grained, clayey quartz sandstone, with lesser amounts of conglomerate, shale, and siltstone. Some of the shales and siltstones are carbonaceous, and in some areas they grade into low-grade coals, notably at Eradu.

The sandstones are generally poorly sorted and poorly bedded. Cross-bedding is developed in some. Subrounded pebbles and cobbles of quartz, chert, and quartzite occur sporadically in the upper part of the formation.

Stratigraphic relationships: The Wagina Sandstone rests with an abrupt contact on the Carynginia Formation in the outcrop area extending from Woolaga Creek to the Irwin River. This contact is believed to be a disconformity representing a relatively short time interval. However, in the subsurface there is a mildly angular unconformable relationship between the Wagina Sandstone and the older Permian units (Swarbrick, 1964; Johnstone and Willmott, 1966). In the area between Dongara and Wicherina drilling has shown that the Wagina Sandstone rests on Permian formations as old as the Holmwood Shale. In this area the Wagina Sandstone is overlain with angular unconformity by Triassic and Jurassic rocks. In outcrop the formation is overlain by Cainozoic units.

The "Indarra Beds" of Playford and Willmott (*in* McWhae and others, 1958) are now included in the Wagina Sandstone. This correlation has been shown through subsurface studies controlled by palynology (Balme, 1964b).

Distribution and thickness: The Wagina Sandstone is exposed in a series of synclines adjoining the Darling Fault along a belt extending from Woolaga Creek to the South Branch of the Irwin River. It is more resistant to erosion than the underlying Carynginia Formation, and crops out around the sides and tops of breakaways. A few poor exposures also occur in the Greenough River near Eradu.

In the subsurface the formation is known to occur in the northern part of the Perth Basin between Dongara and Eradu.

According to Clarke and others (1951), 90 m of Wagina Sandstone are exposed on the South Branch of the Irwin River. Playford and Willmott (1958) measured 251 m of the formation at the Woolaga Creek section, while G. Playford (1959) measured 243 m there. This section is the thickest known in the formation, the maximum subsurface section being some 225 m thick (in Strawberry Hill No. 1 well). An isopach map of the formation is shown as Figure 26.

Fossils and age: The following fossils have been recorded from the Wagina Sandstone:

Spores and pollen (Balme and Hennelly, 1956a, 1956b; Balme, 1964b; Segroves, 1969, 1970, 1971)

Acanthotriletes tereteangulatus Balme and Hennelly
A. villosus Balme and Hennelly
Alisporites gracilis Segroves
Anapiculatisporites ericianus (Balme and Hennelly)
Apiculatisporis levis (Balme and Hennelly)
Bipartitisporis tumulosus Segroves
Calamospora diversiformis Balme and Hennelly
C. sp. cf. *C. microrugosa* (Ibrahim)
Deltoidospora directa (Balme and Hennelly)
Densipollenites indicus Bharadwaj and Salujha
D. pullus Segroves
Dictyotriletes sp. cf. *D. bireticulatus* (Ibrahim)
D. sp.
Dulhuntyispora dulhuntyi R. Potonié
D. inornata Segroves
D. parvithola (Balme and Hennelly)
Gnetaceaepollenites sinuosus (Balme and Hennelly)
Gondisporites imbricatus Segroves
Granulatisporites micronodosus Balme and Hennelly
G. trisinus Balme and Hennelly
G. sp.
Horriditriletes ramosus (Balme and Hennelly)
Indospora clara Bharadwaj
I. laevigata Bharadwaj and Salujha
Klausipollenites sp.
Kraeuselisporites enormis Segroves
K. niger Segroves
K. sp.
Laevigatosporites sp.
Latosporites colliensis (Balme and Hennelly)
Limitisporites moersensis (Grebe)
Lundbladispora sp.
Marsupipollenites triradiatus forma *striatus* Balme and Hennelly
M. triradiatus forma *triradiatus* Balme and Hennelly
Microreticulatisporites bitriangularis Balme and Hennelly
Parasaccites sp. cf. *Virkkipollenites mahtae* Lele
Platysaccus sp.cf. *P. leschiki* Hart
Potoniesporites balmei (Hart)
Protohaploxypinus amplus (Balme and Hennelly)
P. limpidus (Balme and Hennelly)
P. rugatus Segroves
Striatoabietites multistriatus (Balme and Hennelly)
Striatopodocarpites raniganjensis (Bharadwaj)
S. sp. cf. *S. cancellatus* (Balme and Hennelly)
S. sp.
Sulcatisporites ovatus (Balme and Hennelly)
S. sp. cf. *Pityosporites potoniei* Lakhanpal, Sah, and Dube
Tuberculatosporites modicus Balme and Hennelly
Verrucosisporites naumovae Hart
V. sp.
Vittatina sp.

Acritarchs (Balme and Segroves, 1966; Segroves, 1967, 1971)

Circulisporites parvus de Jersey
Haplocystia pellucida Segroves
Leiosphaeridia sp.
Peltacystia calvitium Balme and Segroves
P. monile Balme and Segroves
P. venosa Balme and Segroves
P. venosa galeoides Segroves
Schizosporis dejerseyi Segroves
S. scissus (Balme and Hennelly)
Tetraporina horologia (Staplin)
T. sp.

Incertae sedis (Segroves, 1967, 1971)
Pyramidosporites cyathodes Segroves
Spheripollenites sp. cf. *S. psilatus* Couper

Chlorophyta (Segroves, 1967, 1971)
Botryococcus sp.

Plant macrofossils (Clarke and others, 1951; McWhae and others, 1958; G. Playford, 1959; Balme, 1964b; Rigby, 1966)
Gangamopteris obovata (Carruthers)
?*G. obovata* (Carruthers)
Glossopteris browniana Brongniart
G. sp. cf. *G. communis* Feistmantel
G. indica Schimper
Gondwanidium validum (Feistmantel)
gymnosperm wood
Noeggerathiopsis hislopi (Bunbury)
Paracalamites levis Rigby
?*Pseudoctenis* sp.
Rhabdotaenia? waginae Rigby
Samaropsis sp.
Umbellaphyllites minima Rigby

On the basis of the spores and pollen Balme (1964b) has suggested a Late Permian age for the formation, although the unit may extend into the Kungurian. As a result of Rigby's (1966) identification of Clarke and others' (1951) "?*Annularia*" as *Umbellaphyllites minima* there are now no northern hemisphere taxa in the Wagina Sandstone *Glossopteris* flora.

Environment of deposition: The Wagina Sandstone is believed to be a continental to paralic deposit. Coal swamps occurred in association with fluvial environments in some areas.

Economic aspects: Low-grade coal seams were discovered in the Wagina Sandstone at Eradu in a government calyx bore drilled in 1906. Since then there has been a considerable amount of drilling and some shafts have been sunk in the area, but none of the coal found has yet been judged to be commercially exploitable. Further details are given in the economic geology chapter of this bulletin.

MINGENEW FORMATION

Definition: The name "Mingenew Beds" was used by Maitland (1919) for the sequence of fossiliferous sandstone and siltstone exposed on low rises (now named Simpson Knolls), 2.4 km east of Mingenew. Playford and Willmott (*in* McWhae and others, 1958) amended the name to Mingenew Formation.

The type locality of the formation is at Simpson Knolls (lat. 29° 11′ 50″S, long. 115° 28′ 02″E). However, it is not possible to measure an accurate section there owing to faulting, and Playford and Willmott (1958) proposed that the main reference section be taken as that exposed nearby at Enanty Hill (lat. 29° 10′ 12″S, long. 115° 27′ 15″E). This is poorly exposed, but it is believed to be unfaulted. It had previously been the type locality for the "Enanty Hill Beds" of Johnson and others (1954), but this name is no longer used. The following is a description of the section:

Mingenew Formation (90 m)	Thickness (metres)
Top of formation not exposed, overlain by laterite.	
1. Sandstone, very fine to medium-grained, silty in part, red-brown to yellow, ferruginous in part, poorly sorted, cross-bedded in part; with interbedded sandy, yellow, red and white, micaceous siltstone, ferruginous in part; several thin ferruginous beds, 6-8 m from the top of the section, contain poorly preserved brachiopods, mainly *Neochonetes* and a few bivalves. The section is very poorly exposed	90
Base of formation not exposed.	

Lithology: The Mingenew Formation consists of interbedded sandstone and siltstone. The sandstones are fine to coarse grained and are usually ferruginous, feldspathic, and poorly sorted. Some cross-bedding is present, but the sandstones are generally crudely bedded to massive. The siltstones are poorly exposed, but yellow and white, well-bedded, micaceous, soft, sandy siltstone probably makes up a substantial proportion of the formation. The siltstones are commonly ferruginous, and sometimes fossiliferous. Ferruginization of the unit is thought to be a surface effect associated with lateritization, and it seems likely that these sediments are calcareous in the subsurface.

Stratigraphic relationships: The upper and lower limits of the Mingenew Formation are unknown, but it is thought to be a lateral equivalent of part of the Carynginia Formation (probably the lower part).

Distribution and thickness: The Mingenew Formation is known only from two small areas, near Mingenew and Arrino.

East of Mingenew the formation crops out between Simpson Knolls and Enanty Hill. In this area it is faulted (within the Urella Fault Zone) against the Holmwood Shale to the east and the Champion Bay Group or the Yarragadee Formation to the west. Another occurrence within the Urella Fault Zone is known 5 km west of Arrino (Edgell, 1965).

Fossils and age: The following fossils have been identified from the Mingenew Formation:

Plant macrofossils (Rigby, 1966)
- *Glossopteris ampla* Dana
- *G.* sp. cf. *G. communis* Feistmantel

Brachiopoda (Etheridge Jr., 1907a; Dickins, 1956; Campbell, 1965; Edgell, 1965).
- *Cancrinella* sp.
- *Cleiothyridina macleayana* Etheridge Jr.
- *Gilledia woolagensis* Campbell
- *Hoskingia nobilis* (Etheridge Jr.)
- *Neochonetes pratti* (Davidson)
- *Neospirifer musakheylensis* var. *australis* (Foord)
- *Pseudosyrinx*? sp. cf. *P*? *sinuosa* Thomas (= *Spirifera avicula* of Etheridge Jr.)
- cf. *Spiriferella australasica* (Etheridge Jr.)
- *Strophalosia* sp.
- *Taeniothaerus miniliensis* Coleman (= *Aulosteges baracoodensis* of Edgell and *Productus subquadratus* of Etheridge Jr.)

Bivalvia (Etheridge Jr., 1907a; Dickens, 1956, 1963; Edgell, 1965)
Aviculopecten sp. cf. *A. subquinquelineatus* (M'Coy)
Chaenomya? nuraensis Dickins
Heteropecten sp. cf. *H.* n. sp. A. Dickins
"Modiolus" sp.
Pseudomyalina mingenewensis (Etheridge Jr.)

Gastropoda (Dickins, 1963)
Ptychomphalina maitlandi Etheridge Jr.

The fauna of the Mingenew Formation is dated as Artinskian and is similar to that of the Madeline Formation in the Carnarvon Basin. A correlation with part of the Caryngìnia Formation also seems probable. The questionable *Xenaspis* recorded by Glenister and Furnish (1961) from the formation at Enanty Hill is actually a *Fontannesia* from the adjacent Cadda Formation outcrop (L. J. Peet, pers. comm., 1973).

Environment of deposition: The Mingenew Formation is a shallow-marine deposit.

SUE COAL MEASURES

Definition: The name Sue Coal Measures was introduced by Playford and Low (1972) for the unit of sandstone, siltstone, and coal encountered in a number of exploratory bores drilled in the southern Perth Basin. The upper part of the formation as originally defined by Playford and Low has now been distinguished as a separate unit, the Sabina Sandstone (Playford and others, 1975).

The type section of the formation is in Sue No. 1 well (lat. 34° 03′ 54″S, long. 115° 19′ 04″E) between 1 216 and 3 054 m. The following is a summary of this section, prepared from descriptions by Williams and Nicholls (1966).

Sabina Sandstone, overlying (probably conformably)—

Sue Coal Measures (1 838 m)	Interval & thickness (metres)
9. Sandstone, medium-grained, grading to pale-grey to green granule conglomerate; interbedded with micaceous, brown siltstone; lenses of carbonaceous matter; rare calcareous horizons; garnetiferous and pyritic in places; high-angle cross-bedding common	1 216–1 372 156
8. Siltstone, dark-brown, micaceous; interbedded with fine to coarse-grained sandstone; a few coal seams, fairly abundant carbonaceous matter; calcareous near base; garnetiferous and pyritic; high-angle cross-bedding present	1 372–1 600 228
7. Sandstone, fine to medium-grained; interbedded with dark-grey-brown, micaceous siltstone; thin coal seams common; garnetiferous in places; low-angle cross-bedding present	1 600–1 867 267
6. Sandstone, medium to coarse-grained; interbedded with siltstone; coal and carbonaceous matter common, particularly near base; a few pebbles; garnetiferous, rare arkosic and calcareous lenses; medium-angle cross-bedding present	1 867-2 423 556

5.	Sandstone, fine to very coarse-grained; a few beds of micaceous siltstone; some coal seams and carbonaceous matter; garnetiferous and calcareous in places	2 423–2 682 259
4.	Sandstone, medium to coarse-grained; interbedded with micaceous, dark-grey siltstone; common coal seams up to 5.5 m thick; a few calcareous horizons	2 682–2 862 180
3.	Dolerite sill	2 862–2 869 7
2.	Sandstone, medium to coarse-grained; interbedded with dark-grey to black, micaceous siltstone; coal seams near top; calcareous, garnetiferous and pyritic near base	2 869–3 053 184
1.	Conglomerate, containing pebbles and boulders of granite; rare pebbles of basic igneous rocks; matrix is greenish, coarse-grained sandstone; pebbles are well rounded	3 053-3 054 1

Unconformably overlying crystalline basement rocks.

Lithology: The Sue Coal Measures are a monotonous sequence of interbedded sandstone, siltstone, and coal. The sandstones are fine to very coarse grained, and are generally pale grey to white or greenish in colour. Some are conglomeratic, and grade into fine conglomerate. Cross-bedding is common. The siltstones are dark grey brown to black; they are carbonaceous and clayey and grade into shale and low-grade coal. Seams of sub-bituminous coal occur through much of the section, many of the seams having high silt and clay contents.

A dolerite body, interpreted as a sill, intrudes the formation in Sue No. 1 well between 2 862 and 2 869 m, and a similar intrusive also occurs in Blackwood No. 1 well. It is probably comagmatic with the Lower Cretaceous Bunbury Basalt (J. E. Glover, *in* Williams and Nicholls, 1966).

Stratigraphic relationships: The Sue Coal Measures overlie Precambrian basement rocks in the only hole that has fully penetrated the formation. They are overlain, apparently conformably, by the Sabina Sandstone, or unconformably by the Warnbro Group.

Distribution and thickness: The Sue Coal Measures are known only from the subsurface of the southern part of the Perth Basin. The unit has been encountered in the Sue No. 1, Whicher Range No. 1, Blackwood No. 1, Alexandra Bridge No. 1, Lake Preston No. 1, and Wonnerup No. 1 wells. The maximum known thickness is 1 838 m, and is the type section in Sue No. 1 well.

Fossils and age: Plant remains and plant microfossils are the only fossils recorded from the Sue Coal Measures.

Spores and pollen (Balme *in* Williams and Nicholls, 1966; Balme *in* Union Oil Development Corp., 1968, 1969, 1972)

Acanthotriletes filiformis Balme and Hennelly	1*		
A. tereteangulatus Balme and Hennelly	1	2*	3*
A. villosus Balme and Hennelly	1		
Alisporites sp. cf. *A. tenuicorpus* Balme	1		
A. sp.	1		
Anapiculatisporites dentatus (Balme and Hennelly)	1		
A. ericianus (Balme and Hennelly)	1	2	
Apiculatisporis levis (Balme and Hennelly)		2	3

A. sp.	1			
Barakarites rotatus (Balme and Hennelly)	1			
Calamospora diversiformis Balme and Hennelly	1	2		
Cordaitina sp.	1			
Cycadopites cymbatus (Balme and Hennelly)				4*
C. sp.	1			
Deltoidospora directa (Balme and Hennelly)	1	2	3	
Densipollenites sp.	1			
Dulhuntyispora parvithola (Balme and Hennelly)	1			
Florinites eremus Balme and Hennelly				4
Gnetaceaesporites sinuosus Balme and Hennelly	1	2		
"*G*". sp. A. Balme	1			
Gondisporites sp.	1			
Granulatisporites micronodosus Balme and Hennelly	1	2	3	
G. trisinus Balme and Hennelly	1			
G. sp. A. Balme				4
Horriditriletes ramosus (Balme and Hennelly)	1	2	3	
Indospora clara Bharadwaj	1	2		
Kraeuselisporites sp. cf. K. splendens (Balme and Hennelly)		2		
K. sp. cf. *K. wargalensis* Balme	1			
K. sp.	1		3	
Latosporites colliensis (Balme and Hennelly)	1	2		
Leiotriletes sp. cf. *L. agnatus* Kosanke	1			
L. virkkiae Tiwari		2		
Limitisporites sp. cf. *L. rectus* Leschik	1	2		
L. sp.	1			
Lophotriletes novicus Singh	1	2		
L. sp.	1			
Marsupipollenites striatus Balme and Hennelly	1	2		
M. triradiatus Balme and Hennelly	1	2	3	
Microbaculispora tentula Tiwari	1	2	3	
M. sp.	1			
Nuskoisporites sp.	1	2		4
Osmundacidites sp.	1	2		
Parasaccites sp. cf. *P. gondwanensis* (Balme and Hennelly)		2	3	
P. sp.	1			
Paravittatina lucifer (Bharadwaj and Salujha)	1			
P. sp.	1			
Platysaccus leschiki Hart		2	3	
P. sp.	1			
Polypodiumsporites sp. cf. *P. mutabilis* Balme	1			
Protohaploxypinus amplus (Balme and Hennelly)	1	2	3	
P. sp. cf. *P. diagonalis* Balme	1			
P. limpidus (Balme and Hennelly)	1	2	3	
P. sp. cf. *P. reticulatus* Hennelly	1			
P. spp.	1		3	4
Punctatisporites sp. cf. *P. gretensis* Balme and Hennelly				4
P. sp. A. Balme	1			
Striatoabietites multistriatus (Balme and Hennelly)	1	2	3	
S. spp.	1			
Striatopodocarpidites cancellatus (Balme and Hennelly)	1	2		
S. fusus (Balme and Hennelly)	1	2		
S. sp. cf. *S. phaleratus* (Balme and Hennelly)	1			
S. sp. cf. *S. solitus* (Bharadwaj and Salujha)	1			
S. spp.	1	2		
Sulcatisporites maximus (Hart)	1	2	3	
S. ovatus (Balme and Hennelly)	1	2	3	
S. potoniei (Lakhanpal, Sah, and Dube)		2		
S. sp.	1			
Verrucosisporites sp. cf. *V. gondwanensis* Bharadwaj and Salujha	1			
V. naumovae Hart			3	
Vitreisporites pallidus (Reissinger)	1			
Vittatina circinnata (Luber)	1			
V. fasciolatus (Balme and Hennelly)	1			
V. sp.		2	3	

Incertae sedis (Balme *in* Williams and Nicholls, 1966)				
Maculatispora minimus Segroves		2		
Acritarchs (Balme *in* Williams and Nicholls, 1966; Balme *in* Union Oil Development Corp., 1969, 1972)				
Circulisporis sp.		2		
Leiosphaeridia sp.	1	2		4
Peltacystia calvitium Balme and Segroves	1			
P. venosa Balme and Segroves	1			
Pilasporites calculus Balme and Hennelly	1			
Schizosporis scissus (Balme and Hennelly)	1			
Tetraporina sp.	1			
spinose acritarchs	1			
Chlorophyta (Balme *in* Williams and Nicholls, 1966)				
Botryococcus sp.	1			
Plant macrofossils (Balme *in* Union Oil Development Corp., 1968)				
Glossopteris sp.	1			

*1. Late Permian

*2. Late Artinskian (or possibly Late Permian)

*3. Early Artinskian

*4. Late Sakmarian

The microflora shows that the formation ranges in age from Late Sakmarian to Late Permian and is therefore equivalent to the sequence from the Holmwood Shale to Wagina Sandstone of the northern Perth Basin and to the Collie Coal Measures of the Collie Basin. Glacial deposits equivalent to the Nangetty Formation have not yet been encountered in wells drilled in the southern Perth Basin. The palaeontological evidence does not suggest the presence of any disconformities within the Sue Coal Measures. Acritarchs are rare in the formation, and probably indicate brackish water rather than marine conditions.

Environment of deposition: The Sue Coal Measures are a continental deposit, consisting of alternating fluvial and paludal sediments. This coal-measures sequence is equivalent to most of the mixed marine and continental Permian sequence of the northern Perth Basin, from the Holmwood Shale to the Wagina Sandstone.

Economic aspects: Numerous coal seams occur in the formation. The coal is sub-bituminous, and some seams would be thick enough and sufficiently high in grade to be economic if they were close enough to the surface. Further details are given in the chapter on economic geology in this bulletin.

SABINA SANDSTONE

Definition: The name Sabina Sandstone was introduced by Playford and others (1975) for the sequence of sandstone with minor interbedded shale lying between the Sue Coal Measures and the Lesueur Sandstone in the southern Perth Basin. The type section is in Whicher Range No. 1 well (lat. 33° 50′ 15″S, long. 115° 22′ 11″E) between 3 666 and 3 915 m, a total thickness of 249 m. The following is a description of this section:

Lesueur Sandstone, conformably overlying—	Interval & thickness (metres)
Sabina Sandstone (249 m)	
6. Sandstone, medium-grained, with some fine conglomeratic beds, mainly light-grey with some greenish beds; occasional horizons of shale and sandy shale, some lenses of carbonaceous material	3 666-3 737 71
5. Shale, grey-green to reddish-brown, with subsidiary medium-grained sandstone; one minor coal seam	3 737-3 752 15
4. Sandstone, medium to coarse-grained, clayey, light-grey, containing scattered quartz granules; minor shale	3 752-3 813 61
3. Sandstone, medium-grained, grey, friable, with weak calcareous cement; minor grey shale, grading to siltstone and very fine-grained sandstone	3 813-3 868 55
2. Sandstone, medium-grained, grey, friable	3 868-3 895 27
1. Sandstone, medium-grained, light-grey, friable, in part slightly calcareous; some white clayey matrix; micaceous in places	3 895-3 915 20

Underlain, probably conformably, by Sue Coal Measures.

Lithology: The Sabina Sandstone is a unit of medium to coarse-grained quartz sandstone with some greenish beds and minor thicknesses of grey shale.

Stratigraphic relationships: The Sabina Sandstone is overlain conformably by the Lesueur Sandstone and is underlain, probably conformably, by the Sue Coal Measures. The formation is partly equivalent in age to the Kockatea Shale of the northern Perth Basin.

Distribution and thickness: The Sabina Sandstone is recognized only in wells that have been drilled in the southern part of the Perth Basin. The maximum known thickness is 561 m in Lake Preston No. 1 well.

Fossils and age: The following microflora has been recorded from the Sabina Sandstone:

Spores and pollen (Balme *in* Union Oil Development Corp., 1968, 1972; Dolby and Williams *in* Young and Johanson, 1973)

Alisporites tenuicorpus Balme		2*
A. sp.	1*	2
Calamospora sp.		2
Convolutisporites sp.		2
Crustaesporites sp.		2
Cyclogranisporites spp.		2
Densoisporites nejburgii (Schulz)		2
D. playfordi (Balme)	1	2
Ephedripites sp.		2
Falcisporites australis (de Jersey)		2
F. sp.		2
aff. *Fimbriaesporites* sp.		2
Granulatisporites sp.	1	
Guthoerlisporites cancellosus Playford and Dettmann		2
Guttulapollenites hannonicus Goubin		2
Iraquispora labrata Singh		2
Kraeuselisporites cuspidus Balme	1	2
K. rallus Balme		2
K. wargalensis Balme		2
Laevigatosporites sp.		2

Leiotriletes directus Balme and Hennelly		2
L. sp.		2
Lophotriletes sp.		2
Lundbladispora sp.	1	2
Marsupipollenites sp.		2
Microbaculispora sp. cf. *M. villosa* Balme and Hennelly		2
Nevesisporites fossulatus Balme		2
N. sp.	1	2
Osmundacidites senectus Balme		2
Pilasporites calculus Balme and Hennelly		2
Polypodiisporites sp. cf. *P. mutabilis* Balme	1	
Protohaploxypinus spp.		2
Punctatisporites sp.	1	2
Reticulatisporites sp.	1	
Striatoabietites sp.		2
Striatopodocarpites cancellatus (Balme and Hennelly)		2
S. pantii (Jansonius)		2
S. sp.		2
Striomonosaccites sp.		2
Sulcatisporites sp.		2
Taeniaesporites noviaulensis Leschik	1	2
T. obex Balme	1	2
T. pellucidus Goubin	1	
T. sp.		2
Tigrisporites playfordi de Jersey and Hamilton	1	2
Vitreisporites pallidus (Reissinger)		2
Weylandites sp. cf. *W. lucifer* (Bharadwaj and Salujha)		2
Acritarchs (Balme *in* Union Oil Development Corp., 1968)		
Leiosphaeridia spp.		2
Micrhystridium sp. cf. *M. stellatum* Deflandre		2
Schizosporis scissus Balme		2

*1. Early Triassic
*2. Late Late Permian

The Sabina Sandstone was originally thought to be entirely of Early Triassic age and equivalent to the Kockatea Shale (Balme *in* Union Oil Development Corp., 1968). More recently Balme (*in* Union Oil Development Corp., 1972) has shown that whilst the upper part of the formation is Early Triassic, the microflora from the lower part is late Late Permian in age. The Sabina Sandstone is thus believed to record deposition without break across the Triassic-Permian boundary. Accordingly part of the formation was laid down during the time interval represented in the northern Perth Basin by the unconformity between the Wagina Sandstone and the Kockatea Shale.

Environment of deposition: The Sabina Sandstone is believed to be predominantly a fluviatile deposit, although there are some microfloral indications that it becomes paralic to the north.

TRIASSIC

The Triassic is represented in the Perth Basin by five formations having a total maximum thickness that may exceed 2 500 m. In the northern part this sequence is mixed marine and continental, while in the south it is almost entirely continental. The units in the north are (in ascending order) the Kockatea Shale, Woodada Formation, and Lesueur Sandstone. Two units are recognized in the south, the Sabina Sandstone (which is partly of Permian age) below and the Lesueur Sandstone above. The Sabina Sandstone has already been described in the Permian section of this bulletin.

Only two of the Triassic units in the basin have been recognized in outcrop; the Kockatea Shale on either side of the Northampton Block, and the Lesueur Sandstone in a small area around Cockleshell Gully. Triassic rocks are widespread in the subsurface.

KOCKATEA SHALE

Definition: The name Kockatea Shale was introduced by Playford and Willmott (*in* McWhae and others, 1958) for the unit of shale with lesser thicknesses of siltstone and sandstone, overlying Permian or older rocks and underlying Jurassic sediments in the area around the Northampton Block. The type section is situated near the junction of Kockatea Creek with the Greenough River (lat. 28° 33′ 10″S, long. 115° 10′ 10″E). The following is a description of this section:

	Thickness (metres)
Kojarena Sandstone, disconformably overlying—	
Kockatea Shale (12.5 m)	
3. Shale, light-grey to white, mottled yellow, pink, and purple	10
2. Shale, light-grey to white, mottled pink and purple; with prominent thin beds (averaging 1 cm thick) of purple ferruginous claystone	1
1. Quartz sandstone, coarse-grained, in part feldspathic, pink and yellow with white spots, poorly sorted, friable to weakly lithified, crudely bedded; contains clay balls in upper 60 cm, and grades into granule conglomerate in upper 15 cm; moderate to good porosity and permeability; grains well rounded to subangular; feldspar grains kaolinized	1.5

Overlying poorly exposed ?Irwin River Coal Measures, presumably unconformably.

Two sandstone members are recognized in the Kockatea Shale. These are the *Dongara Sandstone Member* and *Bookara Sandstone Member.* They have previously been included in the "Basal Triassic Sandstone" of Hosemann (1971) and the "Yardarino Sandstone" of Playford and Low (1972). However, as previously discussed, recent work by R. G. McKellar of Wapet (written comm., 1972) has shown that much of the "Yardarino Sandstone" and "Basal Triassic Sandstone" are in fact of Permian age. The Permian part has now been included by McKellar in the Yardarino Sandstone Member of the Wagina Sandstone. The Early Triassic parts are placed in the Dongara Sandstone Member and Bookara Sandstone Member of the Kockatea Shale.

The Dongara Sandstone Member is a unit of fine to coarse-grained quartz sandstone developed in the Dongara area. The type section (defined by R. G. McKellar) is in Dongara No. 11 well between 1 682 and 1 701 m, where the member is unconformably underlain by Wagina Sandstone. Elsewhere in the Dongara area it rests on the CaryngInia Formation or the Irwin River Coal Measures. McKellar believes that the unit is of Early Triassic age, but no fossils have been found in it, and we believe there is still the possibility that it forms part of the Wagina Sandstone. Lithologically it is not very different from the Yardarino Sandstone Member of that formation.

The Bookara Sandstone Member was first named informally by P. R. Lehmann of Wapet. The unit consists of medium to coarse-grained feldspathic sandstone, and is recognized in the Bookara-Allanooka area, north of the area underlain by the Dongara Sandstone Member. The type section is in Dongara No. 5 well from 1 497 to 1 508 m. The member occurs within the lower part of the Kockatea Shale and is underlain by typical shale of that formation, dated as Early Triassic.

Lithology: The Kockatea Shale consists of light-grey and greenish-grey to black shale, with lesser thicknesses of siltstone and sandstone. Part of the formation is also commonly calcareous in the subsurface. Outcrops are generally bleached white or pale yellow, with some red and purple to brown ferruginous beds and laminae. Ferruginous concretions also occur in some areas.

Siltstone and very fine-grained sandstone in the formation commonly show cross-bedding and oscillation ripple marks. Siltstone makes up the major part of the unit in some sections adjoining the Northampton Block. Lenticular sandstone and conglomerate units are also developed in the formation (especially at the base) around this block, and can be recognized as distinct members in some areas. Only two have been named (Dongara Sandstone and Bookara Sandstone Members).

Stratigraphic relationships: The Kockatea Shale rests with angular unconformity on various formations of the Permian sequence, the Tumblagooda Sandstone, or Precambrian rocks. It is overlain conformably by the Woodada Formation or unconformably by Lower to Upper Jurassic sediments.

The "Minchin Siltstone" of Johnstone and Playford (*in* McWhae and others, 1958) is now recognized as being equivalent to the Kockatea Shale, and the name has therefore been abandoned.

Distribution and thickness: The Kockatea Shale is widespread in the subsurface of the northern Perth Basin as far south as Jurien Bay. It is not known to occur east of the Urella Fault. The formation crops out only in the small area around the type section (east of the Northampton Block) and between the Greenough and Hutt Rivers (west of the Northampton Block). It extends into the southern part of the Carnarvon Basin, north of the Hutt River.

Thicknesses of surface sections that have been measured are 8.5 m near Moonyoonooka homestead, 12.5 m at the type section, 30 m at Sugarloaf Hill and Mount Minchin, and 38 m just south of Mount Minchin.

The Kockatea Shale is much thicker in the subsurface, the maximum intersection being 777 m in Eneabba No. 1 well, where the base was not reached. In wells around Dongara it is about 300 m thick. An isopach map of the formation is shown as Figure 27.

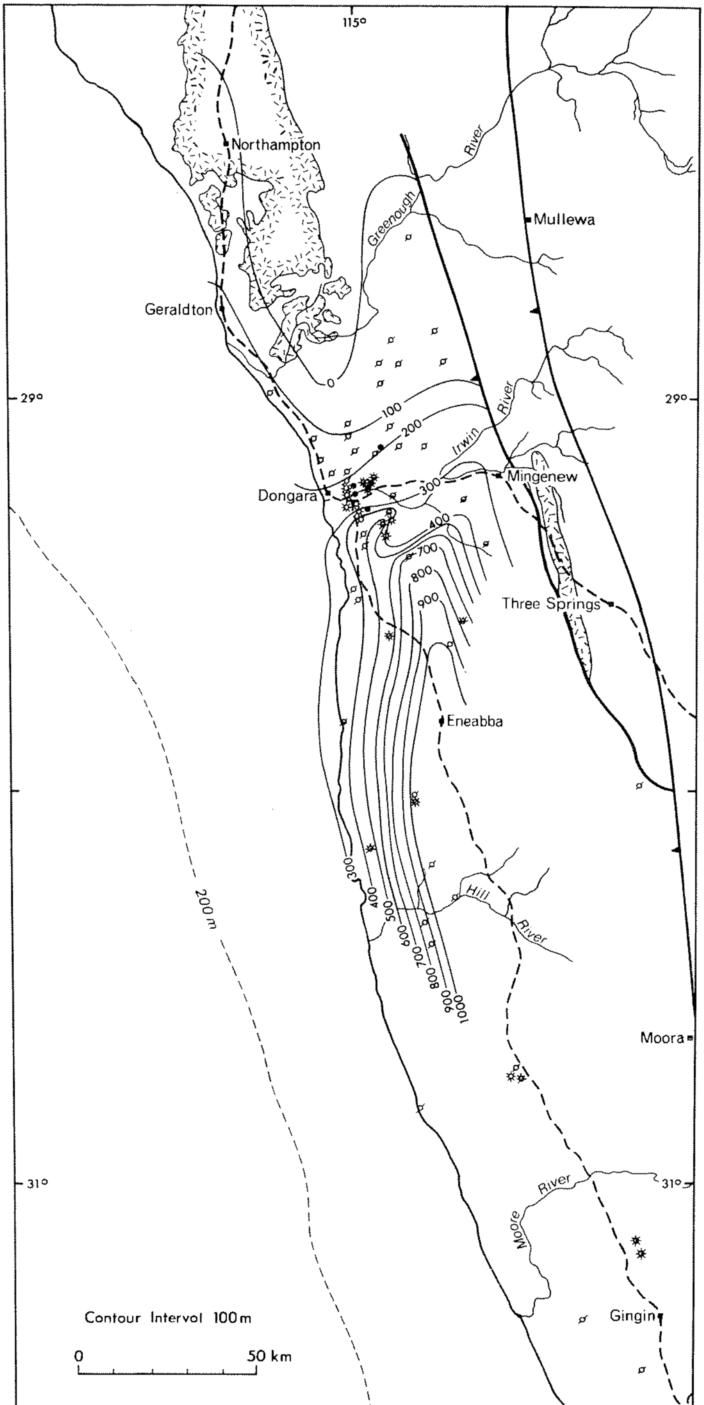

Figure 27. Isopach map, Kockatea Shale (Lower Triassic).

Fossils and age: The Kockatea Shale has yielded a varied flora and fauna, as follows:

Spores and pollen (Balme, 1963; Balme *in* Burdett, 1964; Balme *in* Coleman and Skwarko, 1967)

Crustaesporites sp.
Kraeuselisporites cuspidus Balme
K. saeptatus Balme
Lundbladispora brevicula Balme
L. playfordi Balme
L. willmotti Balme
Lycopodiacidites pelagius Balme
L. sp.
Osmundacidites senectus Balme
Platysaccus sp. cf. *P. papilionis* R. Potonié and Klaus
Protohaploxypinus pellucidis Goubin
Punctatisporites fungosus Balme
Striatites sp. cf. *Taeniaesporites antiguus* Leschik
Taeniaesporites sp. cf. *T. noviaulensis* Leschik
T. obex Balme
Tetraporina sp. cf. *Azonotetraporina*? *horologia* Staplin
Vitreisporites pallidus (Reissinger)

Microplankton (Balme, 1963; Balme *in* Burdett, 1964; Medd, 1966)

Baltisphaeridium sp.
Leiosphaeridia sp.
Micrhystridium breve Jansonius
M. sp. cf. *M. fragile* Deflandre
M. sp. cf. *M. inconspicuum* (Deflandre)
M. setasessitante Jansonius
cf. *Schizosporis* sp.
Veryhachium reductum Deunff
Wilsonastrum colonicum Jansonius
W. spp.

Algae (Wray *in* Karajas, 1969)

Sphaerocodium sp.

Foraminiferida (Jones, 1970)

Ammodiscus sp.

Brachiopoda (Dickens and McTavish, 1963)

"Lingula" sp.

Bivalvia (Dickins and McTavish, 1963; Skwarko and Kummel, 1974)

Anodontophora sp. cf. *A. griesbachi* Bittner
Bakevellia sp.
Claraia perthensis Dickins and McTavish
C. stachei Bittner
Pteriacea indet.
Trigonucula sp.

Nautiloidea (Skwarko and Kummel, 1974)

?*Grypoceras* sp. A.
G. sp. B.

Ammonoidea (Glenister and Furnish, 1961; Dickins and McTavish, 1963; Edgell, 1964a; Skwarko and Kummel, 1974)

Anasibirites kingianus (Waagen)
Arctoceras sp. indet. A.
A. sp. indet. B.
Glyptophiceras? sp. indet.
Gyronites sp. cf. *G. frequens* Waagen
Hemiprionites sp. indet.
?*Koninckites* sp. indet.
Ophiceras (*Discophiceras*) sp. cf. *O.* (*D.*) *subkyokticum* (Spath)
?*Paranorites* sp. indet.

Prionites sp. indet.
Proptychites sp. indet.
Subinyoites kashmiricus (Diener)

Annelida (Dickins and McTavish, 1963)
Spirorbis sp.

Crustacea (other than Ostracoda) (Cockbain, 1974a)
Cyzicus sp. cf. *C. minuta* (Goldfuss)

Ostracoda (Jones, 1970)
Bairdia sp.
Hollinella sp.
Paegnium neutrum Jones
Truncobairdia beaglensis Jones

Conodontophoridea (Jones, 1970; McTavish, 1973)
Neospathodus dieneri Sweet
Spathognathodus sp.

Vertebrata (Cosgriff, 1965)
Deltasaurus pustulatus (Cosgriff)

The ammonoids indicate that the Kockatea Shale is of Early Triassic age. In the Beagle Ridge (B.M.R. No. 10) bore, Dickins and McTavish (1963) identified *Ophiceras* (*Discophiceras*) sp. cf. *O.* (*D.*) *subkyokticum* and *Subinyoites kashmiricus* which they considered to belong to Spath's Otoceratan Fauna of Griesbachian (early Early Triassic) age (Tozer, 1967). However, more recently, McTavish and Dickins (1974) have re-interpreted the ammonoid evidence and now believe that the Kockatea Shale in the Beagle Ridge bore ranges in age from Griesbachian at the base to Smithian at the top. Further north, around Sugarloaf Hill and Mount Minchin, Edgell (1964a) and Skwarko and Kummel (1974) have identified ammonoids (including *Anasibirites kingianus* and *Arctoceras*) from the lower part of the formation that are characteristic of Spath's Owenitan Fauna, of Smithian (late Early Triassic) age (Tozer, 1967). From this it can be demonstrated that the base of the Kockatea Shale is time transgressive as the formation onlaps the Northampton Block.

The amphibian *Deltasaurus* is of interest in that it resembles forms found in the *Cynognathus* zone of the South African Beaufort Formation (Cosgriff, 1965), which is consequently of Early Triassic age (Cosgriff, 1969).

Jones (1970) describes an ostracod assemblage from the formation in B.M.R. No. 10 (Beagle Ridge) bore which includes one genus (*Paegnium*) which elsewhere is known only from the Middle Devonian. Although Jones discounts reworking, it is just conceivable that the ostracod genus was derived from a Devonian formation as is the case with the Devonian spores recorded by Ingram (1967b) from the Cretaceous Otorowiri Siltstone Member of the Yarragadee Formation.

Environment of deposition: The Kockatea Shale is a marine deposit, as is shown by the presence of marine fossils, including bivalves, conodonts, and microplankton. Hosemann (1971) has interpreted the sandstone bodies developed in the lower part of the formation as representing strandline accumulations and possible offshore bars. The shale and siltstone making up the major part of the unit were probably laid down under fairly shallow-marine conditions.

Economic aspects: The Kockatea Shale is believed to be one of the best hydrocarbon sources in the Perth Basin. The Dongara Sandstone Member is an important reservoir in the Dongara Field, and thin sandstone interbeds within the formation produced small amounts of oil in Mount Horner No. 1 well.

WOODADA FORMATION

Definition: The Woodada Formation was named by Willmott and McTavish (*in* Willmott, 1964). It is the unit of interbedded sandstone and siltstone that lies between the Kockatea Shale and the Lesueur Sandstone. The name is taken from Woodada Hill, near the coast, 45 km south of Dongara. The type section is in B.M.R. No. 10 (Beagle Ridge) bore (lat. 29° 49′ 38″S, long. 114° 58′ 30″E) between 334 and 610 m, a total thickness of 276 m. Willmott (1964) also designated a reference section of the formation in Woolmulla No. 1 well from 1 012 to 1 231 m, as the samples are better in this well. The following is a description of the type section:

Lesueur Sandstone overlying, probably disconformably—

Woodada Formation (276 m)	Interval & thickness (metres)
5. Sandstone, fine-grained, light-grey, friable, moderately sorted, thin-bedded and cross-bedded, kaolinitic; subordinate interbedded, dark-grey, laminated, carbonaceous, micaceous siltstone; minor pyrite	334–446 112
4. Siltstone, dark-grey, laminated, sandy to shaly, carbonaceous, micaceous; and light-grey, fine to medium-grained, cross-bedded sandstone	446–462 16
3. Sandstone, fine to medium-grained, massive or well-bedded, kaolinitic	462–472 10
2. Sandstone, fine to medium-grained, light-grey, moderately sorted, massive to thin-bedded and cross-bedded, kaolinitic; interbedded with dark-grey, laminated, sandy to clayey, micaceous siltstone	472–549 77
1. Siltstone, dark-grey, laminated, sandy to shaly, micaceous, interbedded with fine to medium-grained, massive to thin-bedded and cross-bedded, kaolinitic sandstone; minor intraformational breccia	549–610 61

Conformably overlying Kockatea Shale.

Lithology: The upper part of the formation (Unit "A" of McTavish, 1965; unit 5 of the type section above) consists of fine-grained kaolinitic sandstone which is typically light grey, thin bedded, and cross bedded, interbedded with lesser thicknesses of micaceous, dark-grey, finely laminated carbonaceous siltstone. The lower part of the formation (Unit "B" of McTavish, 1965; units 1-4 of the type section above) is an interbedded sequence of fine-grained sandstone and siltstone. The constituent rock types are similar to those in the upper part of the formation, but the sand/shale ratio is much lower.

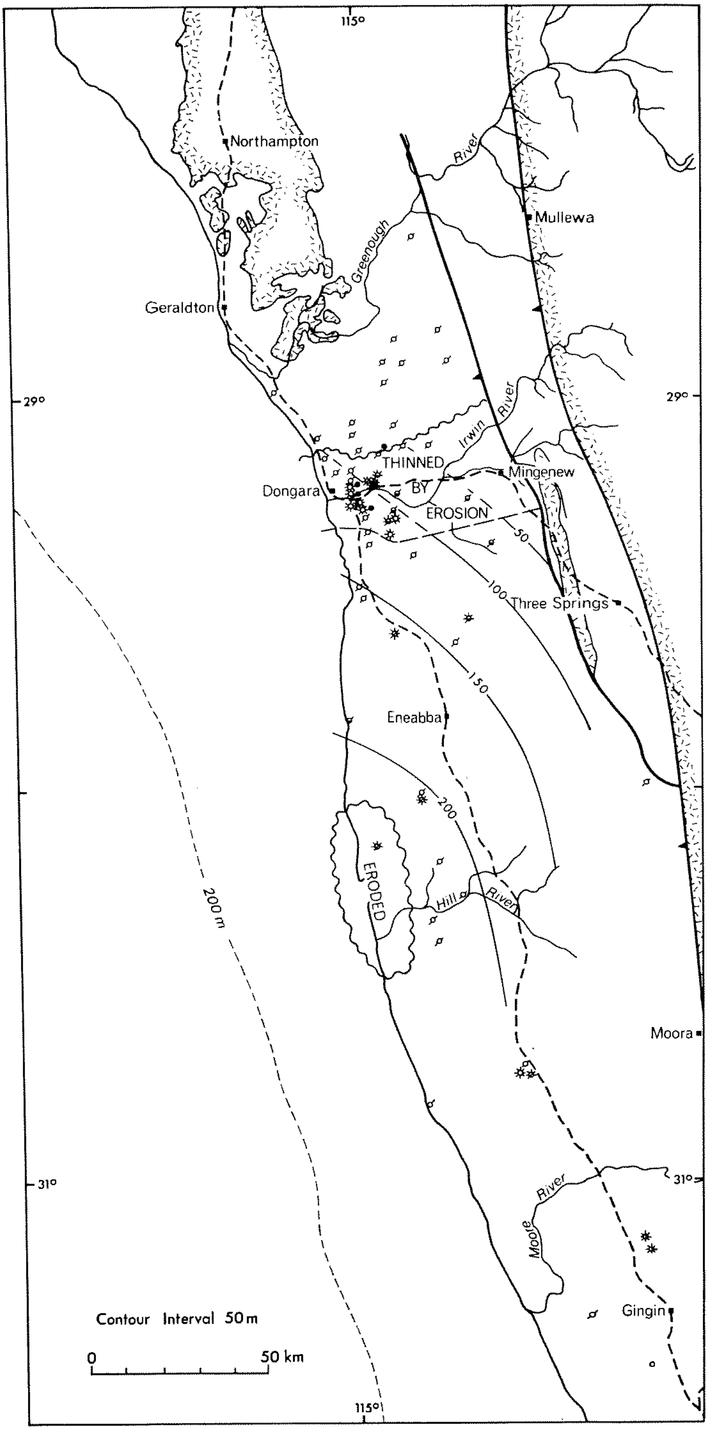

Figure 28. Isopach map, Woodada Formation (Lower-Middle Triassic).

(5)—53419

Stratigraphic relationships: The Woodada Formation rests conformably, with a transitional contact, on the Kockatea Shale, and is overlain, probably disconformably, by the Lesueur Sandstone.

Distribution and thickness: The Woodada Formation is not known to crop out anywhere in the Perth Basin. It is widely distributed in the subsurface, from just north of Dongara to Jurien Bay. The type section in B.M.R. No. 10 (Beagle Ridge) bore is the thickest known, amounting to 276 m, while the reference section in Woolmulla No. 1 well is 219 m thick. An isopach map of the formation is shown as Figure 28.

Fossils and age: The fossils of the Woodada Formation are few and poorly known, but they include leiospheres, spinose acritarchs, rare plant macrofossils and the following spores and pollen:

Spores and pollen (Balme, 1969)

Aratrisporites sp.
Cyclogranisporites sp. cf. *C. arenosus* Mädler
Falcisporites sp.
Platysaccus queenslandi de Jersey
Tigrisporites sp.

The microflora indicate a late Early to Middle Triassic age for the formation (Balme, 1969).

Environment of deposition: Plant microfossils suggest that the Woodada Formation is a paralic deposit. It represents the regressive phase between the marine Kockatea Shale and the continental Lesueur Sandstone.

LESUEUR SANDSTONE

Definition: The name Lesueur Sandstone was introduced by Willmott, Johnstone, and Burdett (*in* Willmott, 1964) for the sandstone unit between the Woodada Formation and the Cockleshell Gully Formation. It is named after Mount Lesueur in the Hill River area, and the type section is in Woolmulla No. 1 well (lat. 30° 01′ 24″S, long. 115° 11′ 28″E) between 429 and 1 012 m. The following is a description of this section:

	Interval & thickness (metres)
Cockleshell Gully Formation, conformably overlying— *Lesueur Sandstone* (583 m)	
6. Sandstone, fine to very coarse-grained, light-grey, kaolinitic, pyritic; a few pebbles (up to 6 mm), strongly cross bedded	429–497 68
5. Sandstone, fine to very coarse-grained, light-grey, kaolinitic, pyritic; a few pebbles; minor medium-grey and light-green, fossiliferous, very micaceous siltstone, in part carbonaceous	497–649 152
4. Sandstone, fine to coarse-grained; with some very coarse-grained, kaolinitic, micaceous, carbonaceous pebbles (up to 10 mm); pyrite nodules common, cross-bedding common; some traces of light-grey-green siltstone	649–664 15

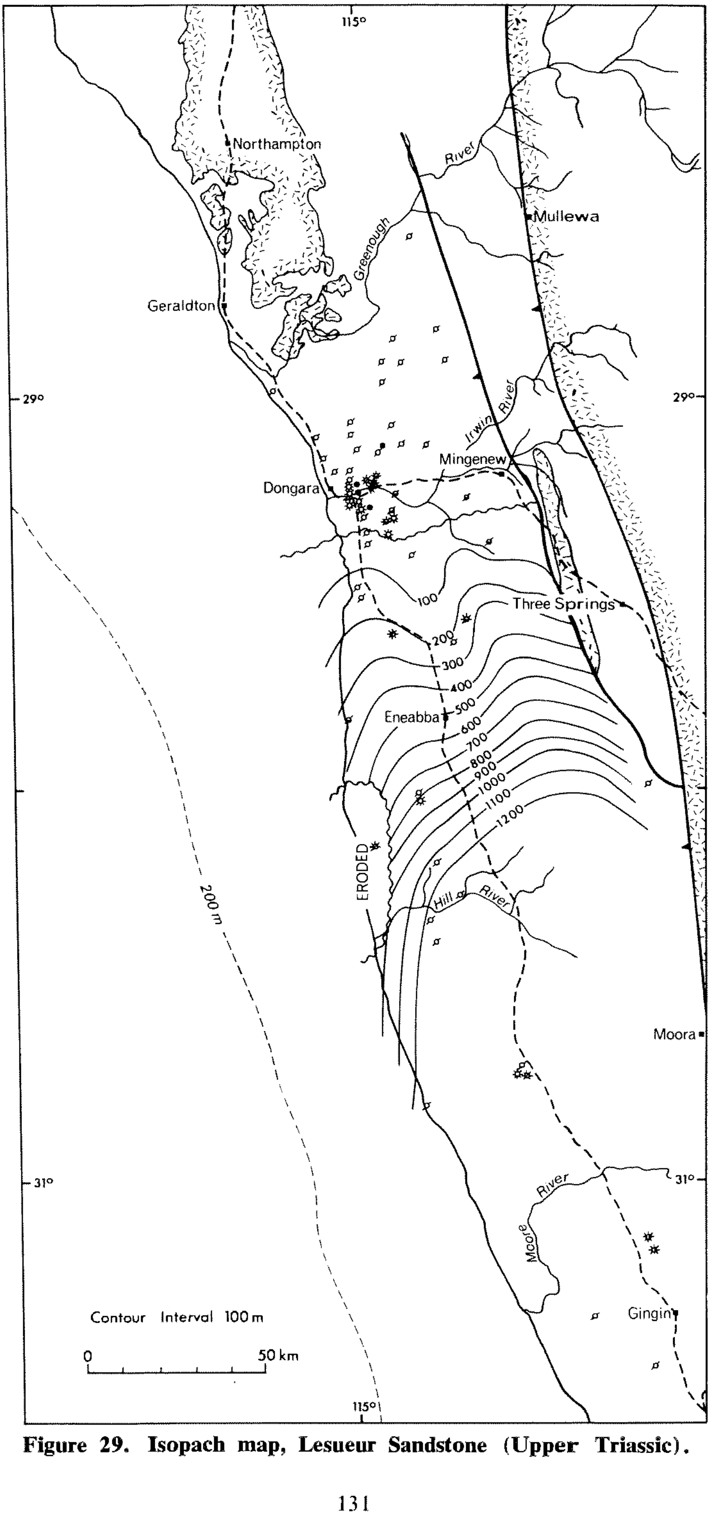

Figure 29. Isopach map, Lesueur Sandstone (Upper Triassic).

3. Sandstone, fine to medium-grained, minor coarse-grained, light-grey; grains subangular to subrounded, in places conglomeratic (pebbles up to 12 mm); rare partings of siltstone and claystone	664–820	156
2. Sandstone, medium to very coarse-grained, white, with green clay matrix; in part conglomeratic; some micaceous siltstone, in places carbonaceous, and red-brown claystone near the base; rare thin seams of coal	820–908	88
1. Sandstone, fine to very coarse-grained, white to light-grey, kaolinitic, feldspathic, carbonaceous, micaceous, strongly cross-bedded; minor siltstone grading to dark-brown-grey, laminated, very micaceous shale, carbonaceous in part	908–1 012	104

Overlying Woodada Formation, probably disconformably.

Lithology: The Lesueur Sandstone consists for the most part of fine to very coarse-grained cross-bedded quartz sandstone, which is commonly kaolinitic and may be feldspathic. It also commonly contains minor amounts of siltstone.

Stratigraphic relationships: The Lesueur Sandstone overlies the Woodada Formation, probably disconformably, and is overlain conformably by the Cockleshell Gully Formation.

Distribution and thickness: The Lesueur Sandstone is widely distributed in the subsurface south of Dongara, reaching a thickness of 1 201 m in Cadda No. 1 well (Elie and others, 1965). It is believed to continue to the southern Perth Basin, where a unit that has been correlated with the Lesueur Sandstone occurs in Pinjarra No. 1, Sue No. 1, and other wells. The maximum thickness is 2 201 m (base not reached) in Pinjarra No. 1 well (Jones and Nicholls, 1966). An isopach map of the formation is shown as Figure 29.

Fossils and age: The fossils in the Lesueur Sandstone include rare plant remains and plant microfossils.

Spores and pollen (Balme *in* Burdett, 1963; Balme *in* Elie and others, 1965; Balme *in* Jones and Nicholls, 1966; Balme, 1969; Balme *in* Union Oil Development Corp., 1968, 1972)

Alisporites spp.	1*	
Apiculatisporis sp.	1	
Aratrisporites paenulatus Playford and Dettmann	1	
A. sp.		2*
Camerasporites sp.	1	
Chordasporites sp.	1	
Concavisporites sp.	1	
Cycadopites follicularis Wilson and Webster		2
C. nitidus (Balme)	1	
Cyclogranisporites sp.		2
Deltoidospora sp.	1	
Dictyophyllidites sp. cf. *D. mortoni* de Jersey	1	
Distalanulatisporites sp.		2
Falcisporites australis (de Jersey)	1	
F. sp. cf. *F. australis* (de Jersey)		2
F. spp.	1	
Inaperturopollenites sp.	1	
Kraeuselisporites sp.	1	2
Leiotriletes sp.	1	2
Lundbladispora brevicula Balme		2
L. playfordi Balme		2

L. willmotti Balme		2
Microreticulatisporites sp.	1	
Monocolpopollenites sp.	1	
Neoraistrickia sp.	1	
Osmundacidites senectus (Balme)		2
O. sp.	1	
Planisporites sp.	1	
Platysaccus queenslandi de Jersey	1	
cf. Polypodiidites sp.	1	
Protohaploxypinus sp.		2
Punctatisporites sp. cf. *P. microtumulosus* Playford and Dettmann	1	
P. sp.	2	
Saturnisporites sp.	1	
Stereisporites sp.	1	2
Striatopodocarpites sp.		2
Taeniaesporites noviaulensis Leschik		2
T. pellucidus (Goubin)		2
cf. *Tigrisporites* sp.		2
cf. *Verrucosisporites* sp.	1	
Vitreisporites pallidus (Reissinger)	1	

*1. Lesueur Sandstone in Dandaragan Trough; upper Lesueur Sandstone in Bunbury Trough

*2. Lower part of Lesueur Sandstone in Bunbury Trough

Plant macrofossils (White, 1962)

Danaeopsis hughesi Feistmantel
Dicroidium sp.
Dictyophyllum sp.
Linguifolium sp.
"Neuropteris punctata Shirley"
Phlebopteris polypodioides Brongniart

The microflora of the Lesueur Sandstone in the Dandaragan Trough indicates a late Middle to Late Triassic age for the unit. However, in the Bunbury Trough the microflora in the lower part of the formation is of Early Triassic age. Hence the Lesueur Sandstone is time transgressive and in the Bunbury Trough it includes time equivalents of the Woodada Formation and part of the Kockatea Shale.

Environment of deposition: The Lesueur Sandstone is believed to be a fluviatile unit. It is thought to have been deposited at the beginning of a major period of block faulting in the basin, which commenced during the Middle Triassic and continued to the Early Cretaceous.

JURASSIC

Jurassic sediments occur widely in the Perth Basin. They are exposed principally in the Geraldton and Hill River areas (Plates 7-9, Fig. 55), and are known from the subsurface over a large part of the basin. The best exposures occur along the west side of the Northampton Block, but these rocks constitute a condensed section that is not as representative of the subsurface Jurassic sequence over most of the basin as are the poor outcrops around Hill River.

The Jurassic section of the basin consists essentially of a thick continental Lower Jurassic sequence, a thin Middle Jurassic marine to paralic sequence, and another thick continental development in the Upper Jurassic, continuing into the

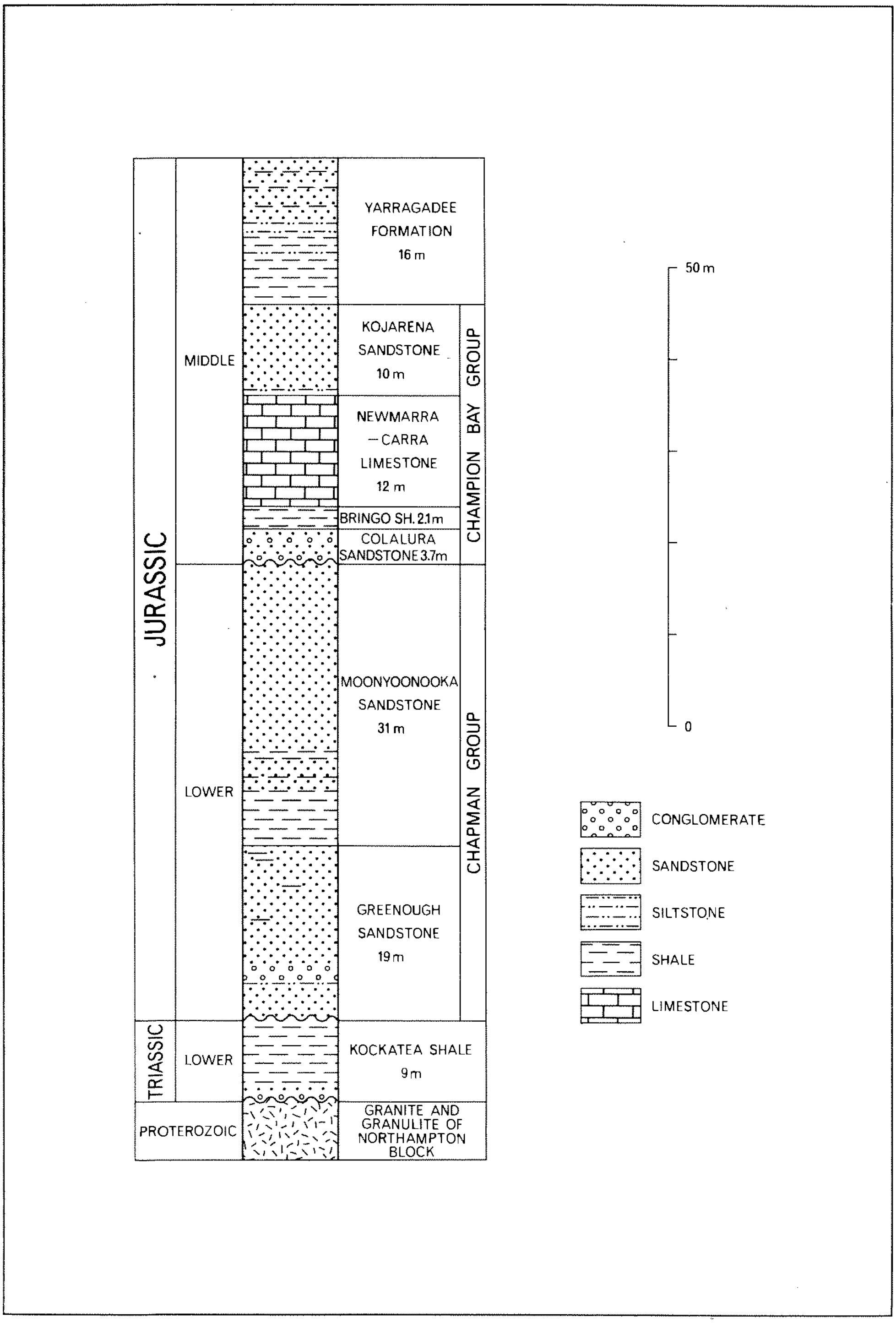

Figure 30. Stratigraphic column, Geraldton area.

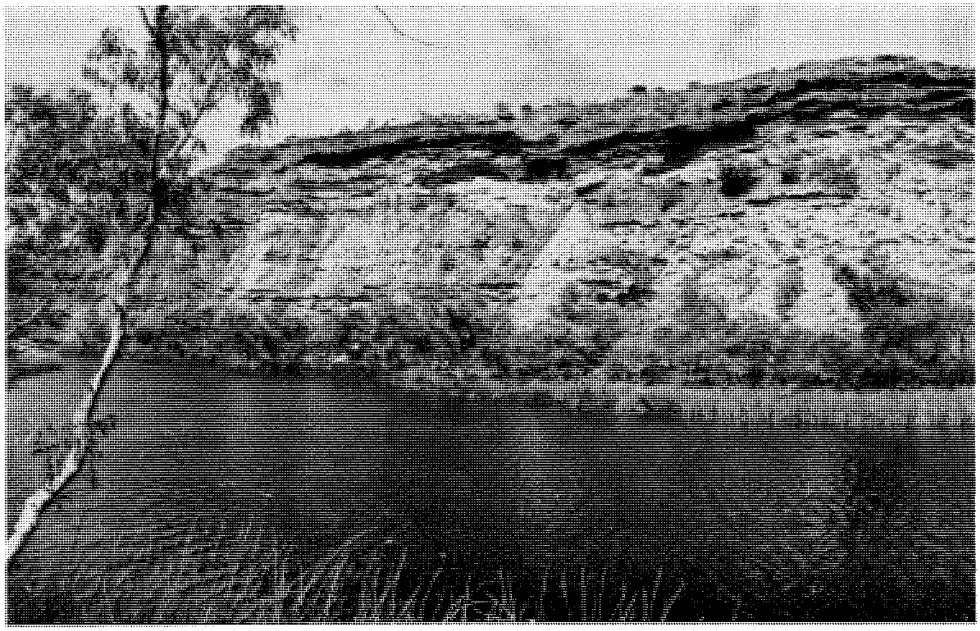

Figure 31. Cliff at Ellendale Pool on the Greenough River, exposing Jurassic sediments of the Chapman and Champion Bay Groups (including lateritized Newmarracarra Limestone near the top of the cliff). Note a small fault near the centre of the photograph.

Lower Cretaceous. The threefold division in the Hill River area (which is also applied in the subsurface throughout much of the basin), consists of the continental Cockleshell Gully Formation at the base, followed by the marine to paralic Cadda Formation, and the continental Yarragadee Formation. The aggregate maximum thickness of these rocks may amount to more than 4 200 m.

East of Geraldton the Jurassic rocks overlap the Precambrian Northampton Block. Again, there is a threefold division of the sequence, consisting of the continental Chapman Group at the base followed successively by the marine Champion Bay Group and the continental Yarragadee Formation (Figs. 30 and 31). Their aggregate thickness in outcrop amounts to only about 180 m.

COCKLESHELL GULLY FORMATION

Definition: The name "Cockleshell Gully Sandstone" was introduced by Playford, Willmott, and McKellar (*in* McWhae and others, 1958), and it was amended to Cockleshell Gully Formation by Willmott (1964). The unit is defined as the interbedded sequence of sandstone, siltstone, claystone, shale, and coal lying between the Lesueur Sandstone and the Cadda Formation. The type section described by Playford and Willmott (1958) is in Cockleshell Gully (lat. 30° 07′ 45″S, long. 115° 11′ 23″E), but this is poorly exposed and is faulted at both top and bottom. As a result, Willmott (1964) nominated reference sections at lat. 30° 15′ 55″S, long. 115° 17′ 30″E for the top of the formation, and in Eneabba No. 1 well (lat. 29° 34′ 14″S, long. 115° 19′ 56″E) for the entire section, and especially the base.

Two members are distinguished in the Cockleshell Gully Formation. The *Eneabba Member* at the base was originally referred to informally in Wapet reports as the "Multicoloured Member", and it was defined by Playford and Low (1972), who nominated the type section in Eneabba No. 1 well from 2 302 to 2 978 m, a total thickness of 676 m. The *Cattamarra Coal Measures Member* had been referred to in Wapet reports as the "Coal Measures Member", part of which formed the "Cattamarra Coal Member" of Willmott (1964). The name was taken from Cattamarra property in the Hill River area. Playford and Low (1972) formalized the current usage, and nominated the type section in Eneabba No. 1 well from 1 790 to 2 302 m. The following is a description of the formation in this well:

Cadda Formation, conformably overlying—

	Interval & thickness (metres)
Cockleshell Gully Formation (1 188 m)	
Cattamarra Coal Measures Member (512 m)	
17. Shale, medium to dark-grey and brown-grey, micaceous, sideritic; minor partings of sandstone	1 790–1 814 24
16. Claystone, medium to dark-grey and brown-grey, in part sideritic; interbedded with medium to light-brown-grey, sideritic siltstone, and black, vitreous coal; minor partings of light-grey, fine to very fine-grained, kaolinitic, micaceous sandstone	1 814–1 859 45
15. Sandstone, fine to coarse-grained, light-grey, kaolinitic, micaceous; a few pebbles near top and pyritic near base; interbedded with black coal and brown-grey, sideritic siltstone	1 859-1 943 84
14. Coal, black, vitreous; some small interbeds of dark-grey and brown, sideritic claystone	1 943-1 963 20
13. Sandstone, fine to very fine-grained, light-grey, kaolinitic, micaceous; and dark-grey and brown-grey, sideritic claystone; interbedded with brown-grey, sideritic siltstone; some black, vitreous coal seams	1 963–2 086 123
12. Sandstone, fine to very fine-grained, pebbly in part, light-grey, micaceous, kaolinitic; minor claystone and siltstone; carbonaceous matter common	2 086–2 153 67
11. Claystone, light to dark-grey-brown, sideritic, carbonaceous; interbedded with light to medium-brown-grey siltstone, in part sandy; light-grey, very fine-grained sandstone	2 153–2 188 35
10. Sandstone, light-grey, fine to very fine-grained, micaceous, kaolinitic, pebbly in part; interbedded with minor brown-grey siltstone, in part sandy; carbonaceous matter common	2 188–2 302 114
Eneabba Member (676 m)	
9. Sandstone, feldspathic, coarse to very coarse-grained, with minor conglomerate; micaceous in part; interbedded with grey siltstone, and multicoloured, carbonaceous claystone	2 302–2 385 83
8. Conglomerate, sandy; interbedded with siltstone	2 385–2 394 9

7.	Quartz sandstone, coarse to very coarse-grained, in part pebbly, feldspathic, micaceous; some beds with white, brown, and green clayey matrix; interbedded light-grey and green, fine to very fine-grained sandstone; some multicoloured, carbonaceous claystone and grey and green siltstone	2 394–2 509	115
6.	Claystone, red-brown, yellow, purple, and green; interbedded with very fine to very coarse-grained sandstone and minor siltstone	2 509–2 545	36
5.	Sandstone, feldspathic, coarse to very coarse-grained, in part pebbly, micaceous; some beds contain white, brown, and green clayey matrix; and light-grey and green, fine to very fine-grained sandstone; some multicoloured, carbonaceous claystone and grey and green siltstone	2 545–2 591	46
4.	Sandstone, fine-grained, in part pebbly; interbedded with sandy claystone, and minor grey and green siltstone	2 591–2 724	133
3.	Claystone, sandy, containing sand grains up to very coarse grained	2 724–2 746	22
2.	Sandstone, fine-grained, light-grey, in part coarse-grained and pebbly; interbedded with sandy claystone, and minor grey and green siltstone	2 746–2 926	180
1.	Claystone, sandy, multicoloured, very poorly sorted, in places conglomeratic; interbedded with clayey, light-grey, poorly sorted quartz sandstone, conglomeratic towards the base	2 926–2 978	52

Conformably overlying Lesueur Sandstone.

Lithology: The Eneabba Member of the Cockleshell Gully Formation is composed of fine to coarse-grained sandstone with interbedded claystone and siltstone. The sediments are characteristically multicoloured (red, yellow, brown, pink, purple, grey, and white). Some minor dark-grey carbonaceous shale also occurs.

The Cattamarra Coal Measures Member consists of very fine to very coarse-grained sandstone with interbedded grey shale and siltstone, which are in part carbonaceous, and seams of coal. The coal seams are strong seismic reflectors, and can be traced over wide areas.

Stratigraphic relationships: The Cockleshell Gully Formation lies conformably below the Cadda Formation or the Yarragadee Formation and above the Lesueur Sandstone. The contacts probably interfinger to some extent.

The Cockleshell Gully Formation is equivalent to the Chapman Group of the Geraldton area. The Eneabba Member probably correlates with the Greenough Sandstone (which is also multicoloured), and the Cattamarra Coal Measures Member with the Moonyoonooka Sandstone (which is carbonaceous in part) of that group.

Distribution and thickness: The Cockleshell Gully Formation is exposed in the Hill River-Eneabba area. All known outcrops belong to the Cattamarra Coal Measures Member. The formation occurs in the subsurface over wide areas of the basin from just south of the Northampton Block to the south coast (Fig. 47). The maximum known thickness is 2 075 m in Pinjarra No. 1 well.

An isopach map of the formation and the Chapman Group is shown as Figure 32, while Figure 47 is a structure contour map drawn on a horizon within the Cattamarra Coal Measures Member.

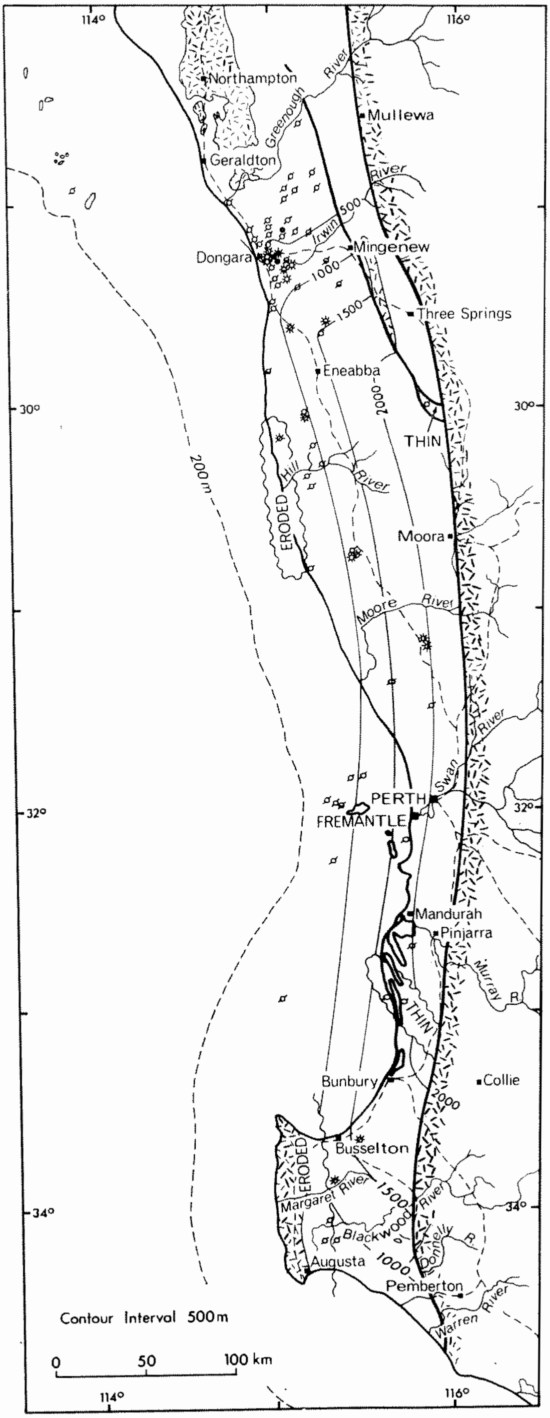

Figure 32. Isopach map, Cockleshell Gully Formation and Chapman Group (Lower Jurassic).

Fossils and age: Plant microfossils are the most abundant fossils in the Cockleshell Gully Formation, especially in the upper member. Macrofossils are uncommon.

Spores and pollen (Balme, 1957; Balme *in* Lehmann, 1966; Balme *in* Smith, 1967; Ingram, 1967c; Balme *in* Bird and Moyes, 1971b)

Alisporites spp.	1*	2*
Anapiculatisporites dawsonensis Reiser and Williams	1	
Apiculatisporis globosus (Leschik)	1	
A. sp.	1	
Araucariacites australis Cookson	1	
Camerozonotriletes sp.	1	
Cingulatisporites saevus Balme	1	
Circulisporites sp.	1	
Classopollis classoides (Pflug)	1	2
Concavisporites juriensis Balme	1	2
Cyathidites australis rimalis Balme	1	
C. minor Couper	1	
C. spp.		2
Cycadopites deterius (Balme)	1	
C. nitidus (Balme)	1	
C. sp.		2
Dictyophyllidites sp. cf. *D. mortoni* (de Jersey)	1	
D. sp.		2
Duplexisporites gyratus Playford and Dettmann	1	
Exesipollenites tumulus Balme	1	2
Granulatisporites sp.		2
Inaperturopollenites turbatus Balme	1	2
Ischyosporites punctatus Cookson and Dettmann	1	
I. sp.	1	
Klukisporites scaberis (Cookson and Dettmann)	1	
Laevigatosporites sp. cf. *L. neddeni* (R. Potonié)	1	
Leiotriletes sp.	1	2
Lycopodiumsporites austroclavatidites (Cookson)	1	
L. sp.	1	
Marsupipollenites sp.	1	
Osmundacidites comaumensis (Cookson)	1	
O. sp. cf. *O. wellmanii* Couper		2
Pilasporites marcidus Balme	1	
Podocarpidites ellipticus (Cookson)	1	
Podosporites sp.	1	
cf. *Polycingulatisporites* sp.	1	
Punctatisporites sp.	1	
Reticulatisporites pudens Balme	1	
Sphagnumsporites sp.		2
Staplinosporites caminus (Balme)	1	
Taurocusporites sp. cf. *T. verrucatus* Schulz	1	
Vitreisporites pallidus (Reissinger)	1	
Zonalopollenites dampieri Balme	1	2
Z. segmentatus Balme	1	

*1. Cattamarra Coal Measures Member

*2. Eneabba Member

Plant macrofossils (Walkom *in* McWhae and others, 1958)
cf. *Thaumatopteris* sp.

Bivalvia (Playford and Willmott, 1958)
bivalve fragments

Insecta (Riek, 1968)
?*Austroblatulla* sp.
Mesothoris westraliensis Riek

The microflora of the Cockleshell Gully Formation is typical of Balme's (1964a) *Exesipollenites* Assemblage which he considers to be of Early Jurassic (Liassic) age. The plant *Thaumatopteris* is also known from the Early Jurassic (Walkom *in* McWhae and others, 1958). Riek (1968, 1970) thought that the insects came from Triassic rocks, but in fact they come from the Cockleshell Gully Formation in the Mintaja Hill area.

Environment of deposition: The Cockleshell Gully Formation is believed to be a fluviatile deposit, laid down during a period of active block faulting in the Perth Basin.

Economic aspects: Coal was first found in the Cockleshell Gully Formation at depths of some 1 900 m in the Eneabba No. 1 well, drilled in 1961. This discovery led to exploration in the Hill River area, where the formation was known to crop out, but no economic seams were located (Johnstone, 1964). Subsequently, exploration was carried out in the Eneabba area itself, and some coal seams have been located there at shallow depths. Further details are given in the chapter on economic geology in this bulletin.

The Cattamarra Coal Measures Member is also a petroleum source and reservoir sequence. The Gingin and Walyering Gasfields occur in this unit, and the gas is thought to be derived principally from the coal and carbonaceous shale. Unfortunately, the sandstones in the formation are generally poor reservoirs, with low permeabilities and lenticular distribution. As a result, each of these fields has only a limited potential. However, it is possible that reservoir conditions may be better in other parts of the basin or that techniques will be developed to substantially increase the recovery from the low-permeability sandstones.

CHAPMAN GROUP

The name Chapman Group was introduced by Playford (1953) and was first published by Arkell and Playford (1954). The group comprises the Greenough Sandstone and the overlying Moonyoonooka Sandstone. These are continental units of Early Jurassic age.

GREENOUGH SANDSTONE

Definition: The name Greenough Sandstone was given by Playford (1953) and Arkell and Playford (1954) to the unit of sandstone with minor claystone and siltstone lying above the granitic rocks or the Kockatea Shale and below the Moonyoonooka Sandstone in the area east of Geraldton. The formation is named after the Greenough River, and the type section is on Moonyoonooka property at lat. 28° 47′ 04″S, long. 114° 48′ 03″E. The following is a description of this section revised from P. E. Playford (1959):

Moonyoonooka Sandstone, conformably overlying—

Greenough Sandstone (19 m)	Thickness (metres)
4. Sandstone, clayey, mottled grey, white, yellow, red, and purple; in places grades into sandy claystone; top marked by an 8 cm bed of hard, ferruginous claystone with purplish bands	14
3. Conglomerate, intraformational, mottled grey, yellow, and red; contains angular and rounded fragments of clay, in a matrix of coarse sand	1.3
2. Claystone, mottled red and white, massive	0.4
1. Sandstone, clayey, yellow, mottled red and white; contains scattered fragments of angular and rounded claystone; fills scour channel in underlying unit, conglomeratic at base; bleached and hardened along joints	3

Disconformably overlying Kockatea Shale.

Lithology: The Greenough Sandstone is typically a mottled red and white argillaceous sandstone, which is medium to coarse-grained and is very poorly sorted and poorly bedded. Lenses of siltstone, claystone, and shale occur in the formation, with quartz-pebble conglomerate in places. The formation is characteristically multicoloured. Red and white mottling predominates, but shades of yellow, purple, and brown are common.

Further details of the petrology and mineralogy of the formation are given by Playford (1953).

Stratigraphic relationships: The Greenough Sandstone disconformably overlies the Kockatea Shale in parts of the area east and north of Geraldton. Elsewhere in this area it unconformably overlies Precambrian granitic and metamorphic rocks. The surface of this unconformity is very irregular, with relief of more than 120 m.

The Greenough Sandstone is thought to correlate with part of the Eneabba Member of the Cockleshell Gully Formation.

Distribution and thickness: The Greenough Sandstone is recognized in the northwestern part of the Perth Basin between the Hutt and Greenough Rivers, and as far inland as Newmarracarra property. Its distribution is limited by the elevation of the Precambrian surface; if this rises higher than about 160 m above sea level the formation pinches out.

The thickest section of the Greenough Sandstone that has been measured is at Kings Table Hill, north of Geraldton, and is some 95 m thick.

Fossils and age: No fossils are known in the formation other than rare fragments of poorly preserved fossil wood. However, the unit is believed to correlate with the Eneabba Member of the Cockleshell Gully Formation, which is of Early Jurassic age.

Environment of deposition: The Greenough Sandstone is believed to be a fluviatile deposit, composed of highly weathered material derived from a granitic source area. Criteria indicating this environment of deposition are: absence of marine fossils, lateral impersistence of beds, variegated colouring, and the presence of intraformational conglomerates and breccias associated with local diastems.

Economic aspects: Parts of the Greenough Sandstone form an attractive building stone, which has been used to a limited extent in the Geraldton area.

MOONYOONOOKA SANDSTONE

Definition: The name Moonyoonooka Sandstone was applied by Playford (1953) and Arkell and Playford (1954) to the unit of sandstone and arkose overlying the Greenough Sandstone and underlying the Champion Bay Group in the area east of Geraldton. The formation is named after Moonyoonooka property, and the type section is on that property at lat. 28° 47′ 18″S, long. 114° 47′ 36″E. The following is a description of this section(after P. E. Playford, 1959):

Colalura Sandstone, disconformably overlying—

Moonyoonooka Sandstone (31 m)	Thickness (metres)
6. Arkose and feldspathic sandstone, very fine to medium-grained, partly silty, chiefly yellow, in part white and grey; contains some thin interbedded shale and siltstone; well-sorted, and usually well-bedded; shows cross-bedding, current ripple marks, and a few mud cracks; some thin intraformational conglomerate present; ferruginous concretions common, barite concretions rare; fossil wood common in the centre of ferruginous concretions; one fossil leaf found	20
5. Sandstone, medium-grained, brown, ferruginous, massive, outcropping prominently	0.1
4. Interbedded shale and fine-grained, cross-bedded feldspathic sandstone; variegated yellow, grey, and white; some beds have salt incrustations	3
3. Shale, black, carbonaceous, containing indeterminable plant fragments	1.5
2. Sandstone, conglomeratic, brown, ferruginous, massive, lenticular, outcropping prominently, with well-rounded quartz pebbles; contains rare fossil wood	0.3
1. Shale, black, carbonaceous, with lenses of brown sandstone, in part feldspathic, conglomeratic, with rare fossil wood; sandstone lenses most abundant near the base, where they are up to several metres long, and on the average 8 cm thick	6

Conformably overlying Greenough Sandstone.

Lithology: The Moonyoonooka Sandstone consists mainly of weakly lithified fine to very fine-grained feldspathic sandstone and arkose. It is predominantly yellow in colour, but is also white, grey, red, and brown. The sandstone and arkose are generally thin bedded, and cross-bedding and current ripple marks are common. Lenses of black to dark-grey shale, coarse-grained sandstone, and conglomerate occur in some areas.

Figure 33.—Exposure beside the road 4 km south-southwest of Gnows Nest Hill showing well-developed disconformable contact between the Moonyoonooka Sandstone (thinly bedded, light coloured) and the overlying Colalura Sandstone (unbedded, dark coloured). The disconformity has a relief of at least 1.5 m at this locality.

Small ferruginous cannon-ball concretions are characteristic of the formation. They have apparently formed as a result of the weathering of pyrite or marcasite nodules.

Details of the petrology and mineralogy of the formation are given by Playford (1953).

Stratigraphic relationships: The Moonyoonooka Sandstone rests conformably on the Greenough Sandstone or unconformably on Precambrian granitic and metamorphic rocks of the Northampton Block. The Moonyoonooka Sandstone is overlain disconformably by the Colalura Sandstone (Fig. 33) or the Newmarracarra Limestone.

Distribution and thickness: The Moonyoonooka Sandstone is recognized only in the area east of Geraldton, from near Kings Table Hill to Mount Hill. It extends inland as far east as the Bringo cutting. Throughout this area, wherever the Moonyoonooka Sandstone overlies Greenough Sandstone, its thickness is usually between 30 and 34 m. Where it overlies Precambrian rocks the thickness is very variable owing to undulations in the basement surface, and it commonly pinches out completely where it abuts buried hills.

Fossils and age: The only fossils commonly found in the Moonyoonooka Sandstone are fragments of wood. A single fossil leaf has been found, which Walkom (*in* P. E. Playford, 1959) identified as being of the *Linguifolium* type. No plant microfossils have been recovered from the formation in its type area, but Early Jurassic to possibly early Bajocian palynological datings have been obtained from sediments thought to correlate with the formation in water bores around Lake Alanooka and in the Bookara and Mount Hill stratigraphic wells.

Environment of deposition: The Moonyoonooka Sandstone is believed to be a fluviatile deposit. This is suggested by the following features of the deposit: fossil wood is present, but no marine fossils are known, the strata are markedly lenticular, and intraformational conglomerates occur in association with cut-and-fill structure.

The unit contains a high percentage of fresh feldspar, and a rich heavy-mineral suite which includes various metastable minerals. This indicates that erosion of the source area must have been fairly rapid, and it seems likely that the Moonyoonooka Sandstone has been derived by the erosion of an uplifted fault block. Strong movement is believed to have taken place along the Darling Fault at that time.

CADDA FORMATION

Definition: The name Cadda Formation was proposed by Playford and Willmott (*in* McWhae and others, 1958) for the sequence of shale, siltstone, sandstone, and limestone lying between the Cockleshell Gully Formation below and the Yarragadee Formation above. The name is derived from Cadda Spring, and the type section is 0.4 km west of this spring at lat. 30° 24′ 20″S, long. 115° 16′ 00″E. This section is faulted, and an accurate thickness cannot be measured, although the typical rock types of the formation are represented.

Lithology: The Cadda Formation consists of light to dark-grey shale, siltstone, and sandstone, with lenticular calcareous beds grading into limestone in some areas. Limestone becomes more conspicuous to the north, closer to the Northampton Block. It also occurs in the outcrop area around the Hill River, but is absent from most well sections.

Exposures of the formation are generally very weathered, and the calcareous rocks are commonly leached and ferruginized under the influence of lateritization. The limestones are usually coquinas of small oyster shells. The sandstones range from coarse to very fine grained, and the non-calcareous types resemble those in the underlying Cockleshell Gully Formation. Some are cross bedded and ripple marked.

Stratigraphic relationships: The Cadda Formation rests with apparent conformity between the Yarragadee Formation above and the Cockleshell Gully Formation

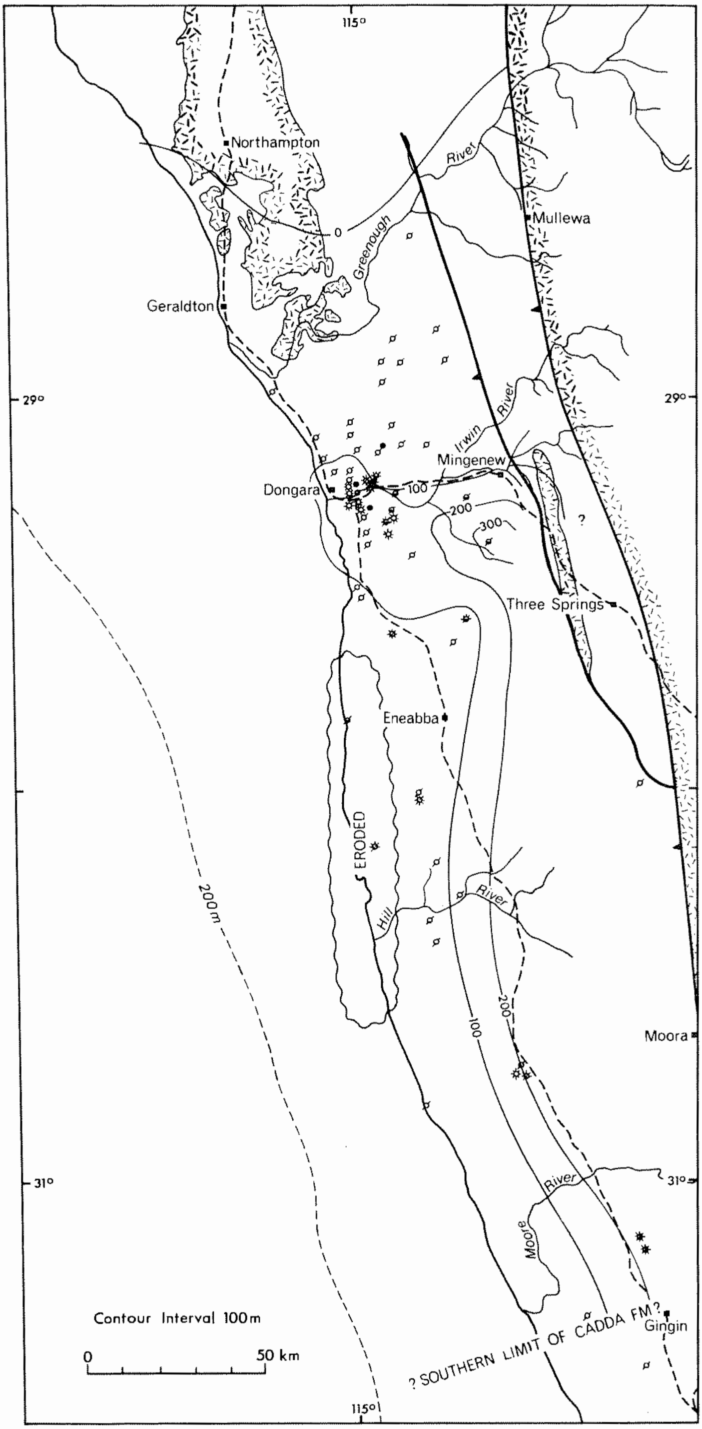

Figure 34. Isopach map, Cadda Formation and Champion Bay Group (Middle Jurassic).

below. It probably interfingers to some extent with each of these formations. The Cadda Formation is equivalent to the Champion Bay Group of the Geraldton area.

Distribution and thickness: The Cadda Formation crops out in the drainage area of the Hill River and Cockleshell Gully, extending for up to 27 km inland. Exposures in this area are very poor. Another poor exposure that is probably best referred to this formation crops out at Enanty Hill near Mingenew, within the Urella Fault Zone.

In its type area the Cadda Formation is about 37 m thick. It is known from the subsurface of the northern Perth Basin between the Northampton Block and the Hill River area, and reaches a maximum thickness of 392 m in Erregulla No. 1 well. To the south the formation is recognized in Gingin No. 1 well, and it may also occur in Cockburn No. 1 well, where the section is of paralic facies. Further south the equivalent section is probably included in the basal part of the Yarragadee Formation. An isopach map of the formation and the equivalent Champion Bay Group is shown as Figure 34.

Fossils and age: The Cadda Formation has yielded a small fauna of molluscs in outcrops in the Hill River and Enanty Hill areas. Spores, pollen, and microplankton are fairly common where the formation is encountered in the subsurface.

Spores and pollen (Balme *in* Johnson, 1964; Balme *in* Coleman and Skwarko, 1967; Balme *in* Hawkins, 1969; Williams *in* Bird and Moyes, 1971b)

Alisporites sp.	1*	
Araucariacites australis Cookson	1	2*
Circulina sp.	1	
Classopollis classoides (Pflug)	1	2
Concavisporites juriensis Balme	1	2
Contignisporites sp.	1	
Cyathidites minor Couper	1	
C. spp.	1	
Dictyophyllidites sp.	1	
Duplexisporites gyratus Playford and Dettmann	1	
Gleicheniidites sp.	1	
Inaperturopollenites turbatus Balme	1	2
Ischyosporites sp. cf. *I. marburgensis* de Jersey	1	
I. sp.		2
Lycopodiumsporites sp.	1	
Osmundacidites comaumensis Cookson	1	
O. wellmanii Couper		2
O. sp.	1	
Pilasporites marcidus Balme		2
Podocarpidites sp. cf. *P. ellipticus* Cookson	1	
P. spp.		2
Staplinosporites caminus (Balme)	1	
Tripartina sp.	1	
Vitreisporites pallidus (Reissinger)	1	2
Zonalapollenites dampieri Balme	1	2
Z. segmentatus Balme		2

Microplankton (Balme *in* Johnson, 1964; Balme *in* Coleman and Skwarko, 1967; Balme *in* Hawkins, 1969; Williams *in* Bird and Moyes, 1971b)

?*Canningia* sp.	1	
?*Gonyaulax* sp.	1	
Leiosphaeridia spp.	1	2
Micrhystridium spp.	1	
cf. *Tenua* sp.	1	

*1. Subsurface records, Dandaragan Trough and Abrolhos Sub-basin
*2. Drillhole at Enanty Hill

Bivalvia (Playford and Willmott, 1958; Coleman and Skwarko, 1967; Skwarko, 1974)

Astarte (*Astarte*) *apicalis* Moore		2*
Camptonectes greenoughi Skwarko		2
Chlamys enantyi Skwarko		2
Cucullaea sp.		2
Gresslya? *sanfordii* (Moore)		2
Meleagrinella sinuata (Teichert)	1*	2
Ostrea spp.	1	
Oxytoma (*Oxytoma*) *decemcostata* Whitehouse	1	2
Pseudolimea sp. cf. *P. duplicata* (Sowerby)		2
Trigonia moorei Lycett	1	2

Ammonoidea (Arkell and Playford, 1954; Coleman and Skwarko, 1967)

Fontannesia clarkei (Crick)		2
Pseudotoites emilioides Arkell	1	
P. semiornatus (Crick)	1	

Coleoidea (Playford and Willmott, 1958)

Belemnopsis sp.	1	

*1. Hill River area
*2. Enanty Hill

The fauna includes the Middle Bajocian genera *Fontannesia* and *Pseudotoites*, which also occur in the Newmarracarra Limestone. The Cadda Formation therefore includes strata of Middle Bajocian age, but the precise upper and lower time limits are uncertain.

Environment of deposition: The Cadda Formation is regarded as a shallow-marine to paralic deposit.

CHAMPION BAY GROUP

The name Champion Bay Group was first used by Playford (1953) and published by Arkell and Playford (1954) for the sequence of marine sandstone, shale, and limestone overlying the Chapman Group and underlying the Yarragadee Formation. It comprises (from the base upwards) the Colalura Sandstone, Bringo Shale, Newmarracarra Limestone, and Kojarena Sandstone.

The Champion Bay Group represents a short-lived transgression by a shallow sea during the Middle Jurassic. It is equivalent to the Cadda Formation of the Hill River outcrop area and the subsurface of much of the basin.

COLALURA SANDSTONE

Definition: The name Colalura Sandstone was first used by Playford (1953) and published by Arkell and Playford (1954) for the thin unit of sandstone at the base of the marine Jurassic sequence over much of the Geraldton area. It is

Figure 35. Colalura Sandstone exposed on Moonyoonooka property, showing abundant ferruginous fossil wood in a matrix of conglomeratic sandstone.

named after Colalura Brook, a tributary of the Greenough River, and the type section is at Spion Kop (lat. 28° 46′ 44″S, long. 114° 48′ 24″E) on Moonyoonooka property. The following is a description of this section (after P. E. Playford, 1959):

Laterite (lateritized Newmarracarra Limestone) overlying—

Colalura Sandstone (2.5 to 3.7 m)	Thickness (metres)
1. Sandstone, very coarse to medium-grained, conglomeratic, yellowish-brown, ferruginous, coarsely cross-bedded, containing a few thin claystone beds; several horizons rich in fossil wood and limonitic nodules	2.5-3.7

Disconformably overlying Moonyoonooka Sandstone.

Lithology: The Colalura Sandstone consists mainly of coarse-grained sandstone, with minor intercalations of claystone, siltstone, and shale. The sandstone is commonly conglomeratic, ranging from dark brown to yellow white in colour. The cement is usually ferruginous, but is calcareous in some localities where it has not been affected by lateritization. A characteristic feature of most exposures is the presence of abundant fossil wood (Fig. 35), and to a lesser extent of oval-shaped ferruginous nodules, which are generally about 2 cm long. The wood ranges in size from the smallest fragments up to logs 1 m long. The nodules and some of the fossil wood are phosphatic at a few localities (including the Bringo cutting), but in most cases the phosphate has been replaced by iron oxide, apparently under the influence of lateritization.

Details of the petrology and mineralogy of the formation are given by P. E. Playford (1959). He concludes that the clastic constituents of the unit are largely derived by reworking of the underlying sediments and Precambrian rocks.

Stratigraphic relationships: The Colalura Sandstone disconformably overlies the Moonyoonooka Sandstone. However, in some areas where the Moonyoonooka Sandstone has pinched out against buried hills, it rests unconformably on Precambrian rocks. The Colalura Sandstone is overlain conformably by either the Bringo Shale or the Newmarracarra Limestone.

Distribution and thickness: The Colalura Sandstone is a thin, discontinuous, but persistent marker horizon at the base of the marine Middle Jurassic sequence of the Geraldton area. It extends from near Howatharra in the north to Mount Hill in the south, and has been recognized as far east as Sandspring property.

The thickest section of the formation that has been measured is 8.5 m thick, but it is generally only about 0.5 m thick. As the sandstone is generally well cemented it is typically well exposed in the form of large slabs.

Fossils and age: Fossil wood is very abundant in the Colalura Sandstone, but it has not been studied in detail. At a few localities, and especially in the Bringo cutting, the Colalura Sandstone contains marine fossils, which are preserved as moulds. P. E. Playford (1959) records the following molluscs:

Bivalvia
- *Astarte (Astarte) cliftoni* Moore
- *A.* sp.
- *Ctenostreon pectiniformis* (Schlothem)
- *Isognomon* sp.
- *Lopha* sp. cf. *L. marshii* (Sowerby)
- *Ostrea* sp.
- *Oxytoma (Oxytoma)* sp. cf. *O.* (*O.*) *decemcostata* Whitehouse
- *Trigonia moorei* Lycett

Coleoidea
- *Belemnopsis* sp.

There are also several unidentified species of bivalves and gastropods, while an echinoid spine, a shark tooth, a reptilian tooth, and a reptilian vertebra have been found in the Bringo cutting.

All the fossils identified in the Colalura Sandstone also occur in the Newmarracarra Limestone, and the Colalura Sandstone is accordingly regarded as being of Bajocian age.

Environment of deposition: The Colalura Sandstone was laid down as the basal shallow-water deposit of a marine transgression. The clastic constituents were largely derived by reworking from the Moonyoonooka Sandstone and weathered Precambrian rocks. Large quantities of fossil wood were incorporated in the sediment, and the environment may have been that of a vegetated paralic swamp. Deposition of both phosphate nodules and/or iron oxide occurred while the formation was accumulating.

Bringo Shale

Definition: The name Bringo Shale was introduced by Playford (1953) and was first published by Arkell and Playford (1954) for the unit of black shale lying between the Colalura Sandstone or Precambrian rocks and the Newmarracarra Limestone. The type section is in the Bringo railway cutting (lat. 28° 44′ 54″S, long. 114° 50′ 54″ E). The following is a description of this section (from P. E. Playford, 1959):

Newmarracarra Limestone, conformably overlying— *Bringo Shale* (2.1 m)	Thickness (metres)
5. Shale, black, grading to yellow in the uppermost 30 cm, phosphatic nodules resting on top; several layers containing small bivalves	0.76
4. Claystone, yellowish-brown, phosphatic, concretionary	0.05
3. Shale, black; rich in small bivalves	0.15
2. Claystone, yellowish-brown, phosphatic, concretionary	0.1
1. Shale, black; abundant small bivalves at the base	1.0

Conformably overlying Colalura Sandstone.

Lithology: The Bringo Shale consists of black shale with some thin yellow phosphatic bands, and a bed with phosphatic nodules near the top of the unit. The phosphatic bands are concretionary, and do not exceed 10 cm in thickness, while the nodules are rounded irregular bodies up to 15 cm long.

Stratigraphic relationships: The Bringo Shale rests conformably between the Colalura Sandstone and the Newmarracarra Limestone. In a few areas it rests directly on Precambrian rocks. The Bringo Shale commonly contains a band of phosphatic nodules at the contact with the Newmarracarra Limestone. This may indicate a brief interval of non-deposition, although otherwise the two formations seem to be quite conformable.

Distribution and thickness: The Bringo Shale has a limited distribution. It is exposed in small areas around Bringo and Sandspring and is known in the subsurface in the Eradu area and possibly south of there. The type section is 2.1 m thick, and the thickness ranges from 1.5 to 2.4 m in the outcrop area. In the subsurface the maximum thickness probably exceeds 10 m.

Fossils and age: Fossils have only been found in the type area of the Bringo Shale. They consist of small bivalves, including species of *Ostrea* and *Meleagrinella*, rare gastropods and *Belemnopsis* guards (P. E. Playford, 1959). The following microflora has been recorded by Balme (1957):

Spores and pollen

Araucariacites australis Cookson
Classopollis classoides (Pflug)
C. sp.
Cyathidites australis rimalis Balme
C. sp. cf. *C. minor* Couper
Gleicheniidites sp. cf. *G. circinidites* Cookson
Laevigatosporites sp. cf. *L. neddeni* (R. Potonié)
Lycopodiumsporites austroclavatiidites (Cookson)
Microcachryidites antarcticus Cookson
Pityosporites sp. cf. *P. ellipticus* (Cookson)
P. pallidus (Reissinger)
Podosporites micropteris (Cookson and Pike)
Zonalapollenites dampieri Balme

The fossils and stratigraphic relations of the formation indicate that it is of Bajocian age.

Environment of deposition: The Bringo Shale was laid down under shallow-water conditions with restricted circulation. It seems to be confined to areas east of ridges of Precambrian rocks, which acted as bars to free water circulation.

NEWMARRACARRA LIMESTONE

Definition: The Newmarracarra Limestone was first named by Glauert (1926) as the "Newmarracarra Beds". This was amended to Newmarracarra Limestone by Playford (1953) and this name was published by Arkell and Playford (1954). It is named after the historic Newmarracarra property, one of the first to be established in the Geraldton area. The type section is at Round Hill (lat. 28° 45′ 31″S, long. 114° 48′ 23″E), and the following is a description of this section:

Kojarena Sandstone, conformably overlying—

Newmarracarra Limestone (10 m)	Thickness (metres)
4. Limestone, light-yellow-grey, sandy, hard, massive, outcropping in large slabs; few fossils	0.6
3. Limestone, light-yellow-grey, weathering greyish-white, hard, massive, outcropping as large slabs; richly fossiliferous	2.4
2. Limestone, light-yellow-grey, clayey, soft, massive; richly fossiliferous	6.4
1. Limestone, light-yellow-grey, sandy, clayey, hard, massive, outcropping as large slabs; richly fossiliferous	0.6

Disconformably overlying Moonyoonooka Sandstone.

Lithology: The Newmarracarra Limestone, where unaffected by laterization, usually consists of limestone composed of entire or little-broken shells. It is commonly sandy, and rarely grades into calcareous sandstone. The limestone is hard, massive, and crudely bedded, typically cropping out as large slabs. In colour it ranges from yellow and grey to bright red. The mineralogy of the limestone is discussed by Playford (1953, 1959).

The formation is extensively altered where it occurs in the zone of weathering below laterite. This results in the complete removal from the rock of calcium carbonate, which is either replaced by iron oxide (mainly hematite) or is simply leached, leaving a residue of its clastic impurities. The leached zone is commonly present between the hematite-rich rock and the unaltered limestone and this can be seen clearly in the Bringo cutting. Further details concerning the alteration of the Newmarracarra Limestone are given by Playford (1953, 1959).

Stratigraphic relationships: The Newmarracarra Limestone rests conformably on the Bringo Shale or the Colalura Sandstone, disconformably on the Moonyoonooka Sandstone, or unconformably on Precambrian rocks. It is overlain conformably by the Kojarena Sandstone or with apparent conformity by the Yarragadee Formation.

Distribution and thickness: The Newmarracarra Limestone extends from near Howatharra to Mount Hill and as far east as the Wicherina area. Exposures of unaltered limestone are rather limited, as the formation is usually decalcified near the surface under the influence of lateritization. The best ouctrops are in the Bringo-Moonyoonooka area.

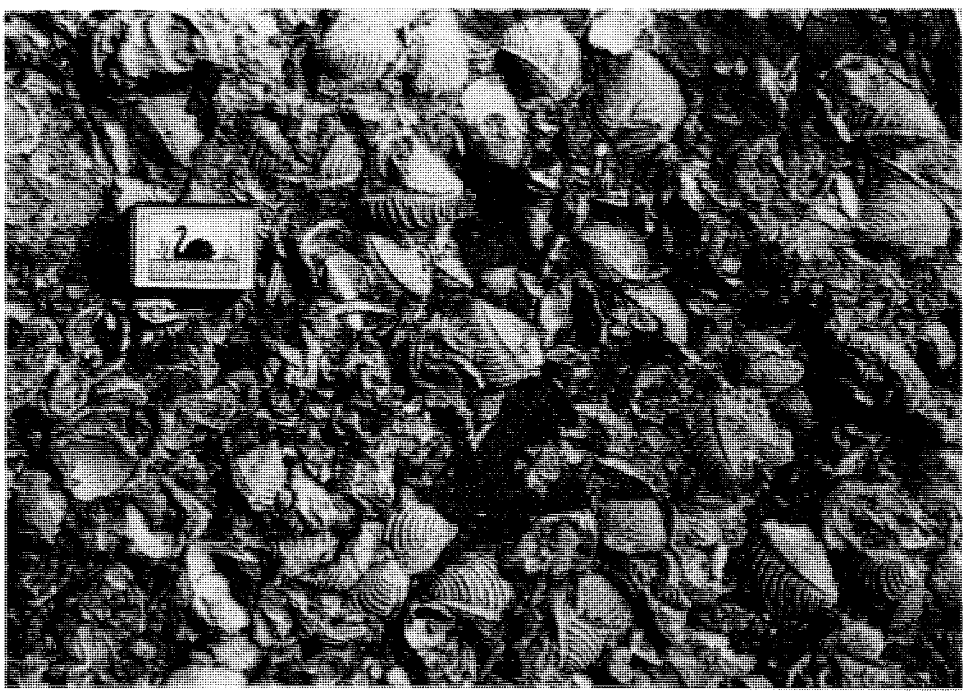

Figure 36. Slab of Newmarracarra Limestone with abundant *Trigonia moorei,* on Moonyoonooka property. This specimen is now in the museum of the Geology Department, University of Western Australia.

The thickest section of the formation that has been measured is 11.5 m thick, on Moonyoonooka property. In the Geraldton Racecourse Bore the unit may be 14.3 m thick. Drilling has shown that in the Allanooka, Mount Hill, and Bookara areas, section equivalent to the Newmarracarra Limestone includes substantial thicknesses of shale and siltstone. South of there the amount of terrigenous sediment increases progressively at the expense of limestone, and south of Mount Hill the equivalent section is considered to be part of the Cadda Formation. A small exposure correlated with the Newmarracarra Limestone by Coleman and Skwarko (1967) occurs in a fault wedge within the Urella Fault Zone at Enanty Hill near Mingenew. However, this exposure may be better regarded (on regional grounds) as being part of the Cadda Formation.

Fossils and age: The Newmarracarra Limestone contains the richest and best preserved fossil invertebrate fauna known from the Perth Basin. Molluscs dominate the fauna, the most common form being the bivalve *Trigonia moorei* which forms some coquinoid beds (Fig. 36). The ammonites and some of the bivalves have been monographed in recent years, but much of the rest of the fauna needs to be redescribed, and this is reflected in the taxonomy of some of the groups in the following fossil list:

Foraminiferida (Moore, 1870; Chapman, 1904a)

Bulimina gregorii Chapman
Cristellaria costata var. *compressa* Chapman
C. costata var. *seminuda* Chapman
C. cultrata Montfort
C. daintreei Chapman
C. decipiens Wisniowski
C. sp. cf. *C. limata* Schwager
C. prominula Reuss
C. rotulata (Lamarck)
C. subulata Reuss
Discorbina rosacea (d'Orbigny)
Flabellina dilatata Wisniowski
Haplophragmium neocomianum Chapman
Marginulina compressa d'Orbigny
M. solida Terquem
Polymorphina burdigalensis d'Orbigny
P. compressa d'Orbigny
P. gutta d'Orbigny
Textularia crater Chapman
Truncatulina wuellerstorfi (Schwager)
Vaginulina intumescens Reuss
V. lata (Cornuel)
V. schloenbachi var. *interrupta* Chapman
V. strigillata Reuss

Bryozoa (Whitehouse, 1924)

Berenicea sp. cf. *B. archiaci* Haime

Brachiopoda (Clarke, 1867; Moore, 1870; Etheridge Jr., 1910)

Rhynchonella variabilis Schlotheim
R. spp.

Bivalvia (Clarke, 1867; Moore, 1870; Etheridge Jr., 1901, 1910; Chapman, 1904b; Maitland, 1907; Glauert, 1910b; Whitehouse, 1924; Teichert, 1940; P. E. Playford, 1959; Skwarko, 1974)

Amphidonta tholiformis (Etheridge Jr.)
A. sp. cf. *A. tholiformis* (Etheridge Jr.)
Astarte (Astarte) apicalis Moore

A. (*A.*) *cliftoni* Moore
A. (*A.*) *tibraddeni* Skwarko
Camptonectes greenoughi Skwarko
"*C.*" *waggrakinensis* Skwarko
Chlamys enantyi Skwarko
Ctenostreon pectiniformis (Schlotheim)
Cucullaea geraldtoni Skwarko
C. inflata Moore
C. semistriata Moore
Gresslya? *sanfordii* (Moore)
Gryphaea sp. indet.
Isognomon (*Isognomon*) sp. indet.
Lopha marshii australiensis Skwarko
L. marshii newmarracarrensis Skwarko
Martesia (*Particoma*) *australis* (Moore)
Meleagrinella sinuata (Teichert)
Modiolus (*Modiolus*) *maitlandi* Etheridge Jr.
nuculid indet.
Oxytoma (*Oxytoma*) *decemcostata* Whitehouse
Parallelodontidae spp.
Parvamussium? *geelvinki* Skwarko
Plagiostoma championi Skwarko
Pseudolimea duplicata (Sowerby)
Tancredia (*Tancredia*) *sandspringi* Skwarko
Trigonia moorei Lycett

The above bivalves have all been redescribed by Skwarko (1974). P. E. Playford (1959) records the following additional forms:

Arca sp.
Avicula inaequalis Sowerby
Cardium sp.
Cypricardia sp.
Gresslya donaciformis (Phillipi)
Hinnites sp.
Isocardia sp.
Lima punctata (Sowerby)
Lucina sp.
Myacites liassianus (Quenstedt)
Mytilus sp. cf. *M. gygerensis* (d'Orbigny)
M. sp.
Opis sp.
Panopea rugosa (Moore)
P. sp.
Pecten calvus (Goldfuss)
P. sp. cf. *P. frontalis* (Dumortier)
P. greenoughensis Moore
P. valoniensis (Defrance)
P. spp.
Perna sp.
Pholadomya ovalum (Agassiz)
Plicatula sp.
Tancredia sp.
Unicardium sp.

Gastropoda (Clarke, 1867; Moore, 1870; Etheridge, Jr., 1910; Glauert, 1910b; P. E. Playford, 1959)

Amberleya sp.
Cerithium greenoughensis Moore
C. sp.
Chemnitzia sp.
Nerinea sp.
Phasianella sp.
Pleurotomaria greenoughensis Etheridge Jr.
P. sp.
Rissoina australis Moore
Trochus sp.

Turbo australis Moore
T. laevigatus Sowerby
T. sp.

Nautiloidea (Crick, 1894)
Nautilus perornatus Crick

Ammonoidea (Moore, 1870; Neumayr, 1885; Crick, 1894; Chapman, 1904b; Etheridge Jr., 1910; Whitehouse, 1924; Spath, 1939; Arkell and Playford, 1954)
Fontannesia clarkei (Crick)
F. fairbridgei Arkell
F. whitehousi Arkell
F. n. sp. indet.
Otoites antipodus Arkell
O.? australis (Crick)
O. (Trilobiticeras?) depressus Whitehouse
O. woodwardi (Crick)
Pseudotoites brunnschweileri Arkell
P. championensis (Crick)
P. emilioides Arkell
P. fasciculatus Arkell
P. leicherti (Neumayr)
P. robiginosus (Crick)
P. semiornatus (Crick)
P. spitiformis Arkell
Sonninia playfordi Arkell
Stemmatoceras sp. cf. *S. subcoronatum* (Oppel)
S. sp. aff. *S. triptolemus* (Morris and Lycett)
Witchellia australica Arkell
Zemistephanus armatus Arkell
Z. corona Arkell

Scaphopoda (Clarke, 1867)
Dentalium sp.

Coleoidea (Clarke, 1867; Moore, 1870; Crick, 1894; Glauert, 1910b; Whitehouse, 1924)
Belemnites canaliculatus Schlotheim
B. canhami Tate
Belemnopsis sp.

Annelida (Clarke, 1867; Moore, 1870; Etheridge Jr., 1910)
Serpula conformis Goldfuss
S. spp.

Ostracoda (Chapman, 1904a; Kellett and Gill, 1956)
"Cythere" lobulata Chapman
"Cytheropteron" australiense Chapman
"Loxoconcha" elongata Chapman
"L." jurassica Chapman
Paradoxorhyncha foveolata Chapman
Procytheridea fortior (Chapman)

Echinoidea (Whitehouse, 1924)
Cidaris sp.

Since Neumayr's (1885) publication, the Newmarracarra Limestone has been recognized as being of Middle Bajocian age. However, whether all three zones of the Middle Bajocian (Sowerbyi, Sauzei and Humphresianum, in ascending order) are represented is uncertain. Neumayr (1885) and Arkell (1949) preferred a Humphresianum Zone dating, whilst Spath (1939) supported a Sauzei Zone age. Arkell (*in* Arkell and Playford, 1954) stated that ". . . the main ammonite assemblage of the Newmarracarra Limestone falls into the Sowerbyi Zone, and there is no longer any definite evidence for the Sauzei Zone".

The presence of *Stemmatoceras* suggests ". . . a still incompletely known representation of the Humphresianum Zone . . ." (Arkell *in* Arkell and Playford, 1954, p. 594).

Playford's range chart (*in* Arkell and Playford, 1954, Fig. 2) would suggest a subdivision of the Sowerbyi Zone into an upper subzone with, for example, *Pseudotoites leicharti* and *P. semiornatus*, and a lower subzone with, for example, *Fontannesia clarkei* and *Pseudotoites emilioides*. However, these subzones may be of only local significance because *Pseudotoites semiornatus* and *P. emilioides* apparently occur together in the same horizon in the Cadda Formation.

Environment of deposition: The Newmarracarra Limestone was laid down on the bottom of a warm, shallow sea. It is made up largely of the remains of thick-shelled, shallow-water benthonic molluscs. Currents introduced some sand, silt, and clay, but the fact that the shells show little abrasion, and the bivalve shells are often closed, indicates that the currents were generally not strong.

The conditions of restricted circulation in some areas which accompanied deposition of the Bringo Shale evidently disappeared when the Newmarracarra Limestone was laid down, possibly owing to a relative rise in sea level.

KOJARENA SANDSTONE

Definition: The name Kojarena Sandstone was introduced by Playford (1953) and was published by Arkell and Playford (1954). The limits of the formation were revised by Playford and Willmott (*in* McWhae and others, 1958) and by P. E. Playford (1959) so as to exclude section that is now placed in the Yarragadee Formation. The formation is named after Kojarena Siding and the type section is in the Bringo cutting (lat. 28° 44′ 54″S, long. 114° 50′ 54″E). The following is a description of this section (after P. E. Playford, 1959):

Yarragadee Formation, conformably overlying—

	Thickness (metres)
Kojarena Sandstone (10.1 m)	
2. Sandstone, reddish-brown, the lower half being mottled grey, brown, and yellow; bedding indistinct; marine fossils in a lens up to 15 cm thick, 5.8 m above the base	9.5
1. Claystone, greyish-white, mottled red; poorly bedded	0.6

Conformably overlying Newmarracarra Limestone.

Lithology: The Kojarena Sandstone consists predominantly of red-brown ferruginous sandstone, with a little claystone in some places, especially at the base. The sandstone is medium to coarse-grained, and is generally very well sorted. The unit is usually poorly bedded to massive, and cross-bedding is sometimes developed. Further details of the petrology and mineralogy are given by Playford (1953, 1959).

Stratigraphic relationships: The Kojarena Sandstone conformably overlies the Newmarracarra Limestone and is overlain by the Yarragadee Formation with apparent conformity. East of the Northampton Block the Kojarena Sandstone conformably overlies the Bringo Shale in some areas (for example, around Bringo), while in others it unconformably overlies the Kockatea Shale or Permian rocks.

Distribution and thickness: The Kojarena Sandstone is the most widely distributed unit of the Champion Bay Group. It crops out on the west side of the Northampton Block from near Howatharra to Mount Hill. On the east side of the block it is exposed along the valley of the Greenough River north and south of Eradu, and may extend almost as far east as the Darling Fault. The thickest development is probably around Eradu, amounting to some 34 m. In the Geraldton area it probably does not exceed 10 m in thickness.

Fossils and age: The Kojarena Sandstone contains few fossils. The best fossils in the formation have been found in the Bringo cutting, where they occur in a thin bed near the middle of the section. The following forms have been identified:

Bivalvia (P. E. Playford, 1959; Skwarko, 1974)
- **Astarte* (*Astarte*) *apicalis* Moore
- *Camptonectes* sp. cf. *C. rigidus* (Sowerby)
- **Cucullaea inflata* Moore
- *Falcimytilus* sp.
- *Grammatodon* (*Indogrammatodon*) *carnarvonensis* Skwarko
- *Tancredia* (*Isotancredia*) *kojarena* Skwarko
- **Trigonia moorei* Lycett

Coleoidea (P. E. Playford, 1959)
- **Belemnopsis* sp.

The forms marked with an asterisk also occur in the conformably underlying Newmarracarra Limestone, and the Kojarena Sandstone is accordingly regarded as being of Bajocian age. Burrows and wood fragments also occur in the unit.

Environment of deposition: The Kojarena Sandstone is thought to be a shallow-marine deposit. The high degree of sorting indicates that it was deposited above wave-base, probably close to the shoreline. It represents the final phase of the Middle Jurassic marine cycle.

YARRAGADEE FORMATION

Definition: The name "Yarragadee Beds" was introduced by Fairbridge (1953) for exposures of sandstone and siltstone on Yarragadee property, 12 km north of Mingenew. The name was changed to Yarragadee Formation by Playford, Willmott, and McKellar (*in* McWhae and others, 1958). The type locality is 2.4 km south-southeast of Yarragadee homestead (lat. 29° 05′ 48″S, long. 115° 24′ 50″E). However, this section is thin and faulted, and Playford and Willmott (*in* McWhae and others, 1958) therefore designated two reference sections, 1.6 km north of Cantabilling homestead in the Hill River area, and in the Bringo cutting. A subsurface reference section may be taken as that in Gingin No. 1 well from 188 to 3 315 m.

The section in the Bringo cutting is very thin, but it includes most of the characteristic rock types in the unit. The following is a description of this section (from Playford and Willmott, 1958):

Yarragadee Formation (15.5 m) Top of formation not exposed; overlain by soil.	Thickness (metres)
13. Sandstone, silty, coarse-grained, light-yellow-brown, poorly sorted	0.3
12. Claystone, white, unbedded, lenticular	0.15
11. Sandstone, silty, coarse-grained, light-yellow-brown, unbedded, poorly sorted	0.6
10. Claystone, silty, white, unbedded; contains rare cannon-ball concretions; lenticular	0.45
9. Sandstone, silty, coarse-grained, conglomeratic in part, light-yellow-brown, unbedded, poorly sorted; quartz grains subangular	2.4
8. Claystone, greyish-white, unbedded, lenticular	0.3
7. Sandstone, medium-grained, yellow-brown, well-sorted, unbedded; quartz grains subangular; contains a few dark-brown cannon-ball concretions	0.9
6. Siltstone, sandy, with some interbedded fine-grained silty sandstone and claystone; variegated yellow, white, and red, thinly bedded, partly cross-bedded; contains some thin ferruginous bands and cannon-ball concretions	1.9
5. Shale, silty in part, grey, grading into white to light-grey siltstone; contains a few thin jarositic bands	1.7
4. Siltstone, sandy, white to yellowish-white, thinly bedded to fissile, grading into fine-grained silty sandstone; contains thin beds of grey claystone, which is partly carbonaceous	1.8
3. Claystone, dark-grey, carbonaceous, grading into siltstone; poorly bedded, containing carbonaceous wood fragments; yellow jarositic beds, irregular in shape, are present; an efflorescence of minute gypsum crystals is present in places	1.7
2. No exposure, due to channel filled with alluvium	1.2
1. Claystone, sandy, silty, greyish-white to grey, mottled pink, poorly bedded, weathered; contains few thin yellow-brown ferruginous beds	2.1

Conformably overlying Kojarena Sandstone.

Two members, the Quinns Shale Member and Otorowiri Siltstone Member are recognized in the upper (Neocomian) part of the formation.

The *Quinns Shale Member* (Bozanic, 1969b), is a well-defined shale unit recognized in the upper part of the Yarragadee Formation in offshore wells between Quinns Rock No. 1 in the north and Sugarloaf No. 1 in the south. It is a strong seismic reflector. The type section is between 1 590 and 1 647 m in Quinns Rock No. 1 well.

The *Otorowiri Siltstone Member* of Ingram (1967a) is recognized in some of the Arrowsmith River and Eneabba water bores in the northern Dandaragan Trough. The type section is in Arrowsmith River No. 25 bore between 253 and 277 m. The member consists predominantly of dark-grey to greenish-grey micaceous siltstone. In some parts it is shaly, sandy, glauconitic, and pyritic.

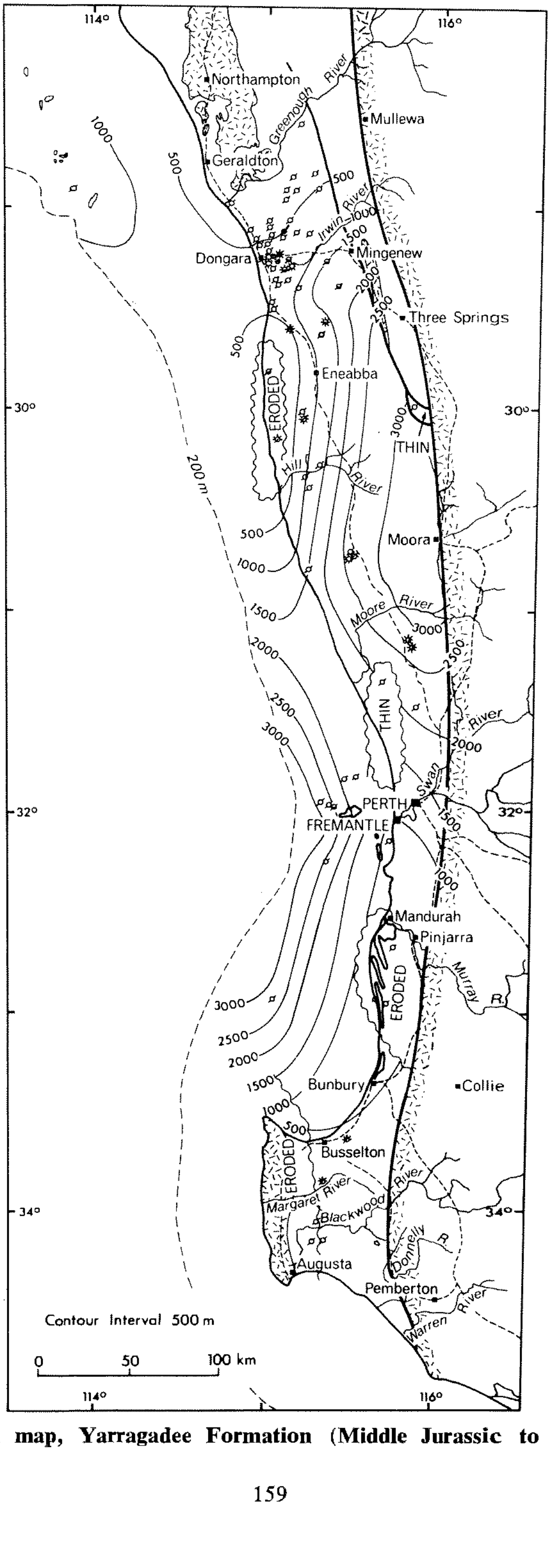

Figure 37. Isopach map, Yarragadee Formation (Middle Jurassic to Lower Cretaceous).

Lithology: The Yarragadee Formation is an interbedded sequence of sandstone and siltstone with lesser amounts of shale, claystone, and conglomerate. The sandstones are generally poorly sorted, and range from very coarse to very fine grained. They are usually poorly bedded, although cross bedding is present locally. The siltstones are generally thin bedded to fissile. Mottled red, yellow, and white colouring is characteristic of the formation at the surface, but in the subsurface it is commonly light to dark grey, with some white and brown beds.

Individual units in the formation are lenticular, with various rock types interfingering in intricate fashion. Differential compaction of shale and siltstone over sandstone lenses results in undulating dips in many areas.

Stratigraphic relationships: Throughout much of the Perth Basin the Yarragadee Formation overlies the Cockleshell Gully Formation or the Cadda Formation conformably, and is overlain unconformably (commonly with an angular relationship) by the Warnbro Group. The formation includes the "Warren River Sandstone", "Blackwood Shale", "Fly Brook Shale", and "Claremont Sandstone" of Fairbridge (1953).

In the Geraldton area the formation usually overlies the Kojarena Sandstone with apparent conformity, but in some localities it rests directly on the Newmarracarra Limestone, and it is not clear whether the absence of Kojarena Sandstone at such localities is due to erosion or to non-deposition. Around Geraldton the formation is overlain by Quaternary deposits.

Distribution and thickness: The Yarragadee Formation is one of the most widespread stratigraphic units in the Perth Basin. It is exposed discontinuously in the northern part of the basin and occurs in the subsurface throughout most of the central and southern parts. Individual exposures are rarely thicker than 30 m. However, the maximum thickness of the unit exceeds 3 000 m. The thickest section drilled to date is in Gingin No. 1 well, amounting to 2 965 m. An isopach map of the formation is shown as Figure 37.

Fossils and age: Plant fossils, especially spores and pollen, are the dominant fossils in the Yarragadee Formation.

Spores and pollen (Balme *in* Smith, 1967; Ingram, 1967b; Balme *in* Bozanic, 1969a, 1969b; Ott *in* Moyes, 1971b, 1971c; Williams *in* Bird and Moyes, 1971a; Williams *in* Moyes, 1971a)

Aequitriradites hispidus Dettmann and Playford	1*			
A. spinulosus (Cookson and Dettmann)	1	2*		
A. verrucosus Cookson and Dettmann	1			4*
Alisporites grandis (Cookson)	1			4
A. similis (Balme)	1			4
A. spp.	1			4
Araucariacites australis Cookson	1		3*	4
Ceratosporites equalis Cookson and Dettmann	1		3	
Cicatricosisporites australiensis (Cookson)	1	2		
C. hughesi Dettmann	1			
C. ludbrooki Dettmann	1			4
Cingulatisporites saevus Balme	1			4
Circulisporites sp.	1			
Classopollis classoides (Pflug)	1		3	4

Contignisporites cooksoni (Balme)	1	2	3	4
C. glebulentus Dettmann	1	2		4
C. multimuratus Dettmann	1		3	4
Coronatispora perforata Dettmann	1		3	4
C. telata (Balme)	1			
Cyathidites australis Couper	1			4
C. concavus (Bolkovitina)	1			
C. minor Couper	1			4
Cycadopites follicularis Wilson and Webster	1			4
C. nitidus (Balme)				4
Dictyophyllidites crenatus Dettmann		2		
D. mortoni (de Jersey)				4
Dictyotosporites complex Cookson and Dettmann	1	2		4
D. speciosus Cookson and Dettmann	1		3	
Duplexisporites gyratus Playford and Dettmann	1			
Foraminisporis asymmetricus (Cookson and Dettmann)	1			
F. dailyi (Cookson and Dettmann)	1			
Foveosporites canalis Balme	1			4
F. parviretus (Balme)	1			4
Gleicheniidites circinidites (Cookson)	1			4
G. senonicus Ross			3	
G. sp.				4
Granulatisporites sp.				4
Inaperturopollenites turbatus Balme	1		3	4
Ischyosporites crateris Balme	1	2		4
I. punctatus Cookson and Dettmann	1			4
I. sp. cf. *I. punctatus* Cookson and Dettmann		2		
Januasporites sp.	1			
Klukisporites scaberis (Cookson and Dettmann)	1			4
Kuylisporites lunaris Cookson and Dettmann	1			
Laevigatosporites n. sp.		2		
Leiotriletes sp.				4
Leptolepidites major Couper	1			
L. verrucatus Couper	1			4
Lycopodiacites asperatus Dettmann				4
Lycopodiumsporites austroclavatiidites (Cookson)	1			4
L. circolumenus Cookson and Dettmann	1		3	4
L. nodosus Cookson and Dettmann	1			4
L. spp.	1			4
Matonisporites crassiangulatus (Balme)	1	2		4
M. sp. cf. *M. phlebopteroides* Couper		2		
Microcachryidites antarcticus Cookson	1		3	4
Murospora florida (Balme)	1	2		4
Neoraistrickia truncatus (Cookson)	1		3	4
Nevesisporites vallatus de Jersey and Paten	1			4
Osmundacidites comaumensis (Cookson)	1			4
Perotriletes sp. aff. *P. rugulatus* Couper	1			
Pilosisporites notensis Cookson and Dettmann	1	2		
Podocarpidites ellipticus (Cookson)	1			4
Podosporites sp.				4
Polypodiidites sp. aff. *P. spinosus* (Khlonova)	1		3	
Punctatisporites sp.				4
Reticulatisporites pudens Balme	1			
Sestrosporites pseudoalveolatus (Couper)	1			4
Staplinosporites caminus (Balme)	1			4
Stereisporites antiquasporites Wilson and Webster				4
Triletes sp. cf. *T. tuberculiformis* Cookson	1			
Trilobosporites antiquus Reiser and Williams				4
T. pulverulentus (Verbitskaya)		2		
T. sp. cf. *T. tribotrys* Dettmann		2		
Vitreisporites pallidus (Reissinger)				4
Zonalapollenites dampieri Balme	1		3	4
Z. segmentatus Balme	1		3	4
Z. trilobatus Balme	1			

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Microplankton (same references as above)

	1	2	3	4
Baltisphaeridium sp.	1			
B. hirsutum (Ehrenberg)		2		
Canningia sp.		2		
Gonyaulax sp.		2		
Horologinella sp.	1		3	
Komewuia sp.			3	
Leiofusa jurassica Cookson and Eisenack			3	
Leiosphaeridia spp.	1		3	4
Micrhystridium sp.	1			4
Palaeostromocystis sp.	1			
cf. *Pterodinium* sp.	1			
Pterospermopsis australiensis Deflandre and Cookson		2		
Schizosporis sp.				4
cf. *Tenua* sp.				4
Veryhachium sp.				4

*1. Neocomian part of Yarragadee Formation

*2. Otorowiri Siltstone Member

*3. Quinns Shale Member

*4. Middle and Upper Jurassic part of Yarragadee Formation

(1, 2, and 3 belong to the *Microcachryidites* assemblage; 4 belongs to the *Dampieri* assemblage).

Plant macrofossils (Arber, 1910; Glauert, 1910c; Walkom, 1921, 1944, 1957; Walkom *in* McWhae and others, 1958)

Araucarites cutchensis Feistmantel
Brachyphyllum expansum (Sternberg)
Cladophlebis australis (Morris)
C. sp.
Elatocladus plana (Feistmantel)
Gleichenites sp.
Isoetites elegans Walkom
Otozamites bechei Brongniart
O. bengalensis (Morris)
O. sp. cf. *O. bunburyanus* Zigno
O. feistmanteli Zigno
O. sp.
Pagiophyllum sp.
Ptilophyllum pecten (Phillips)
P. sp.
Retinosporites indica Feistmantel
Taeniopteris spatulata McClelland
Thinnfeldia talbragarensis Walkom
T. sp.

Bivalvia (Cockbain, 1967)

unionacean, genus and species indet.

In addition to the microflora listed above, the Otorowiri Siltstone Member contains the following remanié forms:

Spores and pollen (Ingram, 1967b)

1. Middle to Late Triassic forms
   Guthoerlisporites cancellosus Playford and Dettmann
   Polycingulatisporites crenulatus Playford and Dettmann

2. Early Triassic forms
   Kraeuselisporites cuspidus Balme
   Lundbladispora playfordi Balme
   L. willmotti Balme
   Osmundacidites senectus Balme
   Taenisporites noviaulensis Leschik

3. Late Permian forms
Acanthotriletes villosus Balme and Hennelly
Dulhuntyispora dulhuntyi R. Potonié
D. parvithola (Balme and Hennelly)
Marsupipollenites sinuosus Balme and Hennelly

4. Early Permian and undifferentiated Permian forms
Kraeuselisporites sp.
Nuskoisporites sp.
"Striatites" sp.

5. Devonian forms
Emphanisporites sp.
?*Geminospora* sp.
Leiozonotriletes carnarvonensis Balme
Punctatisporites sp.

Microplankton (Ingram, 1967b)

1. Late Jurassic forms
Dingodinium jurassicum Cookson and Eisenack
Wanea clathrata Cookson and Eisenack

2. Early Triassic forms
Leiosphaeridia spp.
Micrhystridium spp.
?*Spheripollenites* sp.
Veryhachium (?*Wilsonastrum*) spp.

The microflora of the Yarragadee Formation belong to the *Dampieri* and *Microcachryidites* assemblages of Balme (1964a) which are of Middle to Late Jurassic and ?Tithonian to Aptian age respectively. The unconformably overlying Warnbro Group can be dated as late Neocomian to Aptian, and hence the top of the Yarragadee Formation is no younger than early Neocomian. The Otorowiri Siltstone Member and Quinns Shale Member contain a *Microcachryidites* assemblage and the Jurassic-Cretaceous boundary is taken at the base of the Quinns Shale Member.

Environment of deposition: The greater part of the Yarragadee Formation is believed to be a fluviatile deposit. The Darling and Urella Faults were strongly active during the Jurassic, and the uplifted blocks east of the faults are thought to have been the source of much of the sediment making up the formation. The upper (Lower Cretaceous) part of the unit was laid down in shallow-marine, paralic, and continental environments.

CRETACEOUS

Cretaceous sedimentary rocks are widespread at or near the surface over a large part of the Perth Basin, but exposures are generally poor. Cretaceous rocks are also known from wells drilled on the continental shelf and from deep sea drilling sites DSDP 259 on the continental rise and DSDP 258, DSDP 264, and RC 8-56 on the Naturaliste Plateau (Fig. 38).

An important unconformity is present within the Lower Cretaceous (Neocomian) sequence, separating the Yarragadee Formation below from the Warnbro Group above. The Warnbro Group is overlain disconformably by the Coolyena Group.

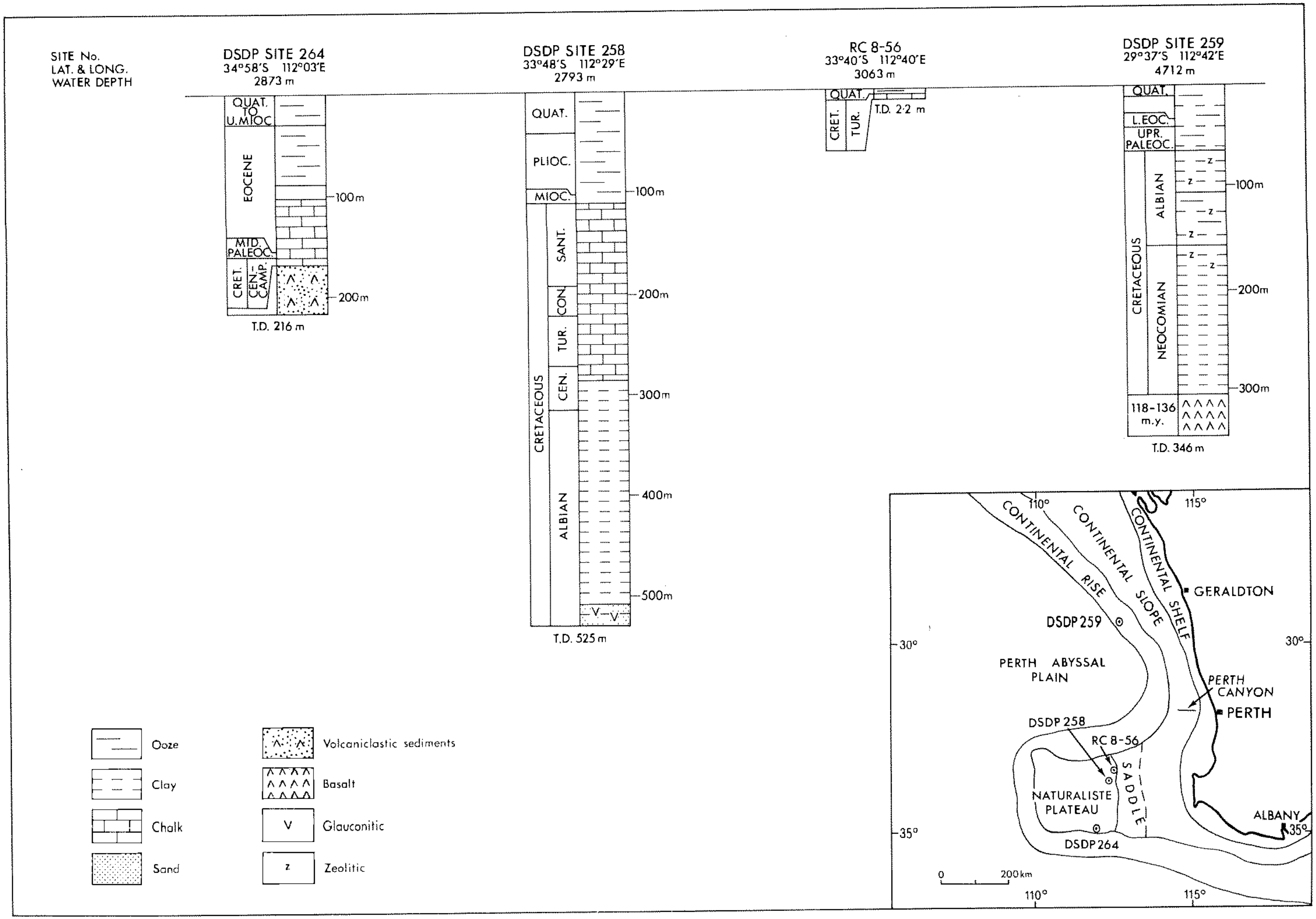

Figure 38. Sections encountered in deep-sea holes drilled on the ocean floor off the southwest coast of Western Australia.

Two isolated units in the southern part of the Perth Basin, the Donnybrook Sandstone and the Maxicar Beds, are probably equivalent to parts of the Warnbro Group.

The total thickness of Cretaceous rocks in the basin is known to be at least 3 100 m (from outcrop information and drilling), but seismic evidence suggests that the thickness could be as great as 12 000 m on the continental shelf west of Perth.

YARRAGADEE FORMATION

The Yarragadee Formation has already been described in the Jurassic section of this bulletin. The formation extends up into the Neocomian, and two named members (the Quinns Shale and Otorowiri Silstone Members) are of this age. The Cretaceous part of the formation ranges from continental to paralic and shallow marine in origin.

WARNBRO GROUP

The name Warnbro Group was proposed by Cockbain and Playford (1973) for the continental to shallow-marine Lower Cretaceous sequence that unconformably overlies the Yarragadee Formation or older units in the Perth Basin. It comprises the South Perth Shale, Leederville Formation, and Dandaragan Sandstone. A structure contour map drawn on the base of the group is shown as Figure 48; north of lat. 28° 30′S, the contours have been drawn on the base of the Winning Group which is the age equivalent of the Warnbro Group in the Carnarvon Basin.

SOUTH PERTH SHALE

Definition: The name South Perth Shale was introduced by Fairbridge (1953) for the Lower Cretaceous sequence of shale, with lesser thicknesses of sandstone and siltstone, that was encountered in bores drilled in the Perth metropolitan area. McWhae and others (1958) later amended the "South Perth Formation" to include Fairbridge's South Perth Shale and "Leederville Sandstone", as they considered it impracticable to separate the two units. However, more recent work has shown that the South Perth Shale and Leederville Formation can indeed be recognized as separate formations in the central Perth Basin, even though the boundary between them is generally transitional.

The type section of the South Perth Shale is in the South Perth No. 1 bore (lat. 31° 59′S, long. 115° 51′E), between 498 and 567 m (the base of the bore). The following is a description of this section:

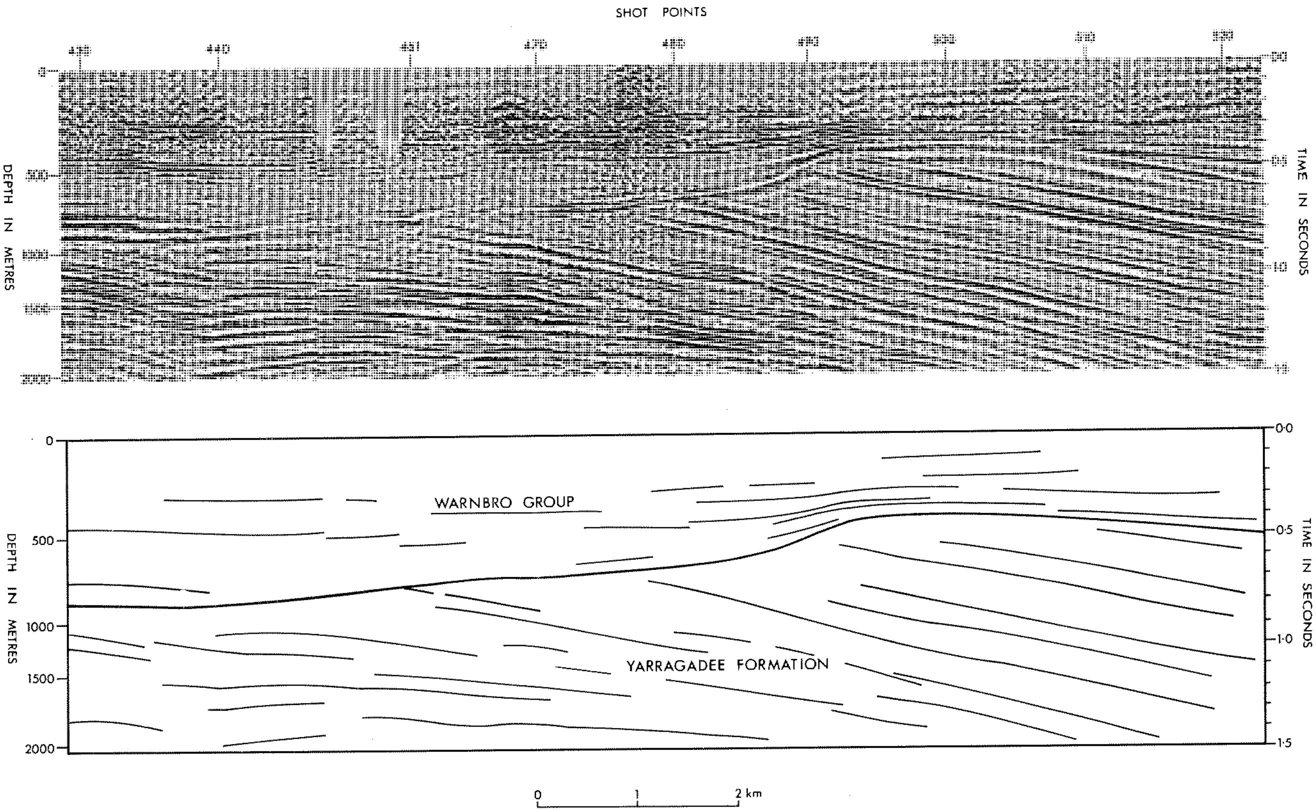

Figure 39. Seismic record section of part of Yanchep Line C (lat. 31° 43′S, long. 115° 48′E to lat. 31° 43′S, long. 115° 55′E) about 12 km south of Bullsbrook, showing the intra-Neocomian unconformity at the base of the Warnbro Group. Record section by courtesy of West Australian Petroleum Pty Ltd.

Kings Park Formation, unconformably overlying—

	Interval & thickness (metres)
South Perth Shale (69 m+)	
2. Shale, grey, pyritic, slightly micaceous, glauconitic, carbonaceous in part; contains scattered grains of quartz and feldspar of medium grain-size; a few bivalve fragments present	498–558 60
1. Sandstone, fine-grained, light-grey, glauconitic, soft and friable	558–567 9

Base of formation not penetrated.

A sandstone unit, the *Gage Sandstone Member,* is recognized at the base of the South Perth Shale in offshore wells. It was named by Bozanic (1969b), and the type section is from 1 588 to 1 801 m in Gage Roads No. 1 well. The member consists of sandstone with interbeds of shale and siltstone. It yielded noncommercial, but encouraging, amounts of oil in Gage Roads No. 1 well.

Lithology: The South Perth Shale consists largely of grey and black shale and claystone, grading to siltstone, and containing some beds of sandstone, especially near the base. The shale is commonly pyritic, and some parts are glauconitic. A few thin calcareous beds occur in certain sections.

Stratigraphic relationships: The South Perth Shale unconformably overlies the Yarragadee Formation. The relationship is commonly angular, and the Yarragadee Formation immediately below the contact ranges from Early Cretaceous to Late Jurassic in age. The relief on the unconformity is considerable in some areas, reaching as much as several hundred metres. This is well shown on a number of seismic sections, one of which is illustrated in Figure 39. The South Perth Shale is overlain, with a conformable and transitional contact, by the Leederville Formation.

Distribution and thickness: The South Perth Shale occurs in the subsurface of the Perth metropolitan area, and beneath the continental shelf west of Perth. The formation is not known to crop out. Its maximum known thickness is 795 m in Warnbro No. 1 well. However, seismic sections indicate that the unit thickens rapidly towards the edge of the continental shelf, where it may be several thousand metres thick.

The Gage Sandstone Member is 213 m thick in its type section, the maximum known thickness being 259 m in Warnbro No. 1 well.

Fossils and age: The following fossils have been recorded from the South Perth Shale:

Spores and pollen (Edgell, 1964a; Balme *in* Smith, 1967; Balme *in* Bozanic, 1969a, 1969b; Williams *in* Moyes, 1971a; Ott *in* Moyes, 1971b)

Alisporites grandis (Cookson)	1*	
A. similis (Balme)	1	
Araucariacites australis Cookson	1	2*
Ceratosporites equalis Cookson and Dettmann	1	2
Cicatricosisporites hughesi Dettmann		2
C. ludbrooki Dettmann	1	
Classopollis classoides (Pflug)	1	2

Contignisporites cooksoni (Balme)	1	2
C. sp. cf. *C. fornicatus* Dettmann	1	
Coronatispora perforata Dettmann	1	
C. telata (Balme)	1	
Crybelosporites stylosus Dettmann	1	
Cyathidites australis Couper	1	
C. concavus (Bolkhovitina)	1	
C. minor Couper	1	
Cycadopites sp.	1	
Densoisporites velatus Weyland and Krieger	1	
Dictyotosporites complex Cookson and Dettman	1	
Foraminisporis dailyi (Cookson and Dettmann)	1	
Foveosporites canalis Balme	1	
F. parviretus (Balme)	1	
Gleicheniidites circinidites (Cookson)	1	
G. senonicus Ross	1	
Inaperturopollenites limbatus Balme	1	
I. turbatus Balme	1	2
Laevigatosporites sp.	1	
Leptolepidites major Couper	1	
Lycopodiumsporites austroclavatidites (Cookson)	1	
L. circolumenus Dettmann	1	2
L. eminulus Dettmann	1	
L. facetus Dettmann	1	
Matonisporites crassiangulatus (Balme)	1	
Microcachryidites antarcticus Cookson	1	2
Murospora florida (Balme)	1	
Neoraistrickia truncatus (Cookson)	1	
Osmundacidites comaumensis Cookson	1	
Podocarpidites ellipticus Cookson	1	
Podosporites micropteris (Cookson)	1	
Polypodiidites sp. aff. *P. spinosus* (Khlonova)		2
Staplinisporites caminus (Balme)	1	
Stereisporites clavus (Balme)	1	
Vitreisporites pallidus (Reissinger)	1	
Zonalapollenites dampieri Balme	1	
Z. segmentatus Balme	1	
Z. trilobatus Balme	1	

Microplankton (Edgell, 1964a; Balme *in* Smith, 1967; Balme *in* Bozanic, 1969a, 1969b; Williams *in* Moyes, 1971a; Ott *in* Moyes, 1971b)

?*Baltisphaeridium* spp.	1	
Canningia sp.	1	
Carpodinium sp.		2
Chlamydophorella nyei Cookson and Eisenack	1	
C. sp.	1	
Cordosphaeridium? *fasciatum* Davey and Williams	1	2
Cribroperidinium edwardsi Cookson and Eisenack	1	
Cyclonephelium distinctum brevispinatum Millioud		2
C. paucimarginatum Cookson and Eisenack	1	
Dingodinium cerviculum Cookson and Eisenack	1	
Diplotesta glaessneri Cookson and Eisenack	1	
Gonyaulacysta sp. aff. *G. hadra* Sarjeant	1	
G. helicoidea Eisenack and Cookson	1	
Hologinella sp.	1	
Hystrichosphaeridium anthophorum Cookson and Eisenack	1	
H. sp. cf. *H. perforata* Gocht	1	
H. pulchrum (Deflandre)	1	
Leiofusa jurassica Cookson and Eisenack	1	
Leiosphaeridia sp.	1	
Micrhystridium spp.	1	
Muderongia mcwhaei Cookson and Eisenack	1	
M. neocomica (Gocht)	1	
M. simplex Alberti	1	
Oligosphaeridium complex (White)	1	
O. pulcherrimum (Deflandre and Cookson)	1	2

Palaeostomocystis sp.	1	
Pseudoceratium turneri Cookson and Eisenack	1	
P. sp.		2
Scriniodinium luridum (Deflandre)	1	2
Tanyosphaeridium isocalamus (Deflandre and Cookson)	1	
T. sp.	1	
Veryhachium reductum Deunff	1	
Foraminiferida (Crespin, 1937; Coleman, 1952; Rao, 1954)		
Ammobaculites spp.	1	
Astacolus sp.	1	
Dentalina sp. aff. *D. colei* Cushman and Dusenbury	1	
D. sp.	1	
Frondicularia sp.	1	
Glandulina sp.	1	
Guttulina sp.	1	
Haplophragmoides sp.	1	
Lagena sp.	1	
Lenticulina spp.	1	
Planularia sp.	1	
Saracenaria sp.	1	
Spiroplectoides sp.	1	
Textularia sp.	1	
Trochammina sp.	1	

*1. South Perth Shale, other than Gage Sandstone Member
*2. Gage Sandstone Member

Radiolaria (Rao, 1954), bivalve fragments (Playford and Willmott, 1958), and ostracods (Crespin, 1937) have also been recorded from the formation.

The spores and pollen from the South Perth Shale belong to Balme's (1964a) *Microcachryidites* assemblage of ?Tithonian to Aptian age. However, the microkplankton, especially *Cordosphaeridium? fasciatum, Muderongia neocomica,* and *M. simplex*, show that the formation is of late Neocomian age.

Environment of deposition: The South Perth Shale is a shallow-marine formation, probably grading to paralic in some sections.

LEEDERVILLE FORMATION

Definition: The name "Leederville Sandstone" was introduced by Fairbridge (1953) for the Lower Cretaceous unit of sandstone, shale, and conglomerate overlying the South Perth Shale in the Perth metropolitan area. The unit was included in the "South Perth Formation" by McWhae and others (1958) and it was redefined as the Leederville Formation by Cockbain and Playford (1973). The type section is in the Leederville Valley (Redan Street) bore (lat. 31° 56′ 09″S, long. 115° 50′ 07″E) between 198 and 433 m. The following is a description of this section:

Kings Park Shale, disconformably overlying—	Interval & thickness (metres)
Leederville Formation (235 m)	
3. Claystone, grey, pyritic, with glauconitic patches and scattered quartz pebbles	198-266 68
2. Claystone, grey, pyritic, friable, with quartz pebbles; minor fine to medium-grained grey, pyritic, poorly sorted sandstone, containing scattered quartz pebbles	266-343 77
1. Sandstone, fine-grained, well-sorted, in part friable, containing quartz pebbles; with fine-grained silty and clayey, pyritic sandstone; minor claystone in upper 25 m	343-433 90

Conformably overlying South Perth Shale.

Lithology: The Leederville Formation is an interbedded sequence of sandstone, shale, siltstone, claystone, and minor conglomerate. Sandstone predominates in some sections, but in others (including the type section) it is not the major constituent, and for this reason the name Leederville Formation is preferred to "Leederville Sandstone". Glauconite and pyrite are present in some beds, and thin seams of coal or lignite occur in the southern Perth Basin.

Stratigraphic relationships: The Leederville Formation conformably overlies the South Perth Shale with a transitional (and possibly interfingering) contact in the Perth area and beneath the continental shelf opposite Perth. Elsewhere it unconformably overlies the Yarragadee Formation or older units. The older underlying units comprise the Cattamarra Coal Measures Member of the Cockleshell Gully Formation in the Mandurah-Pinjarra area, the Eneabba Member of that formation in Preston No. 1 well, and the Lesueur Sandstone or Sue Coal Measures on the Vasse Shelf. The Leederville Formation is overlain with probable disconformity by the Osborne Formation or (in certain parts of the Perth metropolitan area) disconformably by the Kings Park Formation. The Leederville Formation may be equivalent to part of the Dandaragan Sandstone and to the Bullsbrook Beds, Donnybrook Sandstone, and Maxicar Beds. Each of these units occurs as isolated exposures over restricted areas, and their stratigraphic relationships are indefinite. The "Strathalbyn Sandstone" (Fairbridge, 1953), "Moochamullah Sandstone" (Playford and Willmott, 1958), and "Quindalup Beds" (Lowry, 1967) are now included in the Leederville Formation. In the Agaton water bores Passmore (1969) referred to the formation as the "marine member of the South Perth Formation".

Distribution and thickness: The Leederville Formation was originally recognized in the section penetrated in artesian wells around Perth. In this area it is generally about 250 m thick. It thickens offshore to a maximum of 545 m in Gage Roads No. 1 well.

The formation is known to extend in the subsurface from the southern part of the Perth Basin (as far south as Blackwood No. 1 well) to the Watheroo area. It is known to crop out only in the Gingin-Moore River area, and in the Blackwood River valley.

Fossils and age: Spores, pollen, and microplankton are the only fossils so far recorded from the Leederville Formation.

Spores and pollen (Balme *in* Bozanic, 1969a, 1969b; Williams *in* Moyes, 1971a; Ott *in* Moyes, 1971b)

Alisporites grandis (Cookson)
A. similis (Balme)
Araucariacites australis Cookson
Ceratosporites equalis Cookson and Dettmann
Cicatricosisporites ludbrooki Dettmann
Classopollis classoides (Pflug)
Contignisporites cooksoni (Balme)
Coronatispora telata (Balme)
Cyathidites australis Couper
C. concavus (Bolkhovitina)
C. minor Couper
Cycadopites sp.
Cyclosporites hughesi (Cookson and Dettman)
Densoisporites velatus Weyland and Krieger
Dictyotosporites complex Cookson and Dettmann
Foveosporites sp. cf. *F. canalis* Balme
Gleicheniidites circinidites (Cookson)
G. senonicus Ross
Inaperturopollenites limbatus Balme
Ischyosporites crateris Balme
Klukisporites scaberis (Cookson and Dettmann)
Leptolepidites verrucatus Couper
Lycopodiumsporites austroclavatidites (Cookson)
L. circolumenus Cookson and Dettmann
L. eminulus Dettmann
Matonisporites crassiangulatus (Balme)
Microcachryidites antarcticus (Cookson)
Murospora florida (Balme)
Neoraistrickia truncatus Cookson
Osmundacidites comaumensis (Cookson)
Podocarpidites sp. cf. *P. ellipticus* Cookson
Zonalapollenites dampieri Balme
Z. trilobatus Balme

Microplankton (Cookson and Eisenack, 1958, 1962a, 1962b; Eisenack and Cookson, 1960; Edgell, 1964a; Balme *in* Bozanic, 1969a, 1969b; Williams *in* Moyes, 1971a; Ott *in* Moyes, 1971b)

Apteodinium conjunctum Cookson and Eisenack
Ascodinium sp.
Baltisphaeridium sp.
Belodinium dysculum Cookson and Eisenack
Canningia colliveri Cookson and Eisenack
Canninginopsis denticulata Cookson and Eisenack
Cannosphaeropsis sp. cf. *C. utinensis* O. Wetzel
Chlamydophorella nyei Cookson and Eisenack
Cribroperidinium edwardsi (Cookson and Eisenack)
Cyclonephelium areolatum Cookson and Eisenack
C. attadalicum Cookson and Eisenack
C. compactum Deflandre and Cookson
C. distinctum Deflandre and Cookson
C. distinctum brevispinatum Millioud
Cymatiosphaera sp.
Dingodinium cerviculum Cookson and Eisenack
Diplotesta glaessneri Cookson and Eisenack
Domasia discophora Cookson and Eisenack
Gonyaulacysta cassidata (Eisenack and Cookson)
G. diaphanis (Cookson and Eisenack)
G. hyalodermopsis (Cookson and Eisenack)
G. muderongensis (Cookson and Eisenack)
G. tenuiceras (Eisenack)

Hexagonifera sp.
Horologinella lineata Cookson and Eisenack
H. sp. indet.
Hystrichodinium pulchrum (Deflandre)
Hystrichosphaeridium recurvatum polypes Cookson and Eisenack
Lecaniella dictyota Cookson and Eisenack
Leiosphaera sp.
Lithodinia sp.
Micrhystridium sp.
Muderongia mcwhaei Cookson and Eisenack
M. neocomica (Gocht)
M. sp. aff. *M. simplex* Alberti
M. sp. cf. *M. staurota* Sarjeant
M. tetracantha (Gocht)
Oligosphaeridium anthophorum (Cookson and Eisenack)
O. complex (White)
O. pulcherrimum (Deflandre and Cookson)
Palaeostomocystis fragilis Cookson and Eisenack
Pareodinia aphelia Cookson and Eisenack
Pterodinium cornutum Cookson and Eisenack
P. magnoserratum Cookson and Eisenack
Pterospermopsis eurypteris Cookson and Eisenack
Rhombodella natans Cookson and Eisenack
Scriniodinium attadalense (Cookson and Eisenack)
S. luridum (Deflandre)
Spinidinium styloniferum Cookson and Eisenack
Spiniferites ramosus (Ehrenberg)
Tanyosphaeridium sp. cf. *T. isocalamus* (Deflandre and Cookson)
Tenua? sp.
Trichodinium castaneum (Deflandre)

The spores and pollen belong to the *Microcachryidites* assemblage of Balme (1964a). Microplankton suggest a late Neocomian to Aptian age for the Leederville Formation.

Environment of deposition: The Leederville Formation is of mixed shallow-marine, paralic, and continental origin. The onshore section is mainly continental (except in the Watheroo area), and it becomes more marine beneath the continental shelf.

DANDARAGAN SANDSTONE

Definition: The name Dandaragan Sandstone was introduced by Conrad and Maynard (1948) and was published by Fairbridge (1953). The definition was modified by Willmott and McKellar (*in* McWhae and others, 1958). It is the unit of sandstone between the Yarragadee Formation and the Molecap Greensand that is exposed in the Dandaragan area. The type section is located 6.5 km west of Dandaragan, below the "Hole-in-the-Wall" phosphate deposit (lat. 30° 41′ 30″S, long. 115° 38′ 30″E). The following is a description of this section (from Playford and Willmott, 1958):

Molecap Greensand, conformably overlying—

Dandaragan Sandstone (33 m)	Thickness (metres)
9. Sandstone, medium-grained, moderately well-sorted, feldspathic, grains subrounded to rounded, massively bedded, ferruginous, dark-red, friable. Uppermost bedding surface is impregnated with dufrenite	8.0
8. Sandstone, medium to coarse-grained, dark-red, ferruginous, moderately sorted, grains subrounded to rounded, with some feldspar, friable. Grades into unit above	1.5
7. Sandstone, medium-grained, dark-red, ferruginous, rather poorly sorted, with subangular to subrounded grains, but also with some rounded grains, friable	10.0
6. Sandstone, coarse to very coarse-grained, brown, rather poorly sorted, subangular to subrounded grains	1.8
5. Sandstone, medium to coarse-grained, ferruginous, moderately sorted, massively bedded, grains subangular to subrounded	1.5
4. Sandstone, very coarse-grained, grading into fine conglomerate, poorly sorted, grains subangular, yellow-brown, friable, very poorly exposed	1.2
3. No exposure	6.0
2. Sandstone, coarse-grained, red-brown, crudely bedded, moderately sorted, with subangular to subrounded grains, friable	2.4
1. Sandstone, coarse to very coarse-grained, grading into fine conglomerate, yellow-brown to brown and red, very poorly sorted, crudely bedded, sand grains subangular to angular, pebbles up to 1 cm; thin beds of medium-grained, poorly sorted, ferruginous sandstone, with some feldspar	0.9

Unconformably overlying Yarragadee Formation.

Lithology: The Dandaragan Sandstone is a sequence of medium to coarse-grained, ferruginous, feldspathic, massively bedded sandstone, grading in places into fine conglomerate. Cross-bedding is developed at some localities. The top bedding surface of the formation is characteristically stained green by the iron phosphate, dufrenite.

Stratigraphic relationships: The Dandaragan Sandstone overlies the Lower Cretaceous part of the Yarragadee Formation, possibly with a slightly angular relationship. It is overlain, probably disconformably, by the Molecap Greensand. A probable correlative of the Dandaragan Sandstone is the Leederville Formation.

Distribution and thickness: The Dandagaran Sandstone has been mapped discontinuously at the surface from Emu Hill, north of Dandaragan, to Poison Hill. It is usually a cliff-forming unit in the Dandaragan area, capping the prominent Dandaragan Scarp. It ranges in thickness from 33 m to about 1 m, showing considerable variations over short distances in some areas.

Fossils and age: Fossil wood fragments were found during the present investigation in the Dandaragan Sandstone 9 km southwest of Dandaragan, and Fairbridge (1953) also mentions the presence of fossil wood in the formation. From its stratigraphic position the unit is believed to be of Aptian age.

Environment of deposition: The Dandaragan Sandstone is thought to be a shallow-marine deposit, but no marine fossils have been found to substantiate this interpretation.

BULLSBROOK BEDS

Definition: The name Bullsbrook Beds was first used by Etheridge (1907c) for the plant-bearing unit exposed along the front of the Darling Scarp immediately east-northeast of the township of Bullsbrook East. The type section is located at lat. 31° 39′ 53″S, long. 116° 02′ 40″E, and is described below (as measured by F. B. Williams and M. G. McKellar of Wapet):

Bullsbrook Beds (76 m)	Thickness (metres)
Upper limit of formation not exposed; overlain by laterite and sand.	
12. Sandstone, medium to coarse-grained, red-brown, conglomeratic in part, poorly sorted, poorly bedded, porous, quartz grains subrounded; includes a 1 m bed of medium-grained, white to light-grey, moderately well-sorted, silty, friable, crudely bedded sandstone	6.7
11. No exposure	15.0
10. Siltstone, red-brown, ferruginous, micaceous, poorly bedded, soft, poorly exposed; contains a few fine sand grains	1.8
9. Sandstone, medium to coarse-grained, red to black, poorly sorted, poorly bedded, quartz grains subangular, moderately friable; contains numerous lenses of quartz-pebble conglomerate, and white and red sandy, ferruginous siltstone	9.1
8. Siltstone, sandy, white, micaceous, poorly bedded to massive, partly silicified along a small fault; quartz sand is fine to coarse-grained; thin beds within the unit contain poorly preserved fossil leaves and other plant material	5.2
7. Sandstone, medium to coarse-grained, red to black, poorly sorted, moderately friable, poorly bedded, poorly exposed, slightly porous, quartz grains subangular; contains some conglomeratic lenses	5.2
6. No exposure	3.4
5. Sandstone, medium to coarse-grained, red and yellow, ferruginous, in part conglomeratic, moderately hard, porous, partly lateritized	0.6
4. No exposure	4.3
3. Sandstone, medium to coarse-grained, red to black, poorly sorted, poorly bedded, contains some conglomeratic lenses, moderately friable	7.3
2. No exposure	12.5
1. Siltstone, white, micaceous, soft, poorly bedded, contains a small percentage of medium-grained, rounded sand; interbedded with fine to coarse-grained, silty, white, yellow, and red, micaceous, poorly bedded and cross-bedded, partly ferruginous sandstone	4.6

Base of formation not exposed, but nearby known to unconformably overlie Precambrian granitic gneiss.

Lithology: The Bullsbrook Beds are a sequence of alternating poorly sorted sandstone and siltstone. The sediments are generally very weathered and are partly lateritized. Variegated colouring in shades of red, yellow, grey, and white is common.

Stratigraphic relationships: The Bullsbrook Beds were laid down in a valley incised into the Darling Scarp in Early Cretaceous times. They rest unconformably on Precambrian granitic rocks, and the sequence is approximately horizontal. The beds are probably overlain disconformably by the Osborne Formation, which is poorly exposed nearby.

Exposures along the scarp 8 to 14 km north of Bullsbrook East townsite that had been mapped as Bullsbrook Beds by Low and others (1970) are now regarded as belonging to the Osborne Formation. The most likely correlative of the Bullsbrook Beds in the type area is the Leederville Formation. However, this correlation is not conclusive, and for the present it is advisable to retain the beds as a separate unit.

Distribution and thickness: The Bullsbrook Beds are known only from the small area east of the Darling Fault, east-northeast of Bullsbrook East townsite. The only section that has been measured is the type section, 76 m thick.

Fossils and age: Walkom (1944) reported the occurrence of the fossil leaves *Cladophlebis australis* (Morris), *?Phyllopteris* sp., *Thinnfeldia* sp., *Taeniopteris elongata* Walkom, *Nilssonia* sp., and *Elatocladus* sp. cf. *E. plana* (Feistmantel) in the Bullsbrook Beds. The fossils are poorly preserved, but Walkom favoured an Early Cretaceous age for them.

Ingram (1969) reported on the sporomorph assemblage contained in a sample of black silty clay from a water bore (Bordoni No. 2 bore) drilled 0.5 km north of the northernmost outcrop of Bullsbrook Beds. The sample is almost certainly from that unit. The sporomorphs recovered are mainly long-ranging late Mesozoic forms, but Ingram expressed the opinion that the assemblage is of Early Cretaceous (probably Neocomian) age and that the sample is from a non-marine facies of the Warnbro Group.

The evidence available suggests that the Bullsbrook Beds are most likely to be of Neocomian age, equivalent to the Leederville Formation.

Environment of deposition: The Bullsbrook Beds are interpreted as a fluviatile unit, laid down in a valley cut into the Darling Scarp at the close of the last major period of movement along the Darling Fault in this area during the Neocomian.

DONNYBROOK SANDSTONE

Definition: The name Donnybrook Sandstone was introduced by Saint-Smith (1912) for the sandstone exposed at the surface and in quarries along the front of the Darling Scarp near Donnybrook. The type section is exposed 6 km north of Donnybrook, and this is described below (from Playford and Willmott, 1958):

Donnybrook Sandstone (32 m)	Thickness (metres)
Upper limit of formation not exposed; overlain by Quaternary deposits.	
6. Sandstone, medium-grained, yellow, cross-bedded	3.0
5. Sandstone, medium-grained, grey and yellow, kaolinitic, poorly bedded, partly cross-bedded, well-sorted; contains a few rounded pebbles of quartzite and vein quartz; some lenses of very fine-grained sandstone	9.0
4. Conglomerate, pebble and granule, with rounded granules and pebbles up to 5 cm long of quartz and quartzite; matrix of fine to medium-grained quartz sand	0.15
3. Sandstone, medium-grained, yellow and grey, kaolinitic, poorly bedded, well-sorted, partly cross-bedded	1.5
2. Sandstone, medium-grained, yellow to grey, partly kaolinitic, well-sorted, poorly exposed	12.0
1. Sandstone, fine to medium-grained, yellow, well-sorted, thickly bedded, partly kaolinitic; contains a few quartz pebbles	6.0
Precise contact not exposed, but unconformably overlying Precambrian gneiss and schist.	

Lithology: The Donnybrook Sandstone is a sequence of uniform fine to medium-grained sandstone, which is normally yellow in colour when fresh, and weathers grey. Bedding is generally only poorly developed.

Stratigraphic relationships: The Donnybrook Sandstone rests unconformably on Precambrian rocks east of the Darling Fault. Its relationships to other sedimentary units in the Perth Basin succession are indefinite, but it probably correlates with the Maxicar Beds and part of the Leederville Formation.

Distribution and thickness: The Donnybrook Sandstone is exposed in a belt from 14.5 km south to 6.5 km north of Donnybrook. An exposure is also known at Brookhampton, 6.5 km southeast of Donnybrook. The section at this locality is about 60 m thick, and is the thickest known. The formation apparently fills valleys incised into the Darling Scarp at or near the close of the last major period of movement along the Darling Fault in this area during the Neocomian.

Fossils and age: Teichert (1947a, and *in* Maitland, 1940) reported the occurrence of footprints of a four-footed vertebrate in the Donnybrook Sandstone near Brookhampton. He suggested that these indicated that the formation is of post-Palaeozoic, possibly Triassic, age. Balme (1956) reported Cretaceous plant microfossils in a dark shale from Murphy's Shaft near Donnybrook. He considered that this sample came from the Donnybrook Sandstone, but it is now placed in the Leederville Formation. However, regional correlations suggest that the Donnybrook Sandstone is probably of Neocomian age, equivalent to part of the Leederville Formation.

Environment of deposition: The Donnybrook Sandstone is probably a shoreline deposit laid down during the Neocomian transgression.

Economic aspects: The Donnybrook Sandstone is a well-known building stone. It was used extensively in the past, especially for facing public buildings in Perth, but the quarries have now fallen into disuse.

Blatchford (1900) reported the presence of gold-bearing chalcedonic veins in the Donnybrook Sandstone 3.2 km south of Donnybrook. However, gold-bearing quartz veins are known in the granitic rocks of this area, which was the scene of considerable mining activity in 1898 and 1899, and the presence of gold in the Donnybrook Sandstone itself has not been confirmed by subsequent workers.

MAXICAR BEDS

Definition: The name Maxicar Beds was first used by Lowry (1965) for the unit of ferruginous sandstone which crops out near Maxicar homestead. This is situated some 6.5 km east of Dardanup (lat. 33° 24′ 30″S, long. 115° 49′ 28″E).

Lithology: The unit consists of poorly exposed, ferruginous, feldspathic, medium to coarse-grained sandstone. The sandstone is poorly sorted, with angular to subangular quartz grains. The ferruginous cement of the rock may be a replacement of an original calcareous cement under the influence of lateritization.

Stratigraphic relationships: The stratigraphic relationships of the Maxicar Beds are uncertain, but the beds apparently rest directly on Archaean basement rocks. They occupy a similar position to that of the Donnybrook Sandstone, which crops out 13 km to the south, and the two units may be laterally equivalent.

Distribution and thickness: The Maxicar Beds are recognized only in the type area, where they are about 10 m thick.

Fossils and age: Poorly preserved moulds of several forms of bivalves have been found in the formation. J. M. Dickins (*in* Playford and Willmott, 1958) identified one form as *Pterotrigonia*, and suggested that it is of Jurassic or Cretaceous age. Regional considerations suggest that the unit is most likely to be Neocomian.

Environment of deposition: The Maxicar Beds probably represent shoreline or shallow-marine deposits.

COOLYENA GROUP

The name Coolyena Group was proposed by Cockbain and Playford (1973) for the sequence comprising the Osborne Formation, Molecap Greensand, Gingin Chalk, and Poison Hill Greensand (in ascending order). Coolyena is the Aboriginal name for Molecap Hill, near Gingin. The group consists of the chalk and glauconite-bearing sequence, predominantly of Late Cretaceous age, in the central Perth Basin. It is separated by a disconformity from the underlying Warnbro Group. A regional structure contour map drawn on the base of the group is shown as Figure 49.

OSBORNE FORMATION

Definition: The name Osborne Formation was proposed by McWhae and others (1958) for the sequence of Albian-Cenomanian glauconitic sandstone and argillaceous sediments above the Leederville Formation. It was originally recognized from bores in the Perth metropolitan area. The type section is in the King Edward Street bore (lat. 31° 54′S, long. 115° 49′E) between 37 and 133 m. The following is a description of this section:

	Interval & thickness (metres)
Kings Park Shale, disconformably overlying—	
Osborne Formation (96 m)	
5. Sandstone, glauconitic, calcareous	37-55 18
4. Claystone, silty, black, glauconitic, pyritic, with quartz pebbles; slightly calcareous in the uppermost part, very glauconitic in the lower 2 m	55-92 37
3. Sandstone, greyish-green, glauconitic, subangular grains, friable	92-109 17
2. Claystone, as for unit 4	109-127 18
1. Claystone, silty, sandy, yellowish-grey, pyritic, little mica; contains some carbonaceous fragments	127-133 6

Disconformably overlies Leederville Formation.

Lithology: The Osborne Formation consists of interbedded sandstone (in part calcareous), siltstone, shale, and claystone. It is characteristically glauconitic, and the argillaceous sediments are usually dark grey to black. Pyrite is a common accessory mineral.

Stratigraphic relationships: The Osborne Formation disconformably overlies the Leederville Formation and is overlain, probably conformably, by the Molecap Greensand or disconformably by the Kings Park Formation. It seems likely that the contact with the Molecap Greensand interfingers to some extent. The formation is believed to overlie Bullsbrook Beds east of the Darling Fault near Bullsbrook East township.

Distribution and thickness: The Osborne Formation is recognized from bores in the Perth metropolitan area and offshore in the Warnbro No. 1, Sugarloaf No. 1, and Quinns Rock No. 1 wells. Its absence in some of the offshore and Perth metropolitan area bores is due to the erosion surface at the base of the Kings Park Formation. It has been traced in the subsurface as far north as Watheroo. The formation is exposed at a number of localities on the Darling Scarp near Bullsbrook, along Ellen Brook (Upper Swan area) and along the Moore River near Mogumber. It ranges in thickness from about 60 m to more than 200 m. The exposures of the formation north of Bullsbrook and west of the Darling Fault were originally mapped by Low and others (1970) as "Bullsbrook Formation".

Fossils and age: The Osborne Formation contains Radiolaria, mollusc fragments, a few spores and pollen, and a large and varied assemblage of microplankton.

Spores and pollen (Balme, 1964a)

Aequitriradites sp.
Amosopollis sp.
Cicatricosisporites australiensis (Cookson)
Gleicheniidites spp.
Hoegisporis sp.
Inaperturopollenites limbatus Balme
Microcachryidites antarcticus Cookson
Styxisporites sp.

Microplankton (Cookson and Eisenack, 1958, 1960, 1962a, 1962b, 1968, 1969; Eisenack and Cookson, 1960; Edgell, 1964a)

Aiora fenestrata (Deflandre and Cookson)
Aptea sp. cf. *A. polymorpha* Eisenack
Apteodinium maculatum Eisenack and Cookson
Ascodinium acrophorum Cookson and Eisenack
A. parvum (Cookson and Eisenack)
A. serratum Cookson and Eisenack
Canninginopsis denticulata Cookson and Eisenack
Cannosphaeropsis densa Cookson and Eisenack
C. peridictya Eisenack and Cookson
Carpodinium granulatum Cookson and Eisenack
Chlamydophorella nyei Cookson and Eisenack
C. urna Cookson and Eisenack
Cirrifera unilateralis Cookson and Eisenack
Cleistosphaeridium ancoriferum (Cookson and Eisenack)
Codoniella campanulata (Cookson and Eisenack)
Conosphaeridium striatoconus (Deflandre and Cookson)
C. tubulosum Cookson and Eisenack
Coronifera oceanica Cookson and Eisenack
Cribroperidinium edwardsi (Cookson and Eisenack)
Cyclonephelium clathromarginatum Cookson and Eisenack
C. compactum Deflandre and Cookson
C. distinctum Deflandre and Cookson
C. membraniphorum Cookson and Eisenack
C. paucimarginatum Cookson and Eisenack
Cymatiosphaera pterota Cookson and Eisenack
C. radiata O. Wetzel
C. striata Eisenack and Cookson
Deflandrea acuminata Cookson and Eisenack
D. balcattensis Cookson and Eisenack
D. sp. cf. *D. echinoidea* Cookson and Eisenack
D. foliacea Eisenack and Cookson
D. glabra Cookson and Eisenack
D. parva Cookson and Eisenack
D. tripartita Cookson and Eisenack
Diconodinium dispersum (Cookson and Eisenack)
D. glabrum Eisenack and Cookson
D. inflatum Eisenack and Cookson
D. tenuistriatum Eisenack and Cookson
Dioxya villosa Eisenack and Cookson
Diplotesta luna Cookson and Eisenack
Domasia discophora Cookson and Eisenack
Endoceratium ludbrooki (Cookson and Eisenack)
Fromea amphora Cookson and Eisenack
Gillenia hymenophora Cookson and Eisenack
Ginginodinium spinulosum Cookson and Eisenack
Gonyaulacysta cassidata (Eisenack and Cookson)
G. tenuiceras (Eisenack)
Halophoridia xena Cookson and Eisenack
Hexagonifera chlamydata Cookson and Eisenack
Horologinella obliqua Cookson and Eisenack
Hystrichokolpoma ferox Deflandre

Hystrichosphaeridium arundum Eisenack and Cookson
H. sp. cf. *H. hirsutum* (Ehrenberg)
H. stellatum Maier
Lecaniella dictyota Cookson and Eisenack
L. margostriata Cookson and Eisenack
Leptodinium tenuicornutum Cookson and Eisenack
Litosphaeridium siphoniphorum (Cookson and Eisenack)
Microdinium ornatum Cookson and Eisenack
Odontochitina operculata (O. Wetzel)
O. striatoperforata Cookson and Eisenack
Palaeohystrichophora infusorioides Deflandre
Palaeostomocystis fragilis Cookson and Eisenack
Phoberocysta ceratioides (Deflandre)
Platycystidia diptera Cookson and Eisenack
Pseudoceratium ludbrooki (Cookson and Eisenack)
P. turneri Cookson and Eisenack
Pterodinium cornutum Cookson and Eisenack
P. magnoserratum Cookson and Eisenack
Schizocystia laevigata Cookson and Eisenack
S. rugosa Cookson and Eisenack
Scriniodinium galeatum Cookson and Eisenack
Spinidinium styloniferum Cookson and Eisenack
Stephodinium coronatum Deflandre
Tenua? sp.
Trichodinium castaneum (Deflandre)
Trigonopyxidia ginella (Cookson and Eisenack)
Veryhachium reductum Deunff
V. reductum concavum Cookson and Eisenack
Xiphophoridium alatum (Cookson and Eisenack)

Balme (1964a) named the spore and pollen assemblage from the Osborne Formation the *Hoegisporis* microflora. On the basis of the abundant microplankton, Cookson and Eisenack (1958) have dated the formation as Albian-Cenomanian.

Environment of deposition: The Osborne Formation is a marine unit, probably laid down under relatively shallow-water conditions over an irregular topography.

MOLECAP GREENSAND

Definition: The name Molecap Greensand was introduced by Fairbridge (1953) for the unit of greensand that underlies the Gingin Chalk and overlies the Osborne Formation, the Dandaragan Sandstone, or the Leederville Formation. The type section is in the greensand quarry on Molecap Hill (lat. 31° 22′S, long. 115° 24′E), just south of Gingin. The following is a description of this section (from Playford and Willmott, 1958):

	Thickness (metres)
Gingin Chalk, conformably overlying—	
Molecap Greensand (9 m+)	
1. Greensand, medium-grained, green to dark-green, well-sorted, crudely bedded to unbedded, very friable	9
Base of section not exposed.	

Lithology: In the Gingin area the lithology of the Molecap Greensand is rather uniform, as described in the type section. Around Dandaragan it is commonly a fine-grained, yellow, yellow-brown, brown, greenish-brown, or brown glauconitic sandstone. The unit is crudely bedded and weathering has commonly altered much or all of the glauconite to limonite.

A thin phosphatic bed is present at the top of the formation in the Dandaragan area, and another occurs at the base. The lower bed consists of nodules of white sand and glauconite cemented with phosphorite (collophane) and set in a greensand matrix. Phosphatized wood is common. The green iron phosphate, dufrenite, occurs at the base of the bed and impregnates the surface of the underlying Dandaragan Sandstone.

The upper phosphate bed crops out as phosphate nodules up to 1 cm in diameter in a matrix of red-brown silty sandstone, which grades into greensand in some areas.

Stratigraphic relationships: The Molecap Greensand is overlain conformably by the Gingin Chalk and it conformably overlies the Osborne Formation or disconformably overlies either the Dandaragan Sandstone or the Leederville Formation.

Distribution and thickness: The Molecap Greensand is recognized in discontinuous outcrops from Badgingarra to south of Gingin. In the subsurface it extends as far north as Watheroo. It is not known to occur in the subsurface of the Perth metropolitan area, apparently because of erosion prior to deposition of the Paleocene-Eocene Kings Park Formation.

The type section of the formation is 9 m thick (base not exposed), and the thickness in the Gingin-Dandaragan area is generally between 10 and 12 m. In many areas it is difficult to measure sections of the formation accurately owing to the prevalence of landslips. In the Gingin area the upper boundary occurs at about 150 m above sea level. Where it crops out at a significantly lower level than this, as in MacIntyre Gully, it can be inferred that landsliding is responsible.

In some areas the formation appears to pinch out completely on the irregular disconformity on the underlying Dandaragan Sandstone or the Leederville Formation.

Fossils and age: Macrofossils are rare in the Molecap Greensand, but an abundant microflora has been recorded.

Spores and Pollen (Ingram, in prep.)

Amosopollis cruciformis Cookson and Pike
Camarozonosporites sp. aff. *C. ambigens* (Fradkina)
Clavifera triplex (Bolkhovitina)
Cyathidites australis Couper
C. minor Couper
Gleicheniidites senonicus Ross
Laevigatosporites major (Cookson)
Microcachryidites antarcticus Cookson
Ornamentifera sentosa Dettmann and Playford
Proteacidites sp.
Stereisporites antiquasporites (Wilson and Webster)
Tricolpites pannosus Dettmann and Playford
undifferentiated bisaccates

Microplankton (Deflandre and Cookson, 1955; Cookson and Eisenack, 1958, 1960, 1962b; Eisenack and Cookson, 1960; Edgell, 1964a; Ingram, in prep.)

Aiora fenestrata (Deflandre and Cookson)
Amphidiadema denticulata Cookson and Eisenack
Apteodinium maculatum Eisenack and Cookson
Ascodinium acrophorum Cookson and Eisenack
A. parvum (Cookson and Eisenack)
Cannosphaeropsis peridictya Eisenack and Cookson
Chlamydophorella nyei Cookson and Eisenack
C. urna Cookson and Eisenack
Chytroeisphaeridia sp.
Cleistosphaeridium heteracanthum (Deflandre and Cookson)
C. huguonioti (Valensi)
C. polytrichum (Valensi)
Codoniella campanulata (Cookson and Eisenack)
Conosphaeridium striatoconus (Deflandre and Cookson)
C. tubulosum Cookson and Eisenack
Coronifera oceanica Cookson and Eisenack
Cribroperidinium edwardsi (Cookson and Eisenack)
Cyclonephelium compactum (Deflandre and Cookson)
C. distinctum (Deflandre and Cookson)
Cymatiosphaera eupeplos (Valensi)
C. imitata Deflandre and Cookson
Deflandrea acuminata Cookson and Eisenack
D. balcattensis Cookson and Eisenack
D. sp. aff. *D. balcattensis* Cookson and Eisenack
D. balmei Cookson and Eisenack
D. belfastensis Cookson and Eisenack
D. cooksoni Alberti
D. echinoidea Cookson and Eisenack
D. sp. aff. *D. echinoidea* Cookson and Eisenack
D. foliacea Eisenack and Cookson
D. glabra Cookson and Eisenack
D. granulifera Manum
D. ingrami Cookson and Eisenack
D. minor Cookson and Eisenack
D. nucula Cookson and Eisenack
D. rectangularis Cookson and Eisenack
D. serratula Cookson and Eisenack
D. tripartita Cookson and Eisenack
D. victoriensis Cookson and Manum
Diconodinium sp. cf. *D. glabrum* Eisenack and Cookson
D. multispinum (Deflandre and Cookson)
Dinogymnium sp. cf. *D. heterocostatum* (Deflandre)
D. nelsonense (Cookson)
D. westralicum (Cookson and Eisenack)
Diplofusa gearlensis Cookson and Eisenack
Disphaera macropyla Cookson and Eisenack
Exochosphaeridium phragmites Davey, Downie, Sarjeant, and Williams
E. sp.
Eyrea sp.
Gillinia hymenophora Cookson and Eisenack
Ginginodinium spinulosum Cookson and Eisenack
Gonyaulacysta margaritifera (Cookson and Eisenack)
Heterosphaeridium heteracanthum (Deflandre and Cookson)
Hologinella apiculata Cookson and Eisenack
Hystrichodinium pulchrum Deflandre
Hystrichokolpoma ferox (Deflandre)
Hystrichosphaeridium recurvatum (White)
H. stellatum Maier
Leiosphaeridia spp.
Litosphaeridium flosculus (Deflandre)
Madurodinium ornatum Cookson and Eisenack
Microdinium ornatum Cookson and Eisenack
Nelsoniella aceras Cookson and Eisenack
N. semireticulata Cookson and Eisenack

N. tuberculata Cookson and Eisenack
Odontochitina costata Alberti
O. sp. cf. *O. costata* Alberti
O. cribropoda Deflandre and Cookson
O. sp. cf. *O. operculata* (Wetzel)
O. porifera Cookson
Oligosphaeridium complex (White)
O. pulcherrimum (Deflandre and Cookson)
Palaeoglenodinium sp.
Palaeohystrichophora infusorioides Deflandre
P. minuta Deflandre and Cookson
P. multispina Deflandre and Cookson
Palaeostomocystis apiculata Cookson and Eisenack
P. chytra Drugg
P. laevigata Drugg
P. sp.
Phoberocysta ceratioides (Deflandre)
Platycystidia diptera Cookson and Eisenack
Pterospermopsis ginginensis Deflandre and Cookson
Pyxidiella scrobiculata (Deflandre and Cookson)
Spiniferites cingulatus cingulatus (Wetzel)
S. cingulatus perforatus (Clarke and Verdier)
S. ramosus gracilis (Davey and Williams)
S. ramosus ramosus (Ehrenberg)
Surculosphaeridium sp. cf. *S. longifurcatum* (Firtion)
Trigonopyxidia ginella (Cookson and Eisenack)
Veryhachium spp.
Xenikoon australis Cookson and Eisenack

Plant macrofossils (Simpson, 1912)
Cedroxylon sp.

Bivalvia (Teichert and Matheson, 1944; Feldtmann, 1951; Fairbridge, 1953)
Chlamys fairbridgei Feldtmann
?*C.* sp.
Pecten sp.
Pycnodonta sp.

Coleoidea (Teichert and Matheson, 1944; Fairbridge, 1953)
belemnites indet.

Vertebrata (Teichert and Matheson, 1944; Fairbridge, 1953; Lundelius and Warne, 1960)
fish bones
ichthyosaur, plesiosaur, and mosasaur remains

Deflandre and Cookson (1955) ascribed a Late Cretaceous age to the formation on the basis of the microplankton. B. S. Ingram (pers. comm., 1973) considers the unit to be of Coniacian-Santonian age, with a possibility that the lower part may be late Cenomanian.

Environment of deposition: The Molecap Greensand is a marine deposit, laid down in a shallow sea over an irregular topography. Conditions were apparently unfavourable for the development of a normal benthonic fauna.

Economic aspects: Greensand was mined from the formation at Molecap Hill between 1932 and 1960 and was exported to England for use as a water softener. However, the glauconite is no longer used for this purpose.

Investigations have been made by the C.S.I.R.O. into the possibility of extracting potash from glauconite in this formation (Low, 1965), but this was not found to be economically feasible.

GINGIN CHALK

Definition: The name Gingin Chalk was introduced by Glauert (1910d) for the unit of chalk between the Molecap and Poison Hill Greensands. The type section is in MacIntyre Gully (lat. 31° 19'S, long. 115° 54'E), 1.6 km north of Gingin. The following is a description of this section (from Feldtmann, 1963):

Poison Hill Greensand, conformably overlying— *Gingin Chalk* (19 m)	Thickness (metres)
9. Chalk, mottled grey, glauconitic, clayey	1.3
8. Chalk, pale-grey, even-textured	1.8
7. Chalk, pale-yellowish to white, fine-grained, somewhat sandy, slightly glauconitic	2.8
6. Chalk, grey, fine-grained, very clayey	0.3
5. Chalk, white	0.9
4. Chalk, mottled grey, glauconitic, marly	3.0
3. Chalk, grey, marly, somewhat glauconitic; less distinctly mottled	2.8
2. Chalk, grey, glauconitic; no mottling	1.8
1. Chalk, dark-greyish-green, becoming more glauconitic	4.2

Overlies Molecap Greensand with conformable, transitional contact.

Figure 40. Scanning electron microscope photograph of Gingin Chalk showing abundant coccoliths. Photograph by courtesy of West Australian Petroleum Pty Ltd.

Lithology: The Gingin Chalk is a white, friable, richly fossiliferous, slightly glauconitic chalk, containing thin beds of greensand in some areas. The chalk contains a high proportion of coccolith remains (Fig. 40).

Outcrops of the formation are commonly kankarized at the surface, and such rocks generally lack fossils and glauconite.

Stratigraphic relationships: The Gingin Chalk lies with apparent conformity between the Molecap Greensand below and the Poison Hill Greensand above. In some areas where the Molecap Greensand is missing the Gingin Chalk rests directly on the Dandaragan Sandstone or the Leederville Formation.

The apparent lenticularity of the Gingin Chalk in outcrop can be explained in some areas as being caused by landslides that have obscured the chalk. However, the most important factor causing the chalk to pinch out is probably the influence of lateritization. The laterite surface undulates in this area, and in places where it extended low enough to bring the Gingin Chalk within the deep zone of alteration below laterite, the chalk has been wholly or partly leached out, leaving the clay impurities that it contained. A line of springs commonly marks this black clay horizon. There is also evidence in some areas that the Gingin Chalk may pinch out against the disconformity with the underlying Dandaragan Sandstone or the Leederville Formation.

Distribution and thickness: The Gingin Chalk is exposed in the area between Badgingarra and Gingin. In the subsurface it is known as far north as Watheroo. The type section is 19 m thick, and in most areas the thickness approximates 18 m.

Fossils and age: Fossils from the Gingin Chalk were amongst the earliest to be recorded from the Perth Basin (Gregory, 1861). The following forms have been recognized:

Spores and pollen (Ingram, in prep.)

Amosopollis cruciformis Cookson and Pike
Camarozonosporites sp.
Ceratosporites equalis Cookson and Dettmann
Classopollis classoides Pflug
Clavifera triplex (Bolkhovitina)
Cyathidites australis Couper
C. minor Couper
Gleicheniidites senonicus Ross
Microcachryidites antarcticus Cookson
Ornamentifera sentosa Dettmann and Playford
Proteacidites spp.
Tricolpites sp. cf. *T. pachyexinus* Couper
T. pannosus Dettmann and Playford
Triorites harrisii Couper
undifferentiated bisaccates

Microplankton (Cookson and Eisenack, 1968; Ingram, in prep.)

Aiora fenestrata (Deflandre and Cookson)
Amphidiadema denticulata Cookson and Eisenack
Anthosphaeridium convolvuloides Cookson and Eisenack
Apteodinium cribrosum Cookson and Eisenack
Ascodinium sp.
Cassiculosphaeridia reticulata Davey
Chlamydophorella nyei Cookson and Eisenack

C. urna Cookson and Eisenack
Chytroeisphaeridia sp.
Cleistosphaeridium huguonioti (Valensi)
Cribroperidinium edwardsi (Cookson and Eisenack)
Cyclonephelium distinctum Deflandre and Cookson
Deflandrea acuminata Cookson and Eisenack
D. balcattensis Cookson and Eisenack
D. sp. cf. *D. balcattensis* Cookson and Eisenack
D. belfastensis Cookson and Eisenack
D. cooksoni Alberti
D. cretacea Cookson
D. echinoidea Cookson and Eisenack
D. glabra Cookson and Eisenack
D. lata Cookson and Eisenack
D. rectangularis Cookson and Eisenack
D. tripartita Cookson and Eisenack
D. sp. cf. *D. verrucosa* Manum
D. victoriensis Cookson and Manum
D. sp.
Diconodinium sp. cf. *D. multispinum* (Deflandre and Cookson)
Dinogymnium acuminatum Evitt, Clarke, and Verdier
D. nelsonense (Cookson)
D. westralicum (Cookson and Eisenack)
Disphaera macropyla Cookson and Eisenack
Exochosphaeridium phragmites Davey, Downie, Sarjeant, and Williams
Gillinia hymenophora Cookson and Eisenack
Ginginodinium spinulosum Cookson and Eisenack
Heterosphaeridium conjunctum Cookson and Eisenack
H. heteracanthum (Deflandre and Cookson)
Horologinella apiculata Cookson and Eisenack
H. incurvata Cookson and Eisenack
Hystrichosphaera paradoxa Cookson and Eisenack
H. sp. cf. *H. wetzeli* Deflandre
Hystrichosphaeridium stellatum Maier
Leiosphaeridia spp.
Madurodinium pentagonum Cookson and Eisenack
Micrhystridium spp.
Microdinium ornatum Cookson and Eisenack
Nelsoniella aceras Cookson and Eisenack
N. semireticulata Cookson and Eisenack
N. tuberculata Cookson and Eisenack
Odontochitina costata Alberti
O. cribropoda Deflandre and Cookson
O. sp. cf. *O. operculata* (Wetzel)
O. porifera Cookson
O. sp.
Oligosphaeridium complex (White)
O. pulcherrimum (Deflandre and Cookson)
O. sp.
Palaeohystrichopora infusorioides Deflandre
Palaeostomocystis chytra Drugg
P. laevigata Drugg
Senoniasphaera lordi (Cookson and Eisenack)
Spiniferites cingulatus cingulatus (Wetzel)
S. cingulatus perforatus (Clarke and Verdier)
S. ramosus gracilis (Davey and Williams)
S. ramosus ramosus (Ehrenberg)
Stephodinium coronatum Deflandre
Tanyosphaeridium regulare Davey and Williams
Veryhachium spp.
Xenikoon australis Cookson and Eisenack

Coccolithineae (Chapman, 1917)
various coccolith plates

Foraminiferida (Howchin, 1907; Glauert, 1910c; Chapman, 1917; Edgell, 1957; Belford, 1960)

Alabamina australis australis Belford
A. australis obscura Belford
Ammodiscus cretacea (Reuss)
Archaeoglobigerina cretacea (d'Orbigny)
Bolivinitella eleyi (Cushman)
Bolivinoides strigillata strigillata (Chapman)
Cibicides excavata Brotzen
Citharina geisendoerferi (Franke)
C. suturalis (Cushman)
Dentalina basiplanata Cushman
D. cylindroides Reuss
D. gracilis d'Orbigny
D. luma Belford
D. marcki Reuss
D. megalopolitana Reuss
D. sp. B. Belford
Dorothia bulletta (Carsey)
Eponides concinna Brotzen
Frondicularia archiacina d'Orbigny
F. bulla Belford
F. disjuncta Belford
F. mucronata Reuss
F. planifolium Chapman
F. sp. cf. *F. steinekei* Finlay
F. verneuiliana d'Orbigny
F. sp. C. Belford
Gaudryina pulvina Belford
G. rugosa d'Orbigny
Gavelinella insculpta Belford
G. stellula Belford
Globigerinella aspera (Ehrenberg)
Globotruncana lapparenti bulloides Vogler
G. lapparenti lapparenti Brotzen
G. lapparenti tricarinata (Quereau)
G. marginata (Reuss)
G. spinea Kikoine
G. ventricosa White
Goesella chapmani Cushman
Gyroidina sp. cf. *G. girardana* (Reuss)
G. noda Belford
Haerella conica Belford
Heterohelix globulosa (Ehrenberg)
Lagena amphora var. *paucicosta* Franke
L. sulcata (Walker and Jacob)
Marssonella oxycona (Reuss)
Massilina ginginensis Chapman
Nodosaria sp. cf. *N. affinis* Reuss
N. obscura Reuss
N. prismatica Reuss
N. sp.
Palmula sp. aff. *P. pilulata* Cushman
Pullenia cretacea Cushman
Quadrimorphina allomorphinoides (Reuss)
Reussella szajnochae (Gryzbowski)
Rugoglobigerina bulbosa Belford
R. pilula Belford
R. plana Belford
Spiroloculina sp. cf. *S. cretacea* Reuss
Spiroplectammina laevis var. *cretosa* Cushman
Spiroplectinata compressiuscula (Chapman)
Stilostomella aspera (Reuss)
Verneuilina parri Cushman

Porifera (Etheridge Jr., 1913; Glauert, 1925)
Peronidella? globosa (Etheridge Jr.)
Porosphaera globularis (Phillips)

Scleractinia (Etheridge Jr., 1913)
Coelosmilia? ginginensis Etheridge Jr.

Brachiopoda (Etheridge Jr., 1913; Elliott, 1952; Feldtmann, 1963)
Bouchardiella cretacea (Etheridge Jr.)
cf. *Burmirhynchia* sp.
Crania sp.
Inopinatarcula acanthodes (Etheridge Jr.)
Kingena mesembrina (Etheridge Jr.)
Magnithyris sp.
cf. *"Rhynchonella" limbata* Sowerby
Terebratulina sp.

Bivalvia (Etheridge, Jr., 1913; Feldtmann, 1951, 1963)
Anomia fragilis Feldtmann
A. prideri Feldtmann
Camptonectes ellipticus Etheridge Jr.
Chlamys clarkei Feldtmann
C. curvicosta Feldtmann
C. ginginensis Feldtmann
C. subtilis Feldtmann
C. teicherti Feldtmann
Exogyra variabilis Feldtmann
Gryphaea minuta Feldtmann
G. teicherti Feldtmann
Inoceramus sp. cf. *I. maximus* Lumholz
Mytilus piriformis Etheridge Jr.
Ostrea etheridgei Feldtmann
O. macintyrei Feldtmann
O. philbeyi Feldtmann
Perna coolyensis Feldtmann
Plicatula glauerti Feldtmann
Pseudamussium candidus Feldtmann
Pycnodonte ginginensis Etheridge Jr.
P. strathalbynensis Feldtmann
Spondylus ginginensis Feldtmann
Syncyclonema (Ctenioplеurium) perspinosus Feldtmann
S. (C.) subreticulatus Feldtmann
S. (C.) subserratus Feldtmann

Gastropoda (Feldtmann, 1963)
cf. *Pleurotomaria* sp.

Ammonoidea (Etheridge Jr., 1913; Spath, 1926; Feldtmann, 1963)
Eubaculites sp.
cf. *Eupachydiscus* sp.
Glyptoxoceras sp.
cf. *Parapuzosia* sp.

Amphineura (Feldtmann, 1963)
amphineuran plate

Annelida (Etheridge Jr., 1913)
Rotularia gregaria (Etheridge Jr.)
R. pyramidale (Etheridge Jr.)
Serpula fluctuata Sowerby
Spirorbis sp.

Cirripedia (Etheridge Jr., 1913; Withers, 1923, 1926; Glaessner, 1957)
Calantica (Scillaelepas) ginginensis (Etheridge Jr.)
Euscalpellum sp.
Mesoscalpellum glauerti (Withers)
Zeugmatolepas australis Withers

Ostracoda (Chapman, 1917; Bate, 1972; Neale, 1975)

Apateloschizocythere geniculata Bate
Bairdia sp. cf. *B. austracretacea* Bate
Bythocypris chapmani Neale
B. howchiniana Chapman
Collisarboris cooki Neale
Cretaceratina trispinosa Neale
Cythereis brevicosta obtusa Neale
Cytherella jonesi Neale
C. ludbrookae Neale
Cytherelloidea colemani Neale
C. lunata Neale
C. westaustraliensis Bate
Cytheropteron (Cytheropteron) collisarboris Neale
C. (Aversovalva) mccomborum Neale
C. (A.) sp. cf. *C. (A.) mccomborum* Neale
C. (A.) westaustraliense Neale
Eorotundracythere compta Bate
Eucytherura (Eucytherura) antipodum Neale
E (E.) fissipunctata Neale
Ginginella ginginensis Neale
Hemingwayella ornata Neale
Hemiparacytheridea hemingwayi Neale
Hermanites volans Neale
Hystrichocythere imitata Bate
Limburgina aurora Neale
Macrocypris australiana Neale
Majungaella verseyi Neale
Munseyella tuberculata Neale
Oculocytheropteron praenuntatum Bate
Paracypris n. sp. Neale
Paramunseyella austracretacea Bate
P. prideri Neale
Pedicythere australis Neale
P. sp.
Pennyella pennyi Neale
Pontocyprella? sp.
Premunseyella imperfecta Bate
Rayneria ginginensis Neale
Rostrocytheridea westraliensis (Chapman)
Saida rhomboidea Neale
Scepticocythereis ornata Bate
Semicytherura augusta Neale
S. cretae Neale
Tickalaracythere annula (Bate)
Trachyleberis pennyi Neale
T. raynerae Neale
Uroleberis batei Neale
Verseya pulchra Neale

Insecta (Etherdige Jr., 1913)

?Coleopteran elytra

Crinoidea (Withers, 1924, 1926; Philip, 1963)

Marsupites testudinarius (Schlotheim)
Uintacrinus socialis Grinnel

Echinoidea (Glauert, 1923a; Feldtmann, 1963)

Cidaris comptoni Glauert
cf. *Hemiaster* sp.
cf. *Holaster* sp.

Vertebrata (Feldtmann, 1963)

cf. *Apateodus* sp.

The abundant coccolith assemblage in the formation has yet to be described.

Glauert (1910d) was the first to recognize the Cretaceous age of the Gingin Chalk, although it was not until 1924 when Withers identified *Uintacrinus* that a Santonian age was established. Feldtmann (1951, 1963) has given details of the stratigraphical ranges of various fossils in the formation. At the type section he has shown that *Uintacrinus* occurs from 0 to 4.04 m and *Marsupites* from 4.04 to 6.17 m above the base of the Gingin Chalk. These crinoid genera define the *Uintacrinus* subzone and the *Marsupites* subzone respectively of the *Marsupites testudinarius* zone of the English Chalk. This zone is of late Santonian age. The restriction of these fossils to the lower part of the Gingin Chalk and the presence of the foraminifer *Rugoglobigerina,* not known elsewhere below the Campanian, suggests that the formation is of Santonian-Campanian age.

Environment of deposition: The Gingin Chalk is typical of the widespread chalk deposits that were laid down throughout much of the world during the Late Cretaceous. The unit was deposited on the floor of a shallow warm sea supporting abundant marine life and receiving very little terrigenous detritus.

Poison Hill Greensand

Definition: The name Poison Hill Greensand was proposed by Fairbridge (1953) for the sequence of greensand overlying the Gingin Chalk. The type section is located at Poison Hill (lat. 31° 18′S, long. 115° 53′E), 6.5 km north-northwest of Gingin. The following is a description of this section:

Poison Hill Greensand (23 m)	Thickness (metres)
Upper limit of formation not exposed; overlain by laterite.	
3. Sandstone, glauconitic, coarse-grained, brown; poorly sorted; containing coarse quartz sand and granules; grains well rounded, with small-scale cross-bedding; unit silicified and ferruginized	14.1
2. Sandstone, glauconitic, medium-grained, grey-green to brown; poorly sorted, with some coarse sand and clay; grains well rounded; contains scattered concretions of poorly sorted sandstone; traces of invertebrate burrows; thickly bedded	5.3
1. No exposure	3.6
Conformably overlies Gingin Chalk.	

The glauconite content of this section is believed to have been strongly reduced by weathering.

Lithology: The Poison Hill Greensand consists of greensand and glauconitic sandstone with thin shaly beds. The sediments are generally strongly weathered in outcrop (to depths of about 20 m below laterite) yielding a brown sandstone which is commonly ferruginous and may or may not retain some glauconite. Silicification has also occurred at the surface in some areas. Bedding is generally only crudely developed, with gentle cross-bedding in some areas. In general the arenites are very fine to medium grained in the lower part of the unit, becoming coarse to very coarse grained in the upper part. A feature of much of the formation is the high degree of roundness and sphericity of the quartz sand grains. In some areas (for example near Mungedar homestead) the uppermost exposed beds are pebbly, and they grade into fine conglomerate, with pebbles of quartzite, and very fine-grained micaceous sandstone.

Fairbridge (1953) records that the iron phosphate, dufrenite, occurs in a bed 15 to 20 m above the base of the formation, but this has not been confirmed in our work.

Stratigraphic relationships: Over most of its extent the Poison Hill Greensand conformably overlies the Gingin Chalk and is capped by laterite and associated Quaternary deposits. However, in some areas the formation may rest directly on the Dandaragan Sandstone or the Leederville Formation. It appears to be the only unit of the Coolyena Group that completely covered the irregular surface of the disconformity on top of the Warnbro Group.

Distribution and thickness: The Poison Hill Greensand is the most widespread unit of the Coolyena Group. It is exposed in a belt from near Badgingarra to south of Gingin, and also occurs in the subsurface as far north as Watheroo. The type section is 23 m thick, and the total maximum thickness of the formation probably exceeds 45 m.

Fossils and age: No macrofossils have yet been found in undoubted Poison Hill Greensand, but an abundant microflora has been recorded.

Spores and pollen (Ingram, in prep.)

- *Amosopollis cruciformis* Cookson and Balme
- ?*Balmeisporites* sp.
- *Camarozonosporites* sp. aff. *C. ambigens* (Fradkina)
- *C. amplus* (Stanley)
- *C. bullatus* Harris
- *C.* spp.
- *Cingutriletes clavus* (Balme)
- *Clavifera triplex* (Bolkhovitina)
- *Cyathidites australis* Couper
- *C. concavus* (Bolkhovitina)
- *C. minor* Couper
- *Gleicheniidites senonicus* Ross
- *Laevigatosporites major* (Cookson)
- ?*Liliacidites* sp.
- *Microcachryidites antarcticus* Cookson
- *Nothofagidites senectus* Dettmann and Playford
- *Ornamentifera sentosa* Dettmann and Playford
- ?*O.* sp.
- ?*Polyporopollenites* sp.
- *Proteacidites* spp.
- *Stereisporites antiquasporites* (Wilson and Webster)
- ?*Tetracolporites* sp.
- *Tricolpites* sp. cf. *T. pachyexinus* Couper
- *T. pannosus* Dettmann and Playford
- *Triorites edwardsi* Cookson and Pike
- *T. harrisii* Couper
- undifferentiated bisaccates

Microplankton (Edgell, 1964a; Ingram, in prep.)

Chlamydophorella urna Cookson and Eisenack
Cleistosphaeridium huguonioti (Valensi)
Cribroperidinium sp.
Cymatiosphaera pterota Cookson and Eisenack
Deflandrea acuminata Cookson and Eisenack
D. balcattensis Cookson and Eisenack
D. balmei Cookson and Eisenack
D. belfastensis Cookson and Eisenack
D. cooksoni Alberti
D. cretacea Cookson
D. echinoidea Cookson and Eisenack
D. korojonensis Cookson and Eisenack
D. macrocysta Cookson and Eisenack
D. nucula Cookson and Eisenack
D. pellucida Deflandre and Cookson
D. serratula Cookson and Eisenack
D. spectabilis Alberti
D. sp.
Diconodinium sp. cf. *D. glabrum* Eisenack and Cookson
D. sp. cf. *D. multispinum* (Deflandre and Cookson)
Dinogymnium euclaensis Cookson and Eisenack
D. nelsonense (Cookson)
D. westralicum (Cookson and Eisenack)
D. sp.
Gillinia hymenophora Cookson and Eisenack
Heterosphaeridium heteracanthum (Deflandre and Cookson)
Hologinella apiculata Cookson and Eisenack
Hystrichosphaeridium sp.
Lecaniella margostriata Cookson and Eisenack
Leiosphaeridia spp.
Madurodinium pentagonum Cookson and Eisenack
Micrhystridium spp.
?*Muderongia* sp.
Nelsoniella aceras Cookson and Eisenack
N. semireticulta Cookson and Eisenack
N. tuberculata Cookson and Eisenack
Odontochitina costata Alberti
O. porifera Cookson
Palaeohystrichophora infusorioides Deflandre
Palaeoperidinium spinosum Cookson and Hughes
Palaeostomocystis apiculata Cookson and Eisenack
P. chytra Drugg
P. laevigata Drugg
P. reticulata Deflandre
Platycystidia diptera Cookson and Eisenack
Spiniferites cingulatus cingulatus (Wetzel)
S. ramosus ramosus (Ehrenberg)
Trigonopyxidia ginella (Cookson and Eisenack)
aff. *T.* sp.
Veryhachium spp.
Xenikoon australis Cookson and Eisenack

The microplankton suggest that the formation is of Campanian age with the upper part possibly extending into the Maastrichtian (Ingram, B. S., pers. comm., 1973).

Environment of deposition: The Poison Hill Greensand is a marine deposit which is thought to represent the regressive phase of the Late Cretaceous transgression.

LANCELIN BEDS

Definition: The name Lancelin Beds was introduced by Edgell (1964c) for the unit of light-grey marl which underlies Quaternary sands in the Lancelin No. 2B bore (lat. 31° 04′ 00″S, long. 115° 19′ 20″E) near the township of Lancelin. The following is a description of the section in this bore (after Morgan, 1965):

	Interval & thickness (metres)
Tamala Limestone, unconformably overlying—	
Lancelin Beds (14 m)	
1. Marl, green-grey, glauconitic, slightly sandy; with abundant shell fragments, including *Inoceramus* prisms, brachiopods and sponge spicules	32-46 14

Base of unit not penetrated.

Lithology: The Lancelin Beds consist of light-grey marl containing glauconite and abundant *Inoceramus* fragments. The lithology resembles that of parts of the Gingin Chalk.

Stratigraphic relationships: The unit underlies Quaternary deposits and its base is not known. Its relationships with other Upper Cretaceous units has not been established, but it is likely to be equivalent to the upper part of the Gingin Chalk.

Distribution and thickness: The unit is known only from bores at Lancelin. It is 14 m thick in the type section.

Fossils and age: The following fossils have been recorded from the Lancelin Beds. With the exception of the Porifera and Brachiopoda, all identifications are taken from Edgell (1964c).

Spores and pollen

- ?*Appendicisporites* sp.
- cf. *Araucariacites australis* Cookson
- *Cingulatisporites* sp. aff. *C. valdensis* Couper
- *Gleicheniidites circinidites* (Cookson)
- *Inaperturopollenites emmaensis* Mürr and Pflug
- *Microreticulatisporites scrobiculatus* Ross
- *Pityosporites* sp. cf. *P. microalatus* (R. Potonié)
- *Tricolpites pachexinus* Couper
- *Trilobozonosporites rotalis* (Weyland and Krieger)
- cf. *Vacuopollis semiconcavus* Pflug

Microplankton

- *Aiora* sp. cf. *A. fenestrata* (Cookson and Eisenack)
- *Deflandrea cretacea* Cookson
- *D. echinoidea* Cookson and Eisenack
- *Diconodinium multispinum* (Deflandre and Cookson)
- *D*. sp. aff. *D. spinosissima* (Deflandre)
- *Ginginodinium* sp. aff. *G. spinulosum* Cookson and Eisenack
- *Gonyaulax margaritifera* Cookson and Eisenack
- *Gymnodinium westralium* Cookson and Eisenack
- *Hystrichosphaera furcata* (Ehrenberg)
- *Hystrichosphaeridium complex* (White)
- *H. eoinodes* Eisenack
- *H. heteracanthum* Deflandre and Cookson
- *H*. sp. cf. *H. isocalamus* Deflandre and Cookson
- *H. ramuliferum* Deflandre

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Nelsoniella aceras Cookson and Eisenack
Odontochitina porifera Cookson
Pterospermopsis australiensis Deflandre and Cookson

Foraminiferida

Anomalina rubiginosa Cushman
Archaeoglobigerina cretacea (d'Orbigny)
Bolivinitella eleyi (Cushman)
Bolivinoides granulatus Hofker
Cibicides excavata Brotzen
Dentalina basiplanata Cushman
D. catenula Reuss
Dorothia biformis Finlay
D. bulletta (Carsey)
Ellipsoidella sp. cf. *E. solida* (Brotzen)
Eouvigerina americana Cushman
Frondicularia mucronata Reuss
F. teuria Finlay
Globigerinella aspera (Ehrenberg)
Globotruncana arca (Cushman)
G. mariai Gandolfi
G. ventricosa White
Guttulina hantkeni Cushman and Ozawa
Gyroidina nitida Reuss
Heterohelix globulosa (Ehrenberg)
H. planata (Cushman)
Lagena amphora var. *paucicosta* Franke
L. hexagona (Williamson)
L. sulcata (Walker and Jacob)
Marginulina sp. cf. *M. curvisepta* Cushman and Goudkoff
M. decursecostata Thalmann
M. sp. cf. *M. trinitatensis* Cushman
Marssonella oxycona Reuss
Massilina sp. cf. *M. ginginensis* Chapman
Neoflabellina praereticulata Hiltermann
Nodosaria prismatica Reuss
Planularia sp. aff. *P. leibusi* Brotzen
Planulina rakauroana Finlay
Praebulimina ovulum (Reuss)
Pseudoguembelina striata (Ehrenberg)
Pullenia cretacea Cushman
Robulus macrodiscus
R. spp.
Rugoglobigerina sp. cf. *R. rugosa* (Plummer)
Spiroplectammina gryzbowskii Frizzell
Stensioina n. sp.
Valvulineria allomorphinoides Reuss
Vernelilina parri Cushman

Porifera

sponge spicules

Brachiopoda

shell fragments

Bivalvia

Inoceramus sp.

The general aspect of this fauna is similar to that of the Gingin Chalk. The presence of certain foraminifers, in particular *Bolivinoides granulatus* and *Neoflabellina praereticulata*, indicates a Campanian age for the Lancelin Beds (Edgell, 1964c).

Environment of deposition: The Lancelin Beds are a marine unit, laid down in a warm sea receiving little terrigenous detritus.

BUNBURY BASALT

Definition: The Bunbury Basalt was named the "Bunbury lava flow" by Saint-Smith (1912), and the present name was formalized by McWhae and others (1958). The formation consists of basalt lying between the Yarragadee Formation below and the Leederville Formation above. The type locality is along the beach on the west side of Bunbury (lat. 33° 19′ 30″S, long. 115° 37′ 40″E).

Lithology: The Bunbury Basalt consists of porphyritic or microporphyritic basalt flows (Edwards, 1938; Trendall, 1963). The rock is commonly vesicular, and it shows well-developed columnar jointing in some areas (Fig. 41).

Stratigraphic relationships: In the subsurface the Bunbury Basalt disconformably overlies the Yarragadee Formation and is overlain with apparent conformity by the Leederville Formation. In outcrop the basalt is overlain by Pleistocene Tamala Limestone, and its base is not exposed, other than at the base of the cliffs 1.6 km northwest of Black Point where it overlies Yarragadee Formation.

Distribution and thickness: The Bunbury Basalt crops out at several localities between Bunbury and Black Point, extending as far east as the Darling Fault and as far west as Scott River (Lowry, 1965). The subsurface distribution of the unit has been delineated by aeromagnetic and gravity surveys (Felcman and Lane,

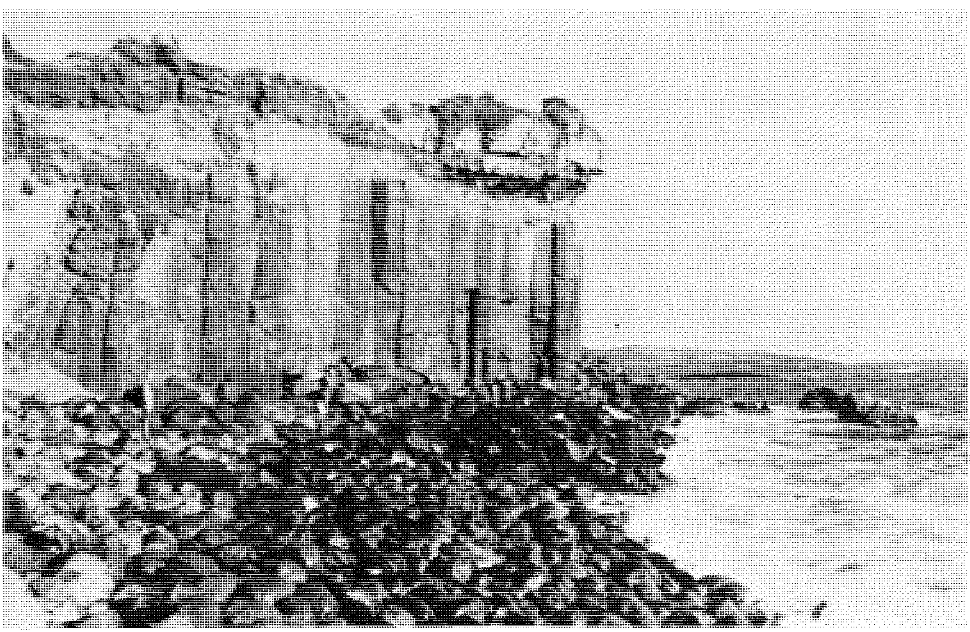

Figure 41. Black Point, southern Perth Basin, a prominent exposure of columnar-jointed Bunbury Basalt.

1963), and is shown as Figure 48. The maximum exposed thickness is 12 m, 1.6 km northwest of Black Point, while the thickest subsurface section is 85 m, in the Boyanup bore. Two basalt units, 21.5 m and 49.1 m thick, are present in Quindalup No. 6 bore.

The Bunbury Basalt is thought to represent successive lava flows, which were spread along valleys eroded into the Yarragadee Formation prior to deposition of the Leederville Formation.

Age: The Bunbury Basalt is probably of Neocomian age. B. E. Balme (pers. comm., 1969) believes on palynological grounds that the sediments immediately above the basalt in Abba River No. 3 bore (Leederville Formation) are Early Cretaceous, whereas those that occur unconformably below (Yarragadee Formation) are Late Jurassic.

Basalt penetrated at the base of a bore drilled at Deep Sea Drilling Project site 259 on the continental rise opposite Geraldton is dated as 118 to 136 m.y. (Heirtzler and others, 1973) and is probably equivalent in age to the Bunbury Basalt. Dolerite that intrudes the Permian Sue Coal Measures in Sue No. 1 (Glover, *in* Williams and Nicholls, 1966) and Blackwood No. 1 wells may be comagmatic with the Bunbury Basalt. The occurrence in Sue No. 1 has been dated as 136 ± 3 m.y. (written comm. from B.M.R., 1972).

UNNAMED SEQUENCE IN GUN ISLAND No. 1 WELL

The Cretaceous sequence in Gun Island No. 1 well near the northern margin of the Perth Basin can be divided into three units, presently unnamed. The upper unit, from 391 to 405 m, consists of yellow, ferruginous, silty limestone grading down into hard white limestone with *Inoceramus* fragments. This overlies a clastic unit (from 405 to 524 m) of fine to coarse-grained sandstone with minor grey siltstone and claystone, which is carbonaceous in part and is glauconitic at the top. This unit has yielded foraminifers including *Globotruncana linneiana* (d'Orbigny) and *Rugoglobigerina* sp. cf. *R. rugosa pennyi* Bronnimann which Schuyleman (*in* Hawkins, 1969) regarded as possibly Campanian in age. The lower unit, from 524 to 908 m, consists mainly of coarse-grained unlithified sand interbedded with black, ferruginous, carbonaceous siltstone and red mudstone, grading down into fine to coarse-grained sand.

Correlation of the stratigraphic units in the Gun Island No. 1 well with the sequence in the rest of the Perth Basin is indefinite. However, the upper two units are tentatively correlated with the Coolyena Group and the lower unit with the Warnbro Group.

TERTIARY

No rocks of undoubted Tertiary age are known to crop out in the Perth Basin, although some unfossiliferous continental deposits exposed in the northern part are believed to be of this age. Part of the widespread laterite and its associated sand are probably Tertiary, but as much of the laterite seems to be Pleistocene, it is described in the Quaternary section of this bulletin.

Tertiary sedimentary rocks are known from bores drilled in the Perth metropolitan area, and offshore on the continental shelf, continental slope, and Naturaliste Plateau (Fig. 38). Paleocene, Eocene, Miocene, and Pliocene rocks are represented, and their maximum thickness probably exceeds 600 m. The Paleocene and Eocene sequence is largely shale and siltstone, with some sandstone and limestone, while the younger sequence consists mainly of carbonates.

KINGS PARK FORMATION

Definition: The name "Kings Park Shale" was introduced by Fairbridge (*in* Coleman, 1952) for the unit consisting mainly of shale and siltstone which overlies Cretaceous and Jurassic rocks in the subsurface of the Perth area, and is overlain by Quaternary deposits. The name was amended to Kings Park Formation by Quilty (1974) as shale is not the dominant lithology in many sections. The type section is in the Kings Park No. 2 bore (lat. 31° 58′ 30″S, long. 115° 50′ 30″E). The following is a description of this section, as deduced from the drilling log and samples that have been preserved:

	Interval & thickness (metres)
Tamala Limestone, disconformably overlying—	
Kings Park Formation (469 m)	
4. Siltstone, sandy, light-grey, calcareous, micaceous, glauconitic, ferruginous in part, with shell fragments and well-rounded quartz grains	23-66 43
3. "Sand". No samples retained	66-146 80
2. Siltstone, grey, calcareous, abundant shell fragments, glauconitic, slightly micaceous in part, with quartz pebbles and grains, very fossiliferous	146-361 215
1. Shale, silty, light-grey, calcareous, abundant fragmented shells, glauconitic, with well-sorted quartz grains; interbedded in the lower part with thin lenses of sandy, glauconitic siltstone; with bands of silty, sandy, grey limestone	361-492 131
Unconformably overlying Leederville Formation.	

Quilty (1974) introduced the name *Mullaloo Sandstone Member* of the Kings Park Formation for the unit penetrated between 68 and 365 m in Quinns Rock No. 1 well. This member also occurs in Charlotte No. 1 well and near the top of the formation in the Claremont Asylum water bores.

Lithology: In most sections the lithology of the Kings Park Formation is essentially as described for the type section. The lowermost unit in bores in the Perth area consists dominantly of grey, calcareous, glauconitic siltstone and shale, with bands of hard, dense, glauconitic limestone. Above this is a sand or sandstone unit, followed by a unit of light-grey, calcareous, sandy, glauconitic siltstone. Overlying the upper siltstone unit in the Rottnest Island bore is a unit of sand or friable sandstone referred to informally by J. R. H. McWhae (*in* Quilty, 1974) as the "Rottnest Sandstone". It is not sure whether this unit should be regarded as belonging to the Kings Park Formation. It was included in that unit by Playford and Willmott (1958), but was excluded by Quilty (1974). However, it seems possible that this unit correlates with the Mullaloo Sandstone Member, which consists of poorly sorted, fine to very coarse-grained quartz sandstone with a clayey matrix. Part of this sandstone is glauconitic.

Stratigraphic relationships: The Kings Park Formation disconformably overlies the Coolyena Group, Leederville Formation, or South Perth Shale, or it overlies the Yarragadee Formation with angular unconformity. It is overlain disconformably by younger Tertiary or Quaternary deposits.

Distribution and thickness: The Kings Park Formation is recognized only from bores in the Perth metropolitan area and from some of the offshore wells opposite Perth and on Rottnest Island. It apparently fills an old river valley or submarine canyon which was deeply incised into the Osborne Formation, Leederville Formation, South Perth Shale, and Yarragadee Formation. The formation pinches out abruptly north and south of Perth against the margins of the ancient valley or submarine canyon.

The thickest known section of the Kings Park Formation in the Perth metropolitan area is in the Claremont Asylum No. 1 bore (532 m), while the type section in Kings Park No. 2 bore is 469 m thick. Its thickness in Warnbro No. 1 well is 215 m, and in the Rottnest Island bore it is 597 m (if the upper sandstone unit is included in the formation) or 382 m (if that sandstone is excluded).

Fossils and age: An extensive fauna and flora, dominated by foraminifers, has been recorded from the Kings Park Formation. A characteristic feature of the fauna is the small size of the individual foraminifers. The following fossils have been identified:

Pollen (Cookson and Eisenack, 1961; Cockbain and Ingram, 1967)

Anacolosidites acutulus Cookson and Pike
Beaupreidites elegansiformis Cookson and Pike
Nothofagidites emarcida (Cookson)
Proteacidites incurvatus Cookson
P. pachypolus Cookson and Pike
Triorites harrisii Couper

together with the following Jurassic and Cretaceous spores and pollen which Cookson and Eisenack (1961) suggest are derived:

Classopollis torosus Reissinger
Hoegisporis lenticulifera Cookson
Zonalopollenites dampieri Balme

Microplankton (Cookson and Eisenack, 1961; Cockbain and Ingram, 1967)

Baltisphaeridium paucifurcatum (Cookson and Eisenack)
Cannosphaeropsis sp. cf. *C. caulleryi* (Deflandre)
Cordosphaeridium floripes breviradiatum (Cookson and Eisenack)
C. floripes floripes (Deflandre and Cookson)
Crassosphaera stellulata Cookson and Manum
Deflandrea bakeri Deflandre and Cookson

D. phosphoritica phosphoritica Eisenack
D. phosphoritica australis Cookson and Eisenack
Diphyes colligerum (Deflandre and Cookson)
Hologinella incurvatum Cookson and Eisenack
Hystrichosphaeropsis borussica (Eisenack)
Leptodinium maculatum Cookson and Eisenack
Psaligonyaulax simplicia (Cookson and Eisenack)
Svalbardella sp. cf. *S. cooksoniae* Manum
Thalassiphora velata (Deflandre and Cookson)
Wetzeliella intermedia Cookson and Eisenack
W. lineidentata Deflandre and Cookson

together with the following Cretaceous forms which Cookson and Eisenack (1961) suggest may be derived:

Deflandrea echinoidea Cookson and Eisenack
Diconodinium dispersum Cookson and Eisenack
Gonyaulax hyalodermopsis Cookson and Eisenack
Nelsoniella aceras Cookson and Eisenack
N. semireticulata Cookson and Eisenack
N. tuberculata Cookson and Eisenack
Odontochitina porifera Cookson

Foraminiferida (Parr, 1938; Coleman, 1952; McGowran, 1964, 1965; Cockbain and Ingram, 1967; Quilty, 1974)

Alabamina westraliensis (Parr)
Ammodiscus sp. aff. *A. incertus* (d'Orbigny)
Angulogerina subangularis Parr
Anomalinoides sp. aff. *A. nobilis* Brotzen
A. perthensis (Parr)
A. sp. cf. *A. praespissaeformis* (Cushman and Bermudez)
A. westraliensis Parr
Astacolus sp. aff. *A. gladius* (Philippi)
Bathysiphon sp.
Bolivinoides oedumi (Brozten)
Bulimina esnaensis LeRoy
Buliminella westraliensis Parr
Cassidulina sp. cf. *C. globosa* Brady
Ceratobulimina westraliensis Parr
Chiloguembelina crinita (Glaessner)
C. trinitatensis (Cushman and Renz)
Cibicides sp. aff. *C. spiropunctatus* Galloway and Morrey
C. umbonifer Parr
C. whitei Martin
C. sp. 1. McGowran
Citharina plummoides (Plummer)
C. sp. 1. McGowran
Conorbina sp.
Cornuspira involvens (Reuss)
Cyclammina incisa (Stache)
Dentalina colei Cushman and Dusenbury
?*D.* sp. aff. *D. eocenica* Cushman
D. insulsa Cushman
D. sp. cf. *D. plummerae* Cushman
D. soluta Reuss
Discorbis assulatus Cushman
Enantiomorphina sp. cf. *E. lemoinei* Marie
Epistominoides sp. cf. *E. midwayensis* Plummer
Fissurina sp. cf. *F. laevigata* Reuss
Frondicularia mucronata Reuss
?*Gaudryina subquadrata* Cushman
Globulina gibba d'Orbigny
Guttulina sp. cf. *G. hantkeni* Cushman and Ozawa
G. lactea (Walker and Jacob)
G. problema d'Orbigny species group
Gyroidincides octocamerata (Cushman and Hanna)
G. sp.
Heronallenia sp. cf. *H. parri* Carter

H. pusilla Parr
Hoeglundina scalaris (Franke)
Karreria pseudoconvexa (Parr)
Kolesnikovella angusta McGowran
Lagena sp. cf. *L. acuticosta* Reuss
L. sp. cf. *L. amphora* Reuss
L. hexagona (Williamson)
L. luciae Parr
L. perthensis Parr
L. terrilli Parr
Lamarckina naheolensis Cushman and Todd
L. rugulosa Plummer
Marginulina hamulus Chapman
Nodosaria latejugata Gümbel
N. sp. cf. *N. longiscata* d'Orbigny
Nonion novozealandicus Cushman
Osangularia plummerae Brotzen
Patellina advena Cushman
Pseudonodosaria manifesta (Reuss)
Pullenia quinqueloba (Reuss)
Quinqueloculina seminulum (Linné)
Q. venusta Karrer
Q. vulgaris d'Orbigny
Rectoglandulina clarkei (Parr)
Robertinoides sp.
Robulus reussi Haque
Saracenaria sp. aff. *S. hantkeni* Cushman
Siphonina (Pulsiphonina) prima (Plummer)
Spirobolivina emmendorferi (Jennings)
Spiroplectammina sp.
Tobolia sp. aff. *T. veronica* Dain
Vaginulina longiforma (Plummer)
Valvulineria sculpturata Cushman
Zeauvigerina aegyptica Said and Kenawy

Paleocene planktonic foraminifers:

Globigerina linaperta Finlay species group
G. mckannai White
Globorotalia chapmani Parr
G. pseudomenardii Bolli
G. pusilla laevigata Bolli
G. velascoensis parva Rey

Early Eocene planktonic foraminifers:

Globigerina linaperta Finlay species group
G. mckannai White
G. sp. cf. *G. taroubaensis* Bronnimann
G. triangularis White
Globorotalia aequa Cushman and Renz
G. broedermanni Cushman and Bermudez
G. dolabrata Jenkins
Pseudogloboquadrina primitiva Finlay
Pseudohastigerina pseudoiota (Hornibrook)

Porifera (Chapman *in* Parr, 1938)

Geodia sp.
Geodites sp.

Scleractinia (Wells, 1942)

?*Oculina* sp.
Trematrochus lateroplenus Dennant

Bryozoa (Stach *in* Parr, 1938)

Costaticella benecostata (Levinsen)
Crisia acropora Busk
Entalophora sp.
Idmonea sp.
Mesostomaria angustiloba (Busk)

Crustacea (other than Ostracoda; Glaessner, 1957)
Protocallianassa australica Glaessner

Ostracoda (Coleman, 1952)
Bairdia sp.
Cythere sp.

The type section of the Kings Park Formation was originally dated as Late Eocene by Parr (1938), but Crespin (*in* Coleman, 1952) suggested that a Paleocene age was more likely. This was confirmed by McGowran (1964) who pointed out that the Kings Park Formation species *Globorotalia chapmani* Parr is a widespread Paleocene foraminifer known elsewhere under other names. Both Cookson and Eisenack (1961) and Cockbain and Ingram (1967) thought that the Kings Park Formation in the Rottnest Island bore was slightly younger and could be Eocene. Subsequently Quilty (1974) has demonstrated that while the type section is of late Paleocene age (Zone P4), the formation in the Rottnest Island bore and the Quinns Rock No. 1 well is early Eocene (Zones P6 to P7). Claremont Asylum No. 2 bore is the only section through the Kings Park Formation in which both Zones P4 and P6 have been recorded (Cockbain, 1973b). The presence of Zone P5 has not been established but it is not certain whether this is due to lack of samples or to a disconformity.

Environment of deposition: The Kings Park Formation is a shallow-marine to estuarine deposit laid down in a drowned river valley (the "ancestral Swan River") or submarine canyon. This valley or canyon may once have connected with the Perth Canyon, which now cuts the continental slope west of Rottnest Island.

STARK BAY FORMATION

Definition: The name Stark Bay Formation was introduced by Quilty (1974) for the Miocene carbonate unit encountered in the Gage Roads, Roe, and Charlotte offshore wells opposite Perth. The type section is in Gage Roads No. 2 well over the interval 362-577 m. The following is a description of this section:

	Interval & thickness (metres)
Unnamed, undated carbonate unit, overlying—	
Stark Bay Formation (215 m)	
4. Calcarenite, light-grey, fine-grained, abundant fossil fragments, traces of glauconite; and white and orange-brown, very fine-grained, hard, massive dolomite, with abundant fossil fragments	362-427 65
3. Dolomite, dark-grey to brown, friable, saccharoidal, crystalline, with minor pyrite; and very hard, translucent chert	427-514 87
2. Dolomite, brown, medium-grained, friable, saccharoidal	514-544 30
1. Calcarenite, white; brown, siliceous, crystalline dolomite; and white to light-grey and dark-brown, very hard, translucent chert	544-577 33

Disconformably overlying Leederville Formation.

Lithology: The Stark Bay Formation consists of friable white bryozoan and echinodermal calcarenite, brown dolomite, and chert.

Stratigraphic relationships: The Stark Bay Formation disconformably overlies the Kings Park Formation or Lower Cretaceous units and is overlain by an unnamed carbonate unit. The nature of the upper contact is unknown.

Distribution and thickness: The Stark Bay Formation is known only from offshore wells opposite Perth: Gage Roads Nos. 1 and 2, Roe. No. 1, and Charlotte No. 1. In Gage Roads No. 1 the formation is 230 m thick, and this is the thickest known section.

Fossils and age: Quilty (1974) records the following fossils from the Stark Bay Formation:

Foraminiferida
- *Globigerina* sp. cf. *G. euapertura* Jenkins
- *G. woodi woodi* Jenkins
- *Globigerinoides quadrilobatus trilobus* (Reuss)
- *G. sicanus* de Stefani
- *Globoquadrina dehiscens* (Chapman, Parr, and Collins)
- *Globorotalia archeomenardii* Bolli
- *G. barisanensis* LeRoy
- *G. obesa* Bolli
- *Lepidocyclina* sp. cf. *L. howchini* Crespin
- *Orbulina universa* d'Orbigny
- *Pavonina triformis* Parr
- *Praeorbulina transitoria* (Blow)
- *Sherbornina cuneimarginata* Wade

Echinodermata
- fragments

Bryozoa
- fragments

The planktonic foraminifers indicate that the formation is of late Early Miocene to early Middle Miocene age (Zones N7 to N9) (Quilty, 1974). The presence of the larger foraminifer *Lepidocyclina* and the planktonic foraminifer *Orbulina* is particularly interesting.

Environment of deposition: The Stark Bay Formation is a carbonate unit laid down under marine conditions with almost no influx of terrigenous material.

VICTORIA PLATEAU SANDSTONE

Definition: The name "Victoria Plateau Beds" was given by Johnson and others (1954) to the sequence of sandstone overlying the Permian sequence and overlain by laterite in the Irwin River area. Earlier, Clarke and others (1951) had used the name "Plateau Beds" for the unit. The name was raised to formation status by Playford and Willmott (1958). The type section is at High Cliff (lat. 29° 56′ 40″S, long. 115° 32′ 45″E) and this is described below (after Playford and Willmott, 1958):

Victoria Plateau Sandstone (20 m)	Thickness (metres)
Top of formation not exposed, capped by soil and laterite debris.	
16. Sandstone, fine-grained, silty, light-yellow-brown or white, bedded to poorly bedded; with a few beds of partly ferruginous, hard, fine conglomerate	5.5
15. No exposure	2.1
14. Sandstone, very fine-grained, silty, grey, unbedded	0.9
13. Sandstone, fine to very fine-grained, cream to white, unbedded, massive, fairly well-sorted, friable to firm	0.6
12. Sandstone, medium to coarse-grained, clayey, silty, light-grey, poorly sorted, firm	0.1
11. Sandstone, fine to very fine-grained, as for unit 13	1.2
10. Sandstone, fine to coarse-grained, light-yellow-brown to cream, poorly sorted, friable to firm	6.0
9. Sandstone, fine-grained, very light-grey, crudely bedded, friable to firm	0.6
8. Sandstone, fine-grained, yellow-brown, unbedded, well-sorted, friable	0.15
7. Sandstone, medium-grained, clayey, white, unbedded, poorly sorted, firm	0.6
6. Sandstone, fine-grained, pale-yellow to pale-yellow-brown, well-sorted, unbedded, grains subrounded to rounded	0.45
5. Sandstone, fine-grained, pale-yellow-brown, poorly sorted, friable to soft, grains subrounded to rounded	0.45
4. Sandstone, fine-grained, white, poorly sorted, grains friable to soft, rounded to subrounded	0.3
3. Conglomerate, pebble-grade, with matrix of poorly sorted very fine to coarse-grained sand, poorly consolidated	0.3
2. Sandstone, medium to fine-grained, light-pinkish-brown, poorly sorted, unbedded, friable	0.3
1. Conglomerate, pebble-grade, brown to black, matrix of poorly sorted coarse to very fine-grained sand; pebbles up to 10 cm in diameter, but most are 6-12 mm	0.3
Rests with angular unconformity on Irwin River Coal Measures (Permian).	

Lithology: The Victoria Plateau Sandstone consists predominantly of light-coloured poorly sorted sandstone, with lesser thicknesses of siltstone and conglomerate. The unit is generally poorly bedded, and cross-bedding is rarely developed.

It is commonly difficult in the field to distinguish the Victoria Plateau Sandstone from some of the Permian units, especially the Wagina Sandstone and Irwin River Coal Measures. This is because exposures are commonly incomplete and the effects of lateritization tend to mask the lithological differences between the units.

Stratigraphic relationships: The Victoria Plateau Sandstone overlies the Permian sequence with angular unconformity. It is capped by laterite or younger Quaternary deposits. The unit is believed to be equivalent to the Pindilya Formation of the southern Carnarvon Basin.

Distribution and thickness: The Victoria Plateau Sandstone is recognized in the area extending from Woolaga Creek in the south to the valley of the Murchison River in the north. It is exposed on the sides of breakaways immediately below the laterite cap. The width of outcrops is commonly too narrow for the unit to be mapped at 1 : 250 000 scale. The formation is commonly less than 3 m thick, and the thickest section that has been measured is the type section (20 m).

Fossils and age: The only fossils that have been found in the formation are rare fragments of silicified fossil wood, and the age is therefore indefinite. However, it probably correlates with the Pindilya Formation and Merlinleigh Sandstone (Upper Eocene) of the Carnarvon Basin.

Environment of deposition: The Victoria Plateau Sandstone may be a fluvial deposit, or alternatively it may represent a transgressive shallow-marine to paralic sequence comparable with the Merlinleigh Sandstone.

HARVEY BEDS

The name Harvey Beds is here proposed for the thin sequence of clay, sandstone, and conglomerate that occurs in valleys cut into the Darling Scarp at various localities between Walyunga and the Donnelly River. The type locality is near Harvey Dam, where individual outcrops show up to 5 m of section, although the unit occurs over a vertical range of at least 45 m (Churchward and Bettenay, 1973). A section near Newlands is 12 m thick (Lowry, 1965).

The beds consist of clay, sandstone, and polymictic conglomerate. Clasts are up to boulder grade, but most are pebbles. Rock types represented include granite, gneiss, quartzite, quartz, and schistose rocks; they are usually moderately well rounded and are from spherical to tabular in shape.

The Harvey Beds usually overlie Archaean rocks, but are also known to overlie Donnybrook Sandstone and Yarragadee Formation. They are commonly capped by laterite.

The Harvey Beds are unfossiliferous, and their age has not been established. Lowry (1965) tentatively favoured an early Pleistocene dating, but later (*in* Low, 1972b) he preferred a Tertiary age. Low and others (1970) questionably assigned the beds to the Permian in the belief that they could be of glacial origin. Finkl and Churchward (1973) suggested that the unit is likely to be of Mesozoic age.

We believe that the beds are of fluvial origin and that they are probably of Tertiary or early Pleistocene age, developed during a period of higher rainfall than today.

UNNAMED SEQUENCE IN GUN ISLAND No. 1 WELL

A sequence of Tertiary carbonate rocks was penetrated in Gun Island No. 1 well (in the Houtman Abrolhos) between 130 and 391 m. It disconformably overlies Cretaceous rocks and is overlain by Quaternary carbonates correlated with the Kwinana Group. Three units can be recognized in this sequence.

From 130 to 246 m there is a sequence of pale-grey fossiliferous and chalky limestone intercalated with minor siliceous limestone. Glauconite and chert nodules are present in the lower part of the unit. The fossils consist of foraminifers, including *Globorotalia inflata* (d'Orbigny), which suggest a Late Miocene or Pliocene age. The middle unit, between 246 and 288 m, consists of calcareous dolomite with minor interbeds of massive dolomite, and has yielded the foraminifer *Lepidocyclina* (?*Trybliolepidina*) sp., which suggests an Early Miocene age. The lowermost Tertiary unit, from 288 to 391 m, consists of massive grey-green, silty, glauconitic calcarenite with pale-green, argillaceous, slightly glauconitic limestone at the base. It contains foraminifers including *Globigerina triloculinoides* Plummer and *Globorotalia aequa* Cushman and Renz, and is of Paleocene or Early Eocene age.

Hawkins (1969) considered that the sequence had closer affinities with the Tertiary of the Carnarvon Basin than with that of the Perth Basin. Although this may be true for the lower unit, which contains more carbonate than the equivalent Kings Park Formation, the other two units in the Tertiary of Gun Island No. 1 well correlate fairly well with the Stark Bay Formation and the overlying "unnamed carbonate unit" in wells drilled offshore in the neighbourhood of Perth.

ASCOT BEDS

The name Ascot Beds is here proposed for a sequence of grey, medium to very coarse-grained calcarenite with a rich molluscan fauna, known from the Bullsbrook, Gnangara, Gosnells, and Redcliffe areas in the Perth metropolitan area (Darragh and Kendrick, 1971). It is named after Ascot Park, Redcliffe. The fauna, which includes the pelagic gastropod *Hartungia typica typica* Bronn, suggests a Pliocene age for the unit (Kendrick, G. W., pers. comm., 1973).

The unit is well developed in the Redcliffe School No. 2 bore where it rests unconformably on the Osborne Formation and is disconformably overlain by a sandy limestone provisionally assigned to the Guildford Formation. The areal extent of the Ascot Beds is unknown. They are absent in the Jandakot bores, where the Guildford Formation rests directly on the Osborne Formation (Kendrick, 1969) and appear to have been removed in many places by post-Pliocene erosion (Allen, A. D., pers. comm., 1973).

UNNAMED CARBONATE UNIT

Quilty (1974) recognized a unit of red to brown limestone or dolomitic limestone which overlies the Stark Bay Formation in Gage Roads No. 1 and No. 2 wells. Details of the age, lithology, and stratigraphic relationships of the unit are indefinite because of the general lack of cuttings obtained while drilling. The foraminifers *Operculina* and *Amphistegina* occur in the unit, but they do not permit accurate age determination.

QUATERNARY

A thin veneer of Quaternary rocks occurs at the surface over much of the Perth Basin, and effectively obscures the older rocks. Laterite and its associated sand are the most extensive of these superficial deposits in the plateau areas, while Pleistocene to Holocene shoreline and dune deposits cover much of the coastal plains. The maximum thickness of Quaternary deposits in the basin amounts to about 150 m, but in most areas they are less than 20 m thick.

Although formal stratigraphic names have been given to many of the Quaternary units, they have not generally been adequately defined, or studied in as much detail as the pre-Quaternary rocks, and most of the units have not been accurately dated. It seems likely that several of them are time transgressive.

LATERITE AND ASSOCIATED SAND

The term laterite is commonly applied in Western Australia to massive, vesicular, or concretionary rocks, composed of iron and aluminium oxides, which overlie weathered rock. The laterite is believed to represent an illuvial soil horizon which probably formed within the zone of fluctuation of the water table under the influence of a climate with high, seasonally distributed, rainfall.

The laterite itself is up to about 5 m thick. It is underlain by weathered rock as much as 40 m thick, which can be differentiated in some areas into a mottled zone above and a pallid zone below. The laterite is commonly overlain by podsolized quartz sand, which is generally up to 10 m thick. The sand is believed to have formed as the eluvial zone of the laterite profile, and to have been redistributed to varying degrees since the period of lateritization.

In some parts of the basin silicification of rocks has occurred below laterite. In other areas siliceous duricust or silcrete has developed in place of the laterite itself.

Over large parts of the Darling, Victoria, and Blackwood Plateaus the laterite surface is almost flat to gently undulating. This caused early investigators to postulate that it formed on a low-lying peneplain that has since been uplifted (Woolnough, 1918). However, later work (Playford, 1954; Prider, 1966; Churchward, 1970; Finkl, 1971; Geidans, 1973; Churchward and Bettenay, 1973) has shown that in many areas in and adjoining the Perth Basin laterite developed on a land surface comparable to that of today. The Darling Scarp was in evidence, and much of the present drainage pattern had already been established at the time that the laterite formed. The laterite surface slopes at angles of up to 10 degrees towards this drainage. This is especially well illustrated in the Geraldton (Plate 8) and Hill River areas (Fig. 42), but it is also clear elsewhere.

Laterite is forming today in the southern part of the Perth Basin and adjoining parts of the Yilgarn Block (Lowry, 1965). In these areas the annual precipitation is in excess of 90 cm, most of it falling during the winter. Laterite is developing within the zone of fluctuation of the water table, and is overlain by podsolized sand. Much of the area is forested, and ferruginized fossil charcoal derived from forest fires occurs in some of the laterite.

Pleistocene deposits are lateritized throughout much of the basin, from the south coast to Geraldton, and it seems likely that laterite probably developed at various times during the Quaternary. Lateritization was presumably most widespread during the periods of highest precipitation. The main laterite of the Darling Range apparently post-dates the Ridge Hill Sandstone, which is thought to be an early Pleistocene or late Tertiary deposit.

Although much of the laterite in the basin may be of Pleistocene age, the oldest laterite is probably Tertiary, perhaps Pliocene, as suggested by Prider (1966). There does not seem to be any clear evidence of early Tertiary laterite in the Perth Basin, although Johnstone and others (1973) suggested that a major period of lateritization occurred in southwestern Australia during the Oligocene and/or Miocene.

Laterite is of considerable economic importance as a source of gravel for road building in the Perth Basin. In addition, bauxitic laterite is being mined along the western side of the Darling Plateau, just east of the Darling Fault (Tomich, 1964).

Figure 42. Valley of Cockleshell Gully, showing laterite surface sloping towards the valley. Typical heath vegetation of the Perth Basin sandplain can be seen in the foreground. The present drainage in this area and other parts of the Perth Basin closely follows an older drainage system which was already established prior to the main period of lateritization.

KWINANA GROUP

The name Kwinana Group is proposed for the Holocene to early Pleistocene or late Tertiary sequence of coastal-dune, beach, and shallow-marine deposits (quartz sand, limestone, and lime sand) exposed on the Swan and Scott Coastal Plains, and comprising the Ridge Hill Sandstone, Yoganup Formation, Bassendean Sand, Tamala Limestone, Safety Bay Sand, Peppermint Grove Limestone, and Rottnest Limestone. It is named after the industrial centre of Kwinana on Cockburn Sound.

Brief descriptions of the formations of the Kwinana Group are as follows:

RIDGE HILL SANDSTONE

The Ridge Hill Sandstone was named by Prider (1948), and the type locality is at Ridge Hill (lat. 31° 55′ 40″S, long. 116° 02′ 18″E) on the Darling Scarp near Perth. It is a thin unit consisting of ferruginous sandstone with a thin basal conglomerate overlying Precambrian crystalline rocks and capped by laterite. It occurs discontinuously along the Ridge Hill Shelf at elevations from 76 to 91 m above sea level, and probably developed as a shoreline deposit during an early Pleistocene or late Tertiary period of high sea level.

The Ridge Hill Sandstone is about 10 m thick at Ridge Hill. It has been mapped in a few exposures from 15.5 km north to 6.5 km south of there, but other unmapped isolated exposures are likely to occur further south. However, the deposits previously thought to correlate with the Ridge Hill Sandstone near the base of the Whicher Scarp (McArthur and Bettenay, 1960) are now placed in the Yoganup Formation by Low (1971c), as the shelf on which they occur is at a lower elevation than the Ridge Hill Shelf, and is thought to have formed during a period of lower sea level.

The heavy-mineral strandline deposits at Eneabba (Baxter, 1972; Lissiman and Oxenford, 1973) may have developed at about the same time as the Ridge Hill Sandstone. The Eneabba strandlines are from about 85 m to 128 m above present sea level.

YOGANUP FORMATION

The name Yoganup Formation was introduced by Low (1971c) for the unit of sand with a basal conglomerate and lenticular beds of clay which occurs along the Yoganup and Waroona Shorelines. It contains discontinuous concentrations of heavy minerals.

The type section is in the open-cut (for heavy-mineral sands) near Yoganup (lat. 33° 38′ 50″S, long. 115° 36′ 10″E). At this locality there is a thin basal conglomerate with rounded quartz and quartzite pebbles, followed by a clayey sand with two ilmenite-rich lenses, each up to 4.5 m thick. This sand is overlain by a lenticular bed of grey clay, followed by yellow sand that probably accumulated as a foredune or beach ridge. The total section is more than 9 m thick (Low, 1971c). The sediments are variably lateritized and any carbonate that they originally contained has been completely leached out.

The Yoganup Formation unconformably overlies the Lower Cretaceous Leederville Formation or Lower Jurassic Cockleshell Gully Formation. It also abuts Precambrian rocks along the Darling Scarp. The formation is best developed in front of the Whicher Scarp, along the Yoganup Shorelines. However, discontinuous exposures occur at the foot of the Darling Scarp for nearly 200 km to the north, where they mark the Waroona Shorelines. The belt of exposures is up to 1.5 km wide. The base of the unit ranges in elevation from about 25 to 45 m above sea level. It may be of early Pleistocene (or possibly late Tertiary) age, but has not been palaeontologically dated.

Bassendean Sand

The name Bassendean Sand was introduced by Playford and Low (1972) for the widespread unit of quartz sand extending over large areas of the Swan and Scott Coastal Plains. On the Swan Coastal Plain its distribution coincides with that of the Bassendean Dune System of McArthur and Bettenay (1960) and the Carbunup Dune System of Lowry (1965). The type area is Bassendean, a suburb of Perth, but no type section has been designated owing to the poorness of vertical exposures through the formation. Its maximum thickness may be about 45 m.

The Bassendean Sand occurs in a strip parallel to the coast, with its western edge generally about 5 km inland. At the surface it appears as a series of low quartz sandhills which probably represent leached coastal eolianites. Some remnants of unleached limestone occur in the formation along the western edge of the deposit, from Harvey Inlet to near Bunbury.

A reference section for the formation selected by Playford and Low (1972) is in Western Titanium Limited's excavation for heavy minerals near Capel, where it comprises deposits of the Capel Shorelines. In the main pit the base of the formation consists of a weathered boulder conglomerate of basalt and quartzite clasts, which is interpreted as a beach deposit. It stands at about 8 m above present sea level and is overlain by about 8 m of quartz sand containing high concentrations of heavy minerals. This is thought to represent a foredune deposit from which all calcium carbonate has been leached. Laterite is developed discontinuously in the sand at about the present water table.

Marine fossils have been found at three localities in the Bassendean Sand, associated with shoreline deposits. These are the reference section in the pit at Capel, and at outcrops 8 km and 11 km southwest of Busselton.

The fossils from the reference section were examined by G. W. Kendrick (written comm., 1971). They were preserved as moulds in a sandstone, and Kendrick identified the bivalves *Chlamys* (*Equiclamys*) *bifrons* (Tate) and

Anodontia sp. cf. *A. sphericula* (Basedow). He tentatively dated these as being of early Pleistocene age.

From the locality 8 km southwest of Busselton, Edgell (1963) identified the bivalves *Katelysia* sp. and *Soletellina* sp., and the gastropods *Austrocochlea* sp. cf. *adelaidea* (Philippi) and cf. *Polinices* sp. The fossils are preserved as moulds in a ferruginous sandstone at an elevation of about 10 m above present sea level.

From the other locality, 11 km southwest of Busselton, Edgell (1963) identified the bivalves *Katelysia* cf. *K. rhytiphora* Lamy and *Soletellina biradiata* Wood. He also recorded the presence of *Fragum erugatum*, a contemporary bivalve species, but G. W. Kendrick (pers. comm., 1974) regards the form as a new unnamed species of *Fragum*, of middle to late Pleistocene age. Kendrick favours a middle Pleistocene dating for the assemblages from both of the fossiliferous outcrops southwest of Busselton.

The Bassendean Sand is thought to have been laid down as shoreline and dune sands during two or more periods of relatively stable sea level, ranging from about 8 to 25 m above present sea level. The unit probably ranges from early to middle Pleistocene, or possibly late Pleistocene, in age.

Tamala Limestone

The name "Tamala Eolianite" was used by Logan (1968) in the Shark Bay area of the Carnarvon Basin for the unit previously known as the "Coastal Limestone" in that area. We are proposing to amend the name to Tamala Limestone, as eolianite is a genetic rather than a lithologic term and most of the formation consists of limestone. We also wish to extend usage of the name to the Perth Basin, as exposures of the unit are essentially continuous between the two basins. The type section, as defined by Playford and others (1975) is at Womerangee Hill on the Zuytdorp Cliffs (in the Carnarvon Basin).

The Tamala Limestone consists of coarse to medium-grained calcarenite, composed largely of skeletal fragments (mainly foraminifers and molluscs), and containing variable amounts of quartz sand. Large-scale cross-bedding is characteristic, while soil horizons and calcified root structures (Figs. 43 and 44) are common.

The formation was deposited as coastal sand dunes (lime-sand eolianite), and in the Perth Basin (especially in the central part), it occurs in several belts representing successive lines of late Pleistocene dunes. The most extensive is the band forming the Spearwood Dune System, but there are also several lines of islands and offshore reefs marking lower stands of sea level. It is likely that more detailed work on the formation will necessitate separate naming of the distinct belts of limestone.

The thickest developments of the formation in the Perth Basin are in the Naturaliste Region and the Hutt River area (probably more than 150 m in both areas). Along the coast south of the Hutt River the formation is spectacularly

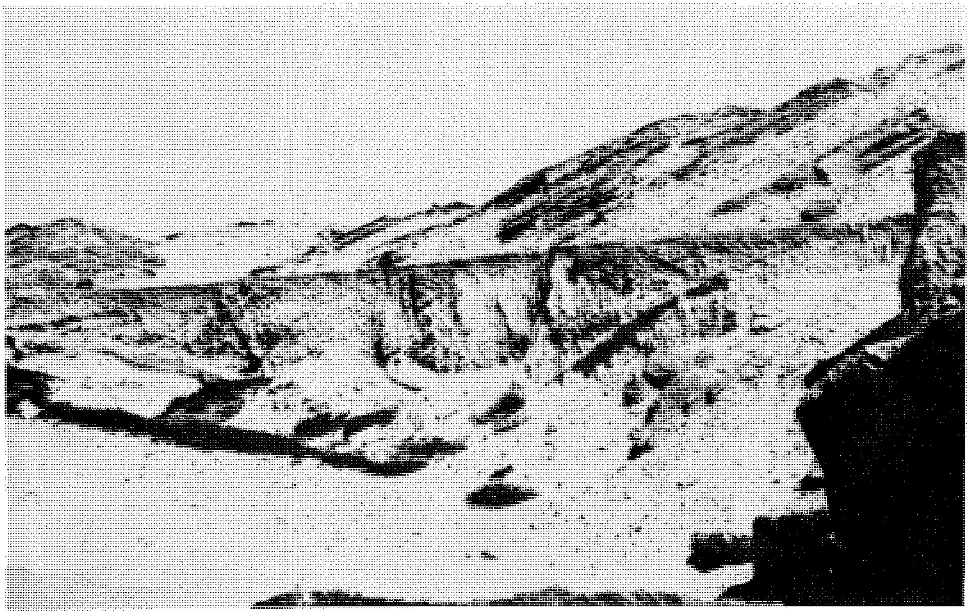

Figure 43. Tamala Limestone, exposed at Hamelin Bay in the Naturaliste Region, showing steep foreset bedding and a prominent fossil soil horizon.

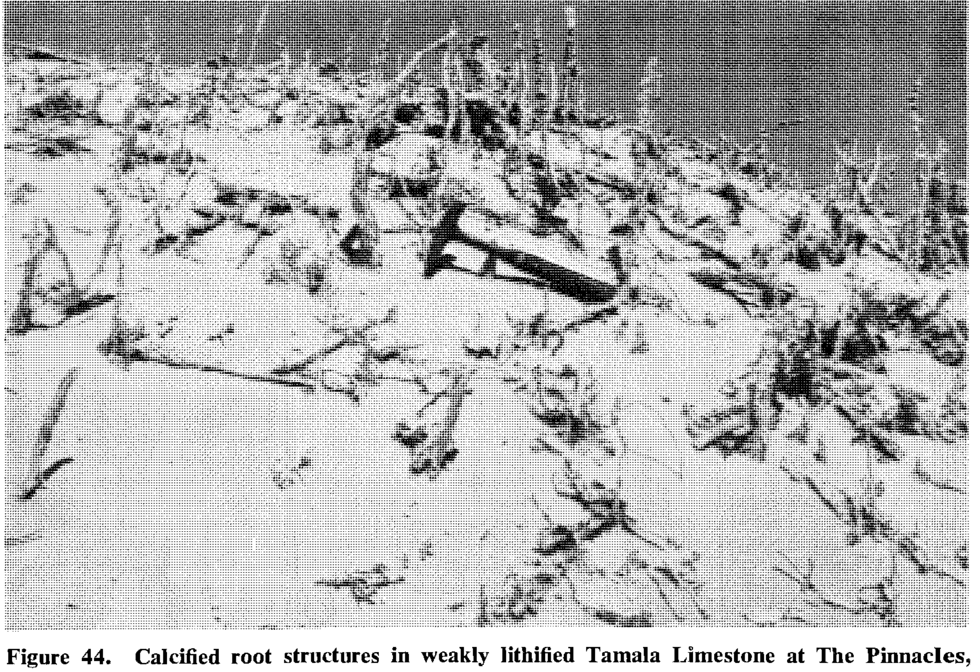

Figure 44. Calcified root structures in weakly lithified Tamala Limestone at The Pinnacles, near Cervantes.

exposed in cliffs up to 75 m high (Fig. 45). In the Naturaliste Region eolianite is piled on Precambrian rocks to a height of about 220 m above sea level.

The Tamala Limestone in the Perth Basin is of late Pleistocene age. A coral from the Rottnest Limestone underlying the Tamala Limestone was dated as 100 000 ± 20 000 years old by Veeh (1966), while a date of 26 800 ± 1 050 years old has been obtained from charcoal in a fossil soil within the formation, and a shell bed beneath has been dated as 32 200 ± 400 years old (Merrilees, D., written comm., 1969).

Safety Bay Sand

Passmore (1967, 1970) used the name Safety Bay Sand for the Holocene coastal sand dunes and shallow-marine to littoral sands in the Rockingham-Safety Bay area. Usage of the name was extended by Playford and Low (1972) to include similar sands throughout the Perth Basin. Distribution of the formation coincides with that of the Quindalup Dune System.

Figure 45. White Cliffs, south of Hutt River, composed of Tamala Limestone. The cliffs are about 60 m high and form the western edge of the Menai Hills.

The sand is made up of shell fragments (mainly foraminifers and molluscs) with variable amounts of quartz and minor feldspar. The calcium-carbonate content is normally greater than 50 per cent. The sand is weakly lithified below the dune surfaces in some areas, marking the first stage in conversion to eolianite.

The type section of the formation was designated by Passmore (1967) as that in the Rockingham Bore R3 (lat. 32° 16′ 53″S, long. 115° 42′ 19″E) from the surface to a depth of 24 m. In some parts of the Perth Basin the thickness may exceed 100 m. It overlies the Tamala Limestone or other Quaternary units.

Heavy-mineral deposits are developed in the Safety Bay Sand along the coast of Geographe Bay (the Quindalup Shoreline) and at some other localities in the basin. They have been mined at Koombana Bay near Bunbury and at Wonnerup.

Deposition of the Safety Bay Sand is continuing today, and in some areas (notably around Bunbury and Busselton) deposition is very rapid, so that in places the coast has prograded more than 100 m in historic times.

PEPPERMINT GROVE LIMESTONE

The Peppermint Grove Limestone was named by Fairbridge (1953) after the Perth suburb of Peppermint Grove, where the type section is exposed on the bank of the Swan River near Scotch College boatshed (lat. 31° 59′ 30″S, long. 115° 46′ 10″E). The section consists of calcarenite and minor calcirudite, which is generally weakly lithified, apart from two well-cemented beds thought by Fairbridge (1953) to represent beach rock. A rich shell bed is present near the top of the unit. The total thickness of the section is 5 m.

The shell bed ranges in elevation from 1.0 to 7.3 m above sea level, and the formation is thought to have developed during an interval of the late Pleistocene when sea level was about 7.5 m higher than today. The unit interfingers with the Tamala Limestone.

The Peppermint Grove Limestone is recognized only in the Swan River area, but similar marine units (such as the Rottnest Limestone) are known elsewhere.

The fauna of the formation includes abundant foraminifers and molluscs, as follows:

Foraminiferida (Parr *in* Fairbridge, 1950)

- *Ammonia* sp. cf. *A. tepida* (Cushman)
- *Amphistegina quoii* d'Orbigny
- *Cibicides lobatulus* (Walker and Jacob)
- *C. mayori* Cushman
- *Discorbis australis* Parr
- *D. dimidiatus* (Jones and Parker)
- *Elphidium advenum* (Cushman)
- *E.* sp. cf. *E. craticulatum* (Fichtel and Moll)
- *E. crispum* (Linné)
- *E.* sp. aff. *E. incertum* (Williamson)
- *E.* sp. aff. *E. macellum* (Fichtel and Moll)
- *E. rotatum* Howchin and Parr
- *Globigerinoides* sp.

Hauerina fragilissima Brady
Marginopora vertebralis Blainville
Peneroplis planatus (Fichtel and Moll)
Planorbulina mediterranensis d'Orbigny
Pyrgo denticulata (Brady)
Quinqueloculina baragwanathi Parr
Q. sp. aff. *Q. costata* d'Orbigny
Q. sp. cf. *Q. seminulum* (Linné)
Q. subpolygona Parr
Q. sp. aff. *Q. vulgaris* d'Orbigny
Siphoninoides echinatus (Brady)
Spiroloculina milletti Wiesner
S. sp.
Textularia agglutinans d'Orbigny
T. sp. aff. *T. conica* d'Orbigny
Triloculina striatotrigonula Parker and Jones
T. subrotunda (Montagu)
T. tricarinata d'Orbigny
T. sp. cf. *T. trigonula* (Lamarck)
T. n. sp.

Bivalvia (Reath, 1925; Fairbridge, 1950; Kendrick, 1960) (common species only)
Electroma sp. cf. *E. georgeiana* (Quoy and Gaimard)
Eumarcia fumigata (Sowerby)
Fragum erugatum (Tate)
Hormomya? n. sp.
Katelysia rhytiphora Lamy
K. scalarina (Lamarck)
Redicirce plebeia (Hanley)
Wallucina assimilis (Angas)

Gastropoda (Reath, 1925; Fairbridge, 1950; Kendrick, 1960) (common species only)
Antisabia erma Cotton
Cacozeliana granarium (Klener)
Calliostoma interruptum Wood
Diala lauta Adams
D. lirulata Thiele
D. translucida Hedley
Dicathais aegrota (Reeve)
Elachorbis tatei (Angas)
Haliotis roei Gray
Haminoea brevis (Quoy and Gaimard)
Notosetia nitens (Fraunfeld)
Parcanassa pauperata (Lamarck)
Patellanax laticostata (Blainville)
Retusa apicina (Gould)
Senectus pulcher Reeve
Zeacumantus cerithium (Quoy and Gaimard)

Reath (1925) suggested that the molluscan fauna indicated that warmer temperatures prevailed when the Peppermint Grove Limestone was deposited. However, more recently, Kendrick (1960) has shown that the molluscan fauna contains less than 20 per cent northern (Dampierian) species and over 70 per cent southern (Flindersian-Peronian) species. He interprets the formation as having been deposited in a shallow-marine gulf which occupied the site of the present-day Swan estuary, under temperatures similar to those occurring today.

Rottnest Limestone

The name Rottnest Limestone (or "Salmon Bay Limestone") was introduced by Fairbridge (1953) for a unit of coral-reef and shell limestone exposed at Salmon Bay on the south coast of Rottnest Island. It is overlain by the Tamala

Limestone and is underlain by older (unnamed) Pleistocene deposits. The occurrence is described by Teichert (1950). The reef consists of *in situ* coral heads including *Acropora* sp., *Favites favosus* (Ellis and Solander) and *Platygyra lamellina* Ehrenberg, and it stands 2.0 to 2.5 m above present low-water level. Equivalents of the unit crop out on the Abrolhos Islands and on the coast at Dongara and the mouth of the Greenough River.

The Rottnest Limestone has been dated as 100 000 ± 20 000 years old by Veeh (1966). It is thought to have formed during a high sea-level stand of the Riss-Würm interglacial period.

MISCELLANEOUS QUATERNARY UNITS

A number of additional Quaternary units have been recognized in the Perth Basin. Some of these are only poorly defined and have not yet been studied in any detail.

GUILDFORD FORMATION

The Guildford Formation was originally referred to by Aurousseau and Budge (1921) as the "Guildford Clays", and the name was revised by Low (1971c). The unit consists of lenticular interbeds of sand, clay, and conglomerate, which are calcareous in places. Most of the unit is of fluvial origin (piedmont to valley-flat environments), but it also includes estuarine and shallow-marine intercalations, especially at the base.

The type area is in the Swan River valley around Guildford, and Low (1971c) designated as the type section the sequence encountered from the surface to a depth of 33 m in the West Guildford artesian bore (lat. 31° 54′ 30″S, long. 115° 57′ 20″E). The formation disconformably overlies the Ascot Beds, or where that unit is missing, it unconformably overlies the Kings Park Formation, Osborne Formation, or Leederville Formation. It is overlain by the Bassendean Sand. The Guildford Formation has been mapped throughout most of the length of the Swan Coastal Plain in front of the Darling Scarp and along the river valleys. The outcrop area corresponds to the Pinjarra Plain of McArthur and Bettenay (1960).

There is evidence of at least two marine horizons in the formation laid down about 5 m above and 15 to 20 m below present sea level. The lowest horizon occurs near the base of the unit, and it contains a rich molluscan fauna in bores in the Jandakot and West Coolup areas. Kendrick (*in* Darragh and Kendrick, 1971) records the following forms from this horizon: the bivalves *Chlamys* (*Equichlamys*) sp. cf. *C. bifrons* (Lamarck), *Cuna* sp., *Deltachion* sp., *Glycymeris* (*Tucetella*) *mayi* Cotton, *Limatula* sp., *Limopsis tenisoni* Woods, *Nuculoma* (*Ennucula*) *kalimnae* (Singleton), *Placamen placidum* (Philippi), *Tawera* sp., and *Zenatiopsis ultima* Darragh and Kendrick; and the gastropods *Austromitra* sp. cf. *A. multiplicata* Ludbrook, *Bellastraea* sp., *Leiopyrga* sp., *Marginella*

(*Austroginella*) *johnstoni* Petterd, and *Semivertagus capillatus* Tate. The shell-bearing beds in the Jandakot area also contain the fresh-water gastropod *Physastra*, which indicates nearby lacustrine or swampy conditions.

The upper marine horizon in the Guildford Formation (about 5 m above present sea level) occurs in the Caversham area as a thin bed containing the bivalves *Anadara* sp. and *Dosinia* sp. (Fairbridge, 1953).

The fauna of the Guildford Formation dates it as Pleistocene (Darragh and Kendrick, 1971). It could span a considerable time range within that epoch, but at least part of the unit is thought to be early Pleistocene.

ROCKINGHAM SAND

The name Rockingham Sand was introduced by Passmore (1967, 1970) for a unit of sand underlying the Tamala Limestone (probably disconformably) and unconformably overlying the Osborne Formation or the Leederville Formation. It has been recognized only in the Rockingham area, and the type section is in Bore R1 (lat. 32° 17′ 19″S, long. 115° 43′ 36″E) from 29 to 110 m below the surface.

The unit consists of yellow-brown, medium to coarse-grained feldspathic quartz sand. It is thought to be a shallow-marine deposit of Pleistocene age.

COOLOONGUP SAND

Passmore (1967, 1970) proposed the name Cooloongup Sand for a unit of sand overlying the Tamala Limestone and underlying the Safety Bay Sand. It is known only in the Rockingham area, and the type section is in Bore RT20 (lat. 32° 16′ 48″S, long. 115° 46′ 53″E) from 6.5 to 10.4 m below the surface.

The unit consists of grey and yellow-brown, fine to coarse-grained feldspathic sand with variable amounts of shelly material. It is thought to be a subaerial to shallow-marine deposit of late Pleistocene or Holocene age.

LIMESTONE AND BEACH RIDGES OF HOUTMAN ABROLHOS

The Houtman Abrolhos archipelago is composed of Pleistocene coralline limestone overlain (in the case of West Wallabi and East Wallabi Islands) by dune limestone correlated with the Tamala Limestone and by Holocene sand and coralline limestone. These were examined in reconnaissance during our survey of the Perth Basin (Playford and others, 1970). They are described in more detail by Teichert (1947b) and Fairbridge (1948b). Fairbridge (1953, 1954) has informally named a "coral reef limestone facies" as the "Pelsart Limestone" and a "lagoon facies" as the "Wallabi Limestone", but insufficient work has been carried out to validate these names.

The islands and their associated reefal deposits offer unequalled opportunities for studying contemporary and Pleistocene coral-algal reefs, and Quaternary climatic, sea-level, and faunal changes.

Muchea Limestone

The Muchea Limestone is a soft marly limestone developed at or near the surface in small patches along the eastern side of the central Swan Coastal Plain. The unit was originally referred to as the "Muchea limestones" by Glauert (1911), and the name was formalized by Fairbridge (1953). Fairbridge reported that the unit contains *Bothriembryon, Austrosuccinnea,* and *Planorbis,* which are living terrestrial or freshwater forms. The thickness of the unit rarely exceeds 1 m.

The origin of the unit is indefinite; it is probably at least in part a kankar-type deposit, although Fairbridge (1953) suggested that it is of lacustrine origin.

Alluvial deposits

Alluvial deposits occur along the river systems in the basin. They consist of clay, silt, and sand in the valley-flat environments, with interfingering conglomerates in the piedmont zone near the Darling Scarp. The alluvial deposits as mapped overlie and possibly interfinger with parts of the Guildford Formation, and they are thought to range from late Pleistocene to Holocene in age.

Colluvial deposits

Holocene colluvium has been mapped along the piedmont zone of the Darling Scarp, where it consists of gravel, sand, silt, and clay derived from the laterite profile and from the underlying Precambrian rocks. Colluvial sand and gravel also occur in front of the laterite-capped plateaus and breakaways.

Lagoonal and estuarine deposits

Holocene deposits of clay and silt occur in the lagoons and estuaries behind the Quindalup and Spearwood Dune System. They consist typically of dark-coloured clay and silt, grading to peat, with lenticular layers of freshwater or estuarine shells in some places.

Lake and swamp deposits

Holocene lake and swamp deposits are represented in various parts of the Swan and Scott Coastal Plains. They include various clay, sand, peat, gypseous, and diatomaceous deposits. They are generally thin, rarely exceeding about 3 m in thickness.

Ephemeral salt to brackish-water lakes occur in the Yarra Yarra Region. Several of these contain thin evaporites and montmorillonite-rich clays.

Low irregular sand dunes have been built up in places around the margins of ephemeral lakes and watercourses, especially in the area west of Moora and Watheroo, where they have been mapped separately. Material in the dunes has been derived from the dry lake and stream beds.

Shell beds on Rottnest Island

Shell beds composed mainly of various marine bivalves are developed around the margins of salt lakes on Rottnest Island. They apparently formed during the early Holocene when sea level was up to 3 m higher than today, before the lakes became separated from the sea.

Spelean deposits

Quaternary spelean (cave) deposits occur in many places in the Tamala Limestone. Some of these contain fossil bones, the best known examples being those of the Naturaliste Region (Lowry, 1965; Merrilees, 1968), especially from Mammoth Cave.

The fauna has been described by Glauert (1910e, 1912, 1914, 1948), Lundelius (1960), and Cook (1963). The fauna from Mammoth Cave has been dated as more than 37 000 years old (Merrilees, 1968). Lundelius (1960) found a younger fauna in the Nannup Cave deposits, which were dated as 8 500 to 12 175 years old.

The cave deposits of the Naturaliste Region have yielded the remains of various monotremes, murids, bats, birds, snakes, gastropods, and plants, together with the following marsupial fossils:

Marsupialia (Merrilees, 1968)

- *Bettongia lesueuri* Quoy and Gaimard
- *B. penicillata* Gray
- *Cercartetus concinnus* (Gould)
- *Dasyurus geoffroyi* Gould
- *Isoodon obesulus* (Shaw)
- *Macropus eugenii* (Desmarest)
- *M. fuliginosus* (Desmarest)
- *M. irma* (Jourdan)
- *Perameles bougainville* Quoy and Gaimard species group
- *Petrogale lateralis* (Gould)
- *Phascolarctos* sp. cf. *P. cinereus* (Goldfuss)
- *Potorous gilberti* (Gould)
- *Protemnodon anak* (Owen)
- *P.* sp. cf. *P. brehus* (Owen)
- *Pseudocheirus occidentalis* Thomas
- *Sarcophilus harrisi* (Boitard)
- *Setonix brachyurus* (Quoy and Gaimard)
- *Sthenurus brownei* Merrilees
- *S. occidentalis* Glauert
- *Thylacinus cynocephalus* (Harris)
- *Thylacoleo* sp.
- *Trichosurus vulpecula* (Kerr)
- *Vombatus hacketti* (Glauert)
- cf. *Wallabia bicolor* (Desmarest)
- *Zygomaturus trilobus* Owen

CHAPTER 5

Structure

The broad structural features of the Perth Basin and its subdivisions have already been discussed in the chapter dealing with general geology. The principal published general references on the structure of the basin are by Thyer and Everingham (1956), Hawkins and others (1965), and Jones and Pearson (1972). Cope (1972) discussed the structure of the southern part. Most of the detailed structural information in the basin has been obtained from seismic surveys.

The overall structure of the Perth Basin may be described as that of an intensely faulted half-graben, defined on the east by the Darling Fault, and limited on the west (for the most part) by the continental slope. Northerly trending uplifts are developed in the central part of the basin along much of its length (the Northampton Block, Beagle Ridge, and Leeuwin Block). The main structural subdivisions of the basin have been discussed previously. They are shown on Figure 8, and the regional structure is illustrated on Figures 46-49 (showing structure contours on basement and various Jurassic and Cretaceous horizons) and Figure 50 (showing a series of cross sections).

FAULTING

The structure of the Perth Basin is dominated by faulting. In many areas there are extensive fault networks in the earliest Cretaceous and older rocks, most of which have north to north-northwest trends. However, much of this complex fault pattern is not seen at the surface owing to the extensive cover of Quaternary deposits, and the positions of most faults have been determined by seismic surveys. Only relatively minor faulting is known to have occurred since mid-Neocomian times, and few of these younger faults have been accurately mapped.

NATURE OF FAULTS

The tectonic style of the Perth Basin is characterized by normal faulting; there is no conclusive evidence of transcurrent movements affecting the Phanerozoic sequence, and reverse displacement is known to have occurred along only one fault cutting Phanerozoic rocks—the Hardabut Fault along the northwestern boundary of the basin. However, the Proterozoic rocks within and

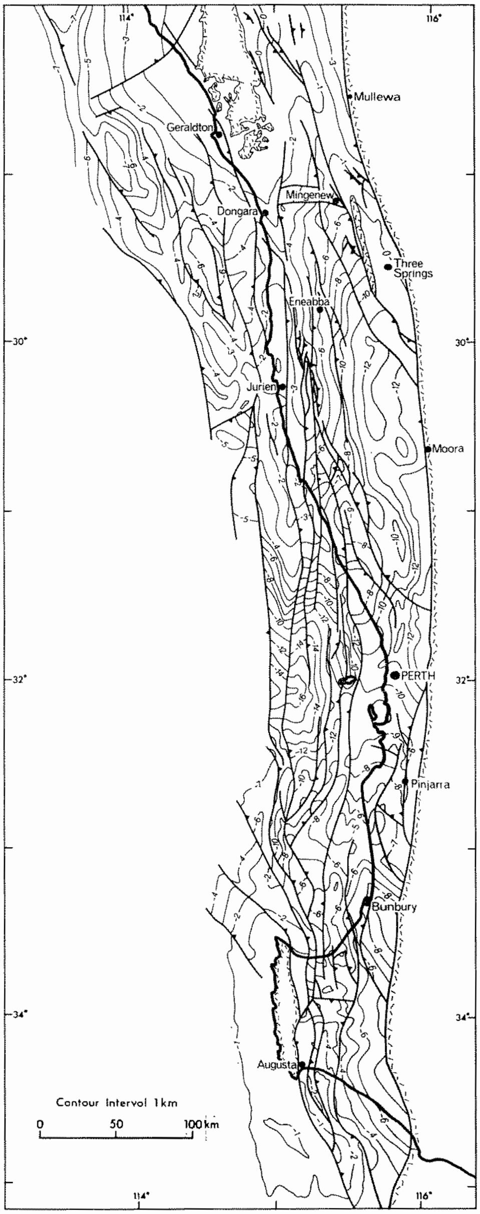

Figure 46. Structure contours, top of Precambrian basement.

bordering the basin commonly show evidence of strong compressive tectonics and are believed to have been affected by transcurrent and/or reverse faulting. It seems possible that the Darling Fault (and perhaps some of the other large faults in the basin) originated as transcurrent faults in Late Proterozoic or early Palaeozoic times, but have since operated as normal faults.

Seismic evidence indicates that most faults in the basin dip at angles of between 55° and 80° (Wapet, written comm., 1973) and, where displacements can be determined, the movements appear to be normal. Fault planes are seldom exposed at the surface, the main exceptions being those in the Tumblagooda Sandstone and Nangetty Formation at Bindoo Hill, and those cutting the Jurassic sediments and Precambrian gneiss in the Bringo cutting. At Bindoo Hill the fault planes dip at between 55° and 85°, and the average is about 70°. The dips of faults cutting the Jurassic sequence in the Bringo cutting range from 50° to 75°, and the average is 62°.

The only low-angle faulting that has been recognized occurs in the Irwin River area, where a normal fault cutting the Holmwood Shale in the Beckett Gully area apparently dips at less than 45°.

Seismic data indicate that many of the larger faults in the basin operated over long periods of time during deposition of the sediments (that is, they are growth faults). Some may have been operative intermittently since the Permian (or possibly earlier). The main period of faulting in the basin was from the Middle Triassic through to the mid-Neocomian. Since then most faults have been essentially quiescent, although there has been active movement along some amounting to several hundreds of metres, and smaller displacements along others have probably occurred in response to differential compaction. Figures 48 and 49, which show the structure of the sequence deposited since the Neocomian phase, illustrate the general lack of strong faulting in this sequence, in marked contrast to Figures 46 and 47 which show intense faulting in the older rocks. Few of the small faults cutting the Neocomian Warnbro Group and younger sediments have been mapped.

DARLING FAULT

General

The Darling Fault is one of the major structural features of the earth's crust. It has been traced at the surface and by geophysical methods for about 1 000 km, from the south coast near Point D'Entrecasteaux to north of the Murchison River near the Badgeradda Range. The maximum throw may exceed 15 000 m. The fault is the dominant structural feature of the Perth Basin, defining its eastern margin for most of its length.

The granitic scarp of the Darling Range has attracted the attention of geologists since the last century. The first published suggestion that it represented a fault scarp was by A. Gibb Maitland *in* David (1911), and the name Darling

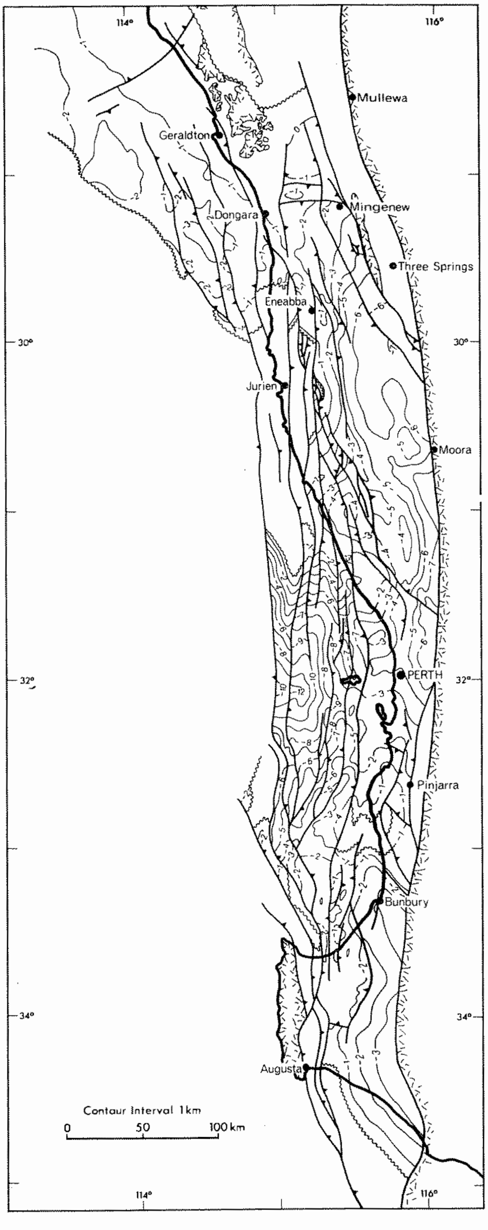

Figure 47. Structure contours, top of Cattamarra Coal Measures Member of the Cockleshell Gully Formation.

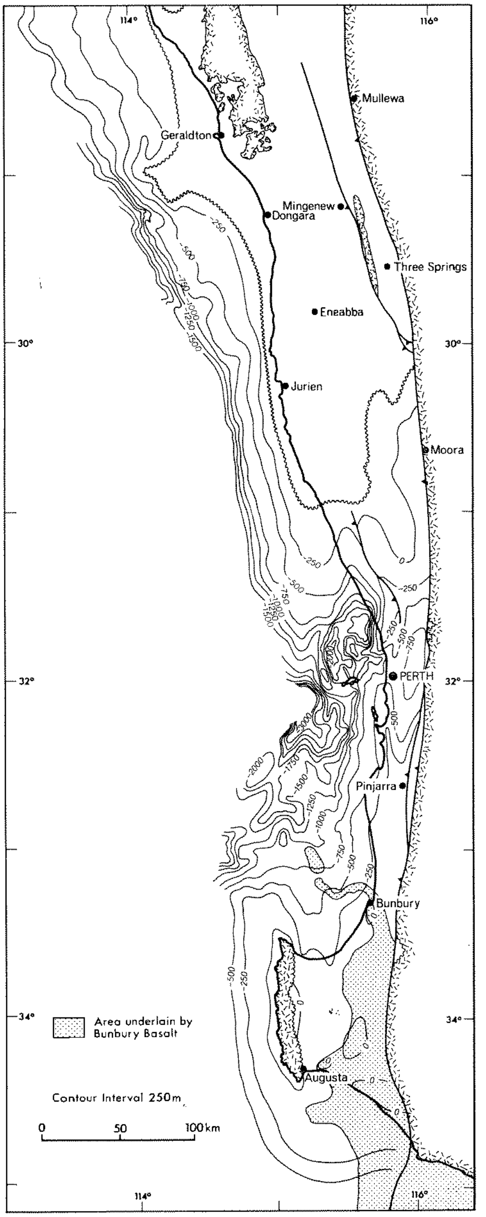

Figure 48. Structure contours, base of Warnbro Group (south of lat. 28° 30'S) and base of Winning Group (north of lat. 28° 30'S). Also showing the areal distribution of the Bunbury Basalt.

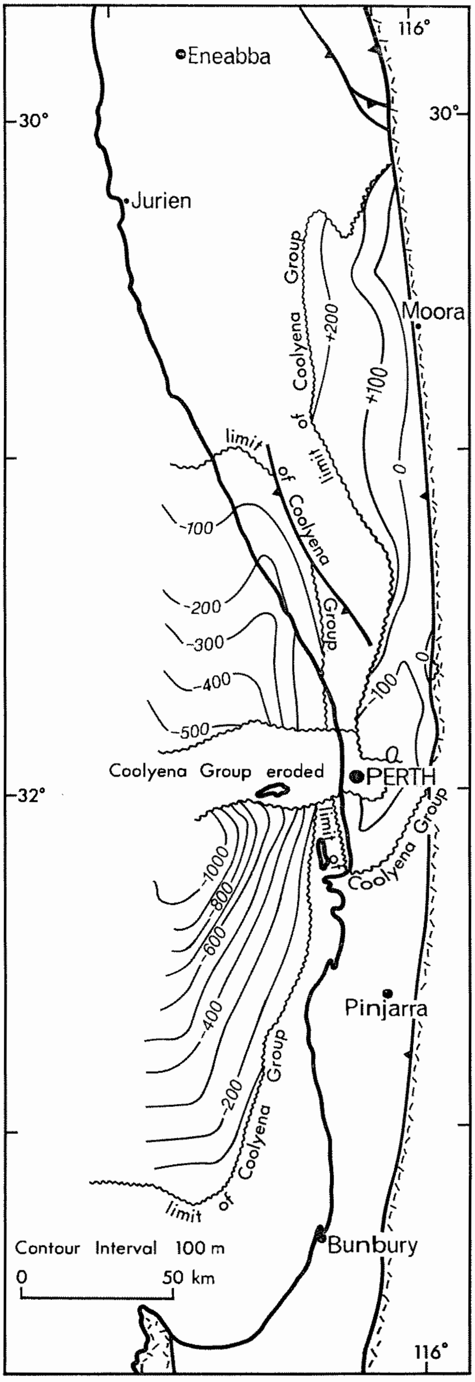

Figure 49. Structure contours, base of Coolyena Group.

Fault was introduced by Saint-Smith (1912). Since then there has not always been general agreement that the scarp is that of a fault. Jutson (1934) reported that Professor D. W. Johnson while visiting Western Australia suggested that the Darling Scarp could be the result of erosion along a monoclinal fold, and Prider (1941) gave evidence in support of this theory.

However, it was not until Vening Meinesz (1948) published the results of a gravity traverse he had made in 1935 from the Darling Plateau over the scarp, the Swan Coastal Plain, and the adjoining continental shelf that there was any real appreciation of the great thickness of sediments in the Perth Basin. Vening Meinesz concluded that a major fault existed in front of the Darling Scarp, and this interpretation has since been confirmed by other geophysical work. However, there has remained considerable uncertainty as to the type of faulting involved—whether normal, reverse, or transcurrent, or a combination of these.

The maximum throw of the Darling Fault (possibly more than 15 000 m) is believed to be in the Moora-Muchea area. North of Coorow the throw in the Phanerozoic diminishes abruptly, and at the surface it throws thin Lower Permian (Nangetty Formation) against Archaean rocks. In this area the Urella Fault becomes the major down-to-the-west fault. Further north (in the Woolaga Creek-Irwin River area) the throw of the Darling Fault in the Permian sediments increases gradually again to about 1 200 m, while that of the Urella Fault steadily diminishes. Gravity surveys indicate that the total throw on the Darling Fault increases to about 3 500 m in the Murchison River area, and the fault apparently dies out very abruptly a short distance north of the Badgeradda Range. At its southern end geophysical data indicate that the Darling Fault persists to the continental slope.

Physiographic expression

The main physiographic expression of the Darling Fault is the Darling Scarp. This is a fault-line scarp, and it is most clearly expressed between Muchea and Dardanup, a distance of some 200 km. Elsewhere the scarp is not so well defined. The maximum relief between Muchea and Moora amounts to 50 to 100 m, while from Moora to Three Springs it is generally less than 50 m. North of Three Springs there is little or no topographic expression of the fault, but in that area it is often clearly expressed on air-photographs owing to changes in vegetation on either side of the fault line. South of Dardanup the scarp persists as far as the Donnelly River, and is generally about 50 m high.

Important localities

There are a number of localities, extending from the Badgeradda Range in the north to Donnybrook in the south, where significant evidence relating to the nature and history of the Darling Fault has been obtained. These localities will be discussed individually.

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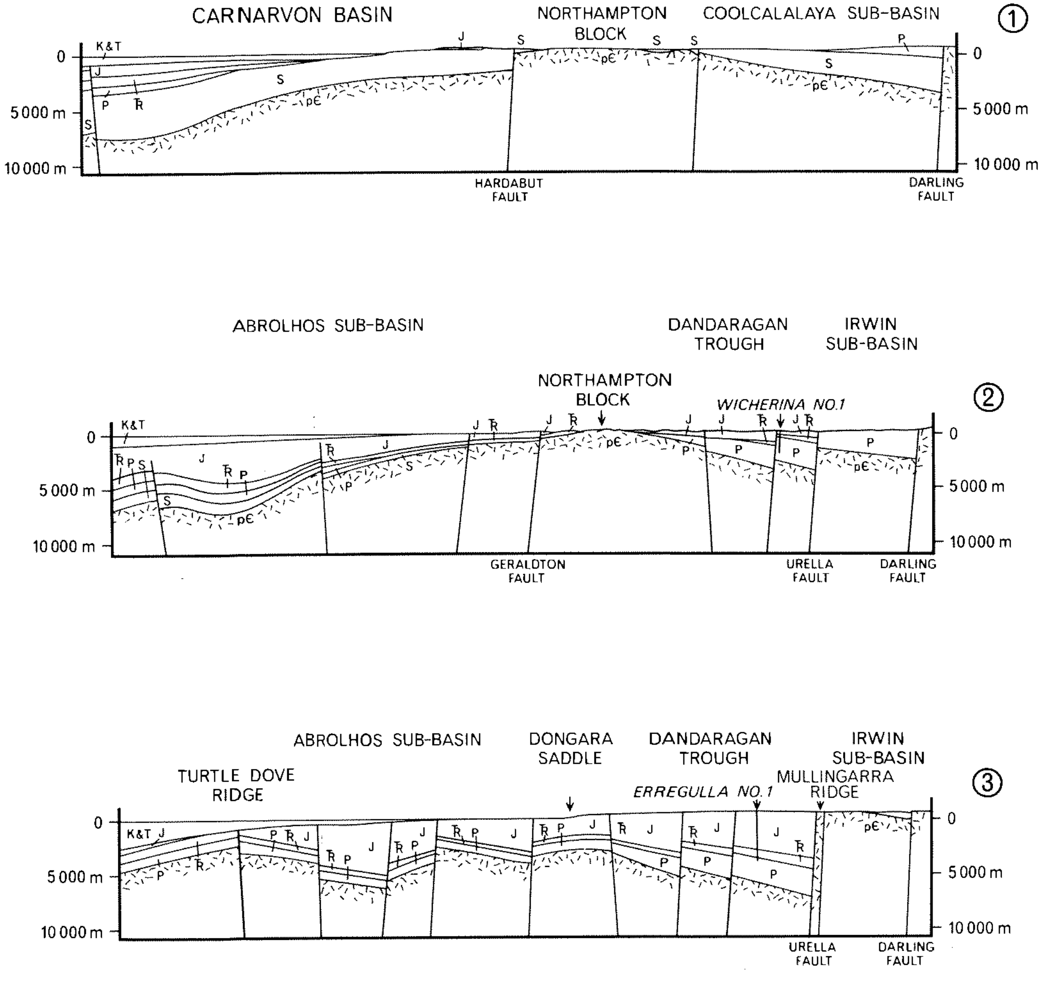
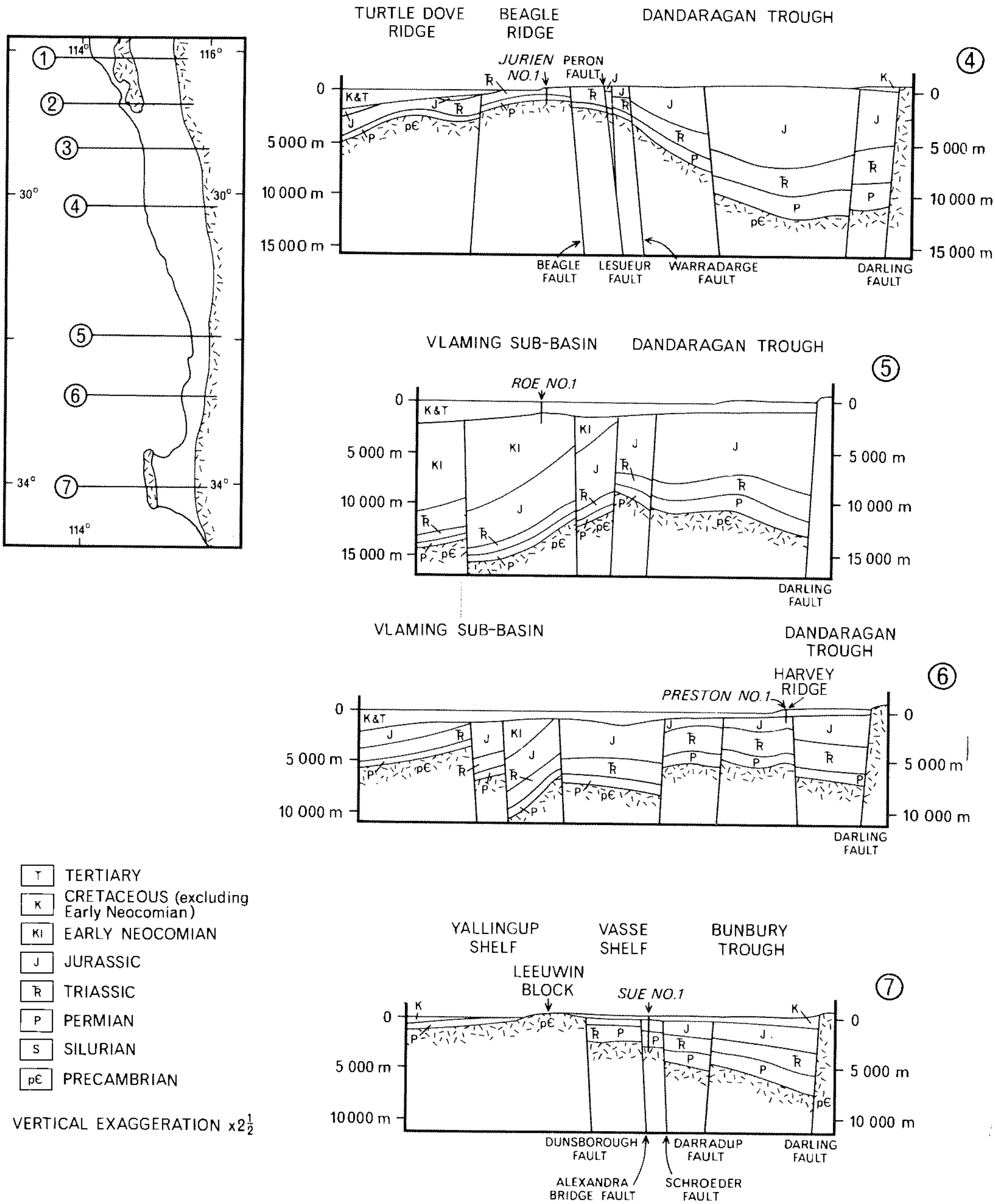


Figure 50 (above and opposite). Geological cross sections through the Perth Basin. See Plate 3 for locations of section lines.


114°
116°
30°
30°
34°
34°
114°
1
2
3
4
5
6
7
TURTLE DOVE RIDGE
BEAGLE RIDGE
DANDARAGAN TROUGH
JURIEN NO.1
PERON FAULT
BEAGLE FAULT
LESUEUR FAULT
WARRADARGE FAULT
DARLING FAULT
0
5 000 m
10 000 m
15 000 m
K&T
J
Ŧ̄R
P
pЄ
K
VLAMING SUB-BASIN
DANDARAGAN TROUGH
ROE NO.1
Kl
VLAMING SUB-BASIN
DANDARAGAN TROUGH
HARVEY RIDGE
PRESTON NO.1
YALLINGUP SHELF
VASSE SHELF
BUNBURY TROUGH
LEEUWIN BLOCK
SUE NO.1
DUNSBOROUGH FAULT
DARRADUP FAULT
ALEXANDRA BRIDGE FAULT
SCHROEDER FAULT
T TERTIARY
K CRETACEOUS (excluding Early Neocomian)
Kl EARLY NEOCOMIAN
J JURASSIC
Ŧ̄R TRIASSIC
P PERMIAN
S SILURIAN
pЄ PRECAMBRIAN
VERTICAL EXAGGERATION x2½

In the *Badgeradda Region* there is a large fault lying east of, and parallel to, the Darling Fault. This has been named the Woodrarrung Fault by Perry and Dickins (1960). They interpreted it as a high-angle reverse fault, dipping west, and suggested that the Archaean gneiss and schist on the west side of the fault have been displaced over the Proterozoic sediments of the Woodrarrung Range. The Proterozoic sediments immediately east of the fault are vertical or slightly overturned in a zone 600 m wide. However, Perry and Dickins do not discuss the possibility that the Woodrarrung Fault has strike-slip displacement; we feel that this possibility should be investigated when further field investigations are carried out in the area.

The relationship of the Woodrarrung Fault to the Darling Fault is uncertain. The two faults are parallel and are less than 10 km apart, which suggests that they are probably genetically related.

In the *Murchison River area* near Bompas Hill there is nothing in the surface exposures or on air-photographs to indicate the precise position of the Darling Fault, but it has strong gravity expression, and may have a throw of as much as 3 500 m in this area. The Sakmarian Nangetty Formation is exposed in the valley of the river near Bompas Hill, and it was mapped by Johnstone and Playford (1955) as crossing the position of the fault as indicated by gravity, to rest directly on Archaean basement rocks. However, in this area it is difficult to distinguish between parts of the Nangetty Formation and the ?Tertiary Victoria Plateau Sandstone, and it is possible that the conglomerate and sandstone crossing the fault line actually belong to the Victoria Plateau Sandstone. If the outcrops are correctly mapped as Nangetty Formation then it would appear that there has been little or no movement along the fault in this area since the Sakmarian, and most of the throw indicated by gravity would pre-date the Permian. The main displacement could then have occurred during deposition of the Silurian Tumblagooda Sandstone, which underlies the Nangetty Formation in this area and is believed to be more than 3 500 m thick.

Near *Mullewa* on the Wooderarrung River and Wenmillia Creek, there are exposures nearly 300 m thick of steeply dipping phyllitic shales with interbedded spilitic lava flows belonging to the Proterozoic Wenmillia Formation. They are cut by a dolerite dyke and by quartz-albite and quartz veins. The contact between the formation and the granitic rocks is a fault which strikes north and dips west at about 75° to 80°. This is believed to be the Darling Fault, as indicated by gravity and air-photograph correlation. Adjacent to the fault the phyllitic shales are strongly contorted and brecciated, and the Archaean granitic rocks east of the fault are also crushed. Further west the shales dip 50° to 60° west and show well-developed drag folds and associated fracture cleavage. The cleavage has a strike of 175° and it dips 70° west, while the drag folds plunge north at 55° and indicate movement of west-block up and to the north. Still further west drag folds and fracture cleavage are absent, and the shales are no longer phyllitic.

The formation is overlain with strong angular unconformity by the Nangetty Formation, which is folded into a gentle syncline having its axis approximately parallel to the Darling Fault.

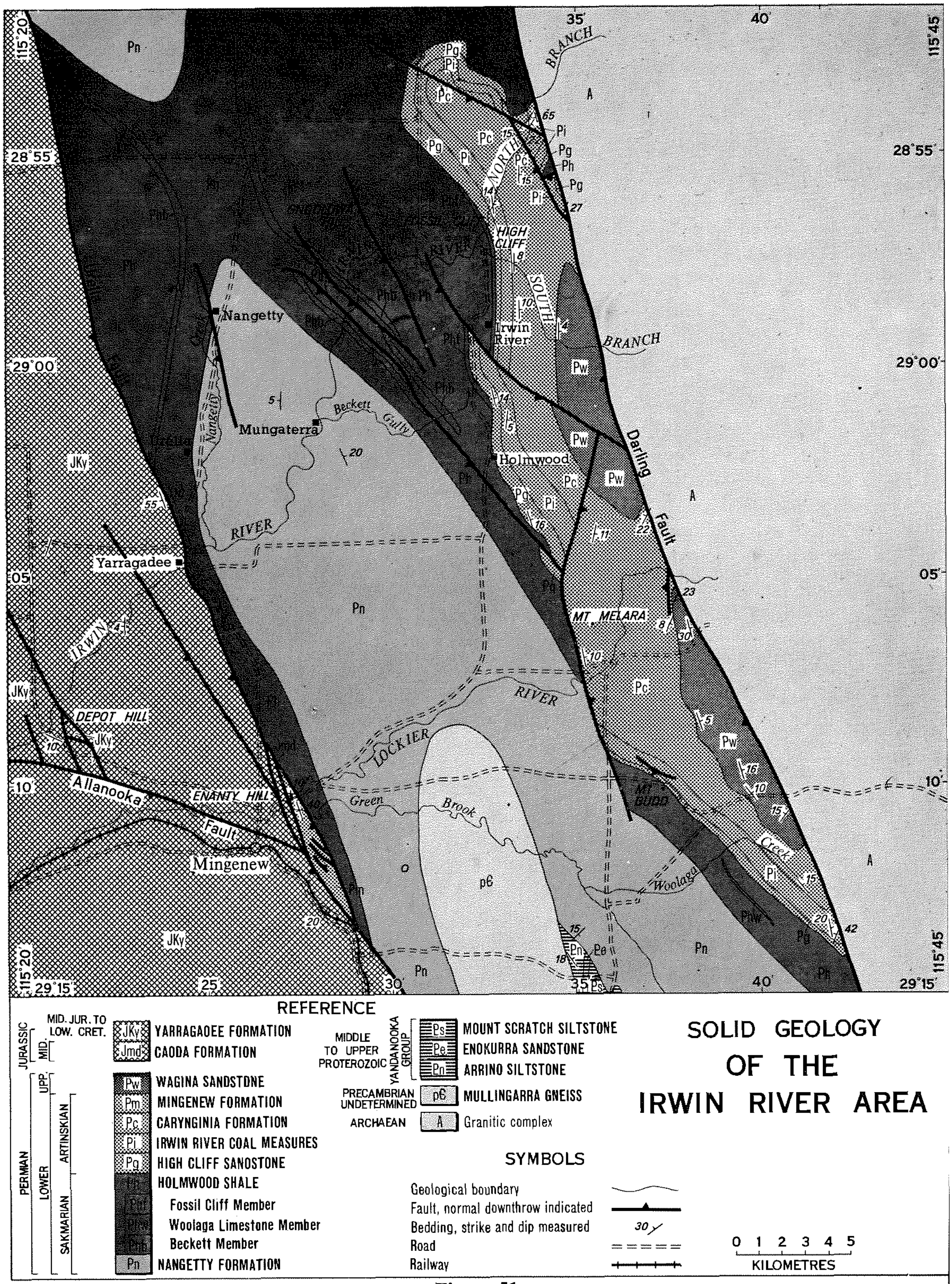
The drag folds, fracture cleavage, contortions, and brecciation in the Wenmillia Formation are believed to have developed during a period of compression associated with early (Proterozoic or early Palaeozoic) movement along the Darling Fault. The drag folds suggest that dextral reverse displacement occurred on the fault when the folds were formed. This deformation took place prior to the Early Permian when the Nangetty Formation was laid down. The gentle syncline in this formation suggests that there has been some subsequent normal down-to-the-west movement on the fault.

The Permian sediments of the *Irwin River area* are thrown against the Archaean granitic rocks of the Yilgarn Block along the Darling Fault (Fig. 51). In this area there has been no more than about 1 200 m of vertical movement on the fault since the Early Permian. The fault plane itself has not been seen, but from its trace on air-photographs where it crosses the Irwin River and other streams it is deduced to be a high-angle west-dipping fault. The Permian sediments in the Irwin River-Lockier River area form a large synclinal downwarp truncated on its eastern side by the Darling Fault, and with its axis for the most part parallel to the fault, although it swings off to the north-northwest at its northern end (Fig. 51 and Plate 6). There are a number of conspicuous subsidiary synclinal troughs along the main syncline. Such structures have generally been interpreted as drag synclines against a normal fault, but they could also have resulted from compaction, and the possibility that they are compressional features cannot be dismissed. However, we believe that it is most likely that the main displacement along the fault in this area since the Permian has been normal.

The throw of the Darling Fault diminishes rapidly in the Permian sediments north of the Irwin River and south of the Lockier River, as successively older Permian units crop out against the fault. The largest fault in this area is the Urella Fault, which is parallel to the Darling Fault and lies west of the Mullingarra Inlier and Ridge. Gravity and magnetometer surveys indicate that its maximum throw may exceed 11 000 m.

There is some evidence in the Irwin River area that the coarseness of the High Cliff Sandstone increases as the Darling Fault is approached. This suggests that a weak scarp may have been present along the line of the fault, and that the Darling Fault was in existence, although relatively inactive, at that time. Possibly there was a pulse of movement along the fault in mid-Permian times, evidenced by the disconformity between the Wagina Sandstone and the Carynginia Formation.

The *Yandanooka area* (Plate 5) is important for study of the Darling Fault. The Proterozoic Yandanooka Group is exposed in this area, and it appears to be folded into a huge syncline between the Mullingarra Inlier and the Darling Fault. The Yandanooka Group is overlain with strong angular unconformity by the



SOLID GEOLOGY OF THE IRWIN RIVER AREA
REFERENCE
JURASSIC
MID. JUR. TO LOW. CRET.
JKy YARRAGADEE FORMATION
MID.
Jmd CADDA FORMATION
PERMIAN
UPP.
LOWER
ARTINSKIAN
SAKMARIAN
Pw WAGINA SANDSTONE
Pm MINGENEW FORMATION
Pc CARYNGINIA FORMATION
Pi IRWIN RIVER COAL MEASURES
Pg HIGH CLIFF SANDSTONE
Ph HOLMWOOD SHALE
Phf Fossil Cliff Member
Phw Woolaga Limestone Member
Phb Beckett Member
Pn NANGETTY FORMATION
MIDDLE TO UPPER PROTEROZOIC
YANDANOOKA GROUP
Ps MOUNT SCRATCH SILTSTONE
Pe ENOKURRA SANDSTONE
Pn ARRINO SILTSTONE
PRECAMBRIAN UNDETERMINED
p6 MULLINGARRA GNEISS
ARCHAEAN
A Granitic complex
SYMBOLS
Geological boundary
Fault, normal downthrow indicated
Bedding, strike and dip measured
Road
Railway
0 1 2 3 4 5
KILOMETRES
Nangetty
Mungaterra
Irwin River
Holmwood
Yarragadee
Mingenew
Allanooka Fault
Darling Fault
DEPOT HILL
ENANTY HILL
MT MELARA
MT BUDD
HIGH CLIFF
NORTH BRANCH
SOUTH BRANCH
IRWIN RIVER
LOCKIER RIVER
Beckett Gully
Green Brook
Woolaga Creek
115°20'
115°45'
28°55'
29°00'
05'
10'
29°15'
25
30
35
40'

Figure 51.

Nangetty Formation. The axis of the syncline is probably parallel to the fault and situated 1.5 to 2.5 km west of it. However, the axis and the east flank of the syncline are exposed at only one locality; the rest of the postulated east flank is entirely covered by the Permian Nangetty Formation or Quaternary rocks. All other exposures of the group are on the west flank.

The syncline is tightly folded, with dips averaging 50° to 55° east on the west limb. The strike of the strata is usually 165° to 170°, parallel to the Darling Fault. At the one locality where the east flank is exposed the west dips are from 55° to 85°. It is clear that such a huge, tightly folded structure could only form through major compression. This compressive phase may have been associated with the original rupture of the Darling Fault.

The sediments of the Yandanooka Group are for the most part heavier than the granitic rocks of the Yilgarn Block or the Mullingarra Inlier, and for this reason the syncline is expressed as a gravity maximum. It is therefore clear that estimates of sediment thicknesses elsewhere in the basin based on gravity do not include the Yandanooka Group (if it is present). In fact, if the group does occur in other areas, the thickness of sediments deduced from gravity surveys would be less than the true thickness.

In the *Moora area* the Proterozoic sediments of the Moora Group are strongly faulted. The sediments dip to the west, steepening to almost vertical near the Darling Fault. Some of the faults are strike faults parallel to the main Darling Fault, but most are oblique to this trend and strike approximately east-northeast. Low (1969) states that some strike faults cut oblique faults, but that the two systems were probably mainly contemporaneous. Most of the dolerite intrusions in the Moora Group follow strike-fault trends, and they seem to have been emplaced after the faulting had occurred.

The nature of faulting in the Moora area is uncertain. Some faults may show strike-slip displacements. Most have only small throws; one of the largest is the Noondine Fault of Logan and Chase (1961), which strikes north, dips west at 65°, and may have a throw of as much as 500 m. The relationships of faults in the Moora Group to the Darling Fault are uncertain. They may pre-date the Darling Fault, or they may have formed during a compressive phase when that fault first developed.

In a small area east of *Bullsbrook* there are exposures of the Lower Cretaceous Bullsbrook Beds resting unconformably on granitic rocks east of the Darling Fault. They are apparently overlain by the Osborne Formation, which crops out on both sides of the fault in this area, as far north as Muchea. The Bullsbrook Beds occupy a valley which was incised into the Darling Fault during the Neocomian, and they are believed to have been deposited during the final phase of the long Triassic-Early Cretaceous period of continental sedimentation in the basin. The elevations of the base of the Osborne Formation on opposite sides of the Darling Fault near Bullsbrook (based on outcrop and bore data) suggest that displacement along the fault since the Albian-Cenomanian (when the Osborne Formation was deposited) has been no more than 130 m, and possibly less than 50 m.

North of the Bullsbrook-Muchea area the fault has probably been essentially quiescent since the mid-Neocomian, whereas to the south the throw since that time probably increases, to reach a maximum opposite Perth.

The structure of the *Darling Range area* east of Perth (see frontispiece) has been discussed by Prider (1941, 1952), Wilson (1958), Playford (1958, 1962), and Frost (1960). Prider (1941) recognized that the Proterozoic Cardup Group rests unconformably on granitic rocks of the Yilgarn Block and dips to the west at an average of about 50°. The dip of the unconformity surface is essentially the same as that of the Cardup Group sediments. Prider noted that drag folds in the shales (Armadale Shale) indicate west-block-up movement and that slickensides are parallel to the dip of the shales. He stated that the drag folds plunge to the south at low angles. R. N. Cope (pers. comm., 1973) has since observed that others plunge to the north. Prider could find no evidence for the existence of the Darling Fault, and he suggested that the Cardup Group exposures occurred on the limb of a monoclinal fold and that this fold was responsible for the Darling Scarp. Prider (1952), extending this hypothesis, suggested that the monocline had been localized by an older sinistral transcurrent fault, which he referred to as the "Darling Archaean Fault". Evidence cited for this lateral movement included the presence of major drag structures in the Archaean rocks of the Yilgarn Block, shear zones and gash veins. Prider suggested that monoclinal downwarping was initiated during the Palaeozoic and continued through the Mesozoic and Cainozoic.

Wilson (1958) described the geology of the Yilgarn Block adjoining the Darling Fault. He interpreted the fault as being an "early Precambrian fundamental structure along which movement has taken place in (possibly) several directions at various times". He stated that there are several mylonite zones near the Darling Scarp where overthrusting from the east seems to have occurred, and that the original Darling Fault may have been a reverse fault dipping to the east at a fairly shallow angle. However, he observed that the present Darling Fault appeared to be a normal fault dipping very steeply to the west.

Wilde (1974) also reports extensive shearing and mylonitization in the granitic rocks and dolerite dykes near the Darling Fault, and suggests that the fault has formed subparallel to an ancient zone of north to north-northeast shearing.

Frost (1960) analyzed jointing in the Precambrian crystalline rocks of the Darling Range near Boya and in the valley of the Helena River. The two oldest joint systems were interpreted by Frost as indicating a Precambrian interval of east-west compression followed by east-west tension. A possible third joint system and some late slickensides were interpreted as indicating periods of horizontal shearing. Other slickensides were thought to indicate east-side-down faulting in association with the intrusion of a swarm of north-northwest-trending dolerite dykes. Frost concluded that these features are consistent with the up-arching and collapse during the Proterozoic of an anticlinal warp, followed during the Phanerozoic by a "more westerly collapse which produced the Darling Fault".

Playford (1958, 1962) suggested that the Cardup Group exposures formed the east limb of a major synclinal or monoclinal downwarp. He stated that the granitic rocks appeared to be involved in the flexure, and that this could only have occurred on such a scale in response to major compression at considerable depth. Playford pointed out that the present Darling Fault must lie to the west of the exposed Cardup Group, and suggested that it developed as a normal fault after the flexuring, and was localized by the steep limb of the syncline. This view is accepted in the present publication.

Perhaps the most important question regarding the history of the Darling Fault in this area is the dating of the last period of movement. The strongly developed fault-line scarp of the Darling Range could be explained as being entirely the result of differential erosion during the Tertiary-Pleistocene transgression. However, subsurface data indicate that the area of the Swan Coastal Plain west of the Darling Scarp has subsided strongly since the mid-Neocomian, allowing deposition of up to 1 000 m of sedimentary rocks of the Warnbro and Coolyena Groups, Kings Park Formation, and Kwinana Group. The strongest subsidence has been in the vicinity of Perth itself, and has resulted in the Perth Syncline or Sunkland of Jutson (1934). Bore data indicate that continental sediments of the Warnbro Group extend short distances east of the fault at a few places opposite Perth, but there are no satisfactory markers to demonstrate whether displacement has occurred on the fault at this level. However, structure contour maps compiled by A. D. Allen as part of a detailed hydrogeological study of the Perth metropolitan area suggest that several hundred metres of movement has probably taken place since the mid-Neocomian.

The fault may have moved during the Cainozoic after deposition of the Paleocene-Eocene Kings Park Formation. The Darling Plateau east of Perth has been uplifted some 300 m since the Eocene (Cope, 1975), and this uplift may be continuing today. The adjoining part of the Perth Basin must have been uplifted epeirogenically by a similar amount unless there has been compensating movement along the Darling Fault. It seems likely that both types of movement have affected the Perth Basin during the Cainozoic, but the evidence is inconclusive. There is no record of activity along the Darling Fault in historic times, although minor Quaternary movement in the Perth area seems possible.

In the *Donnybrook area* the Donnybrook Sandstone and Maxicar Beds rest against the Darling Scarp and in valleys incised into the scarp. These sediments occupy a similar position to that of the Bullsbrook Beds, and they are also thought to be of Neocomian age. They are believed to have been deposited at

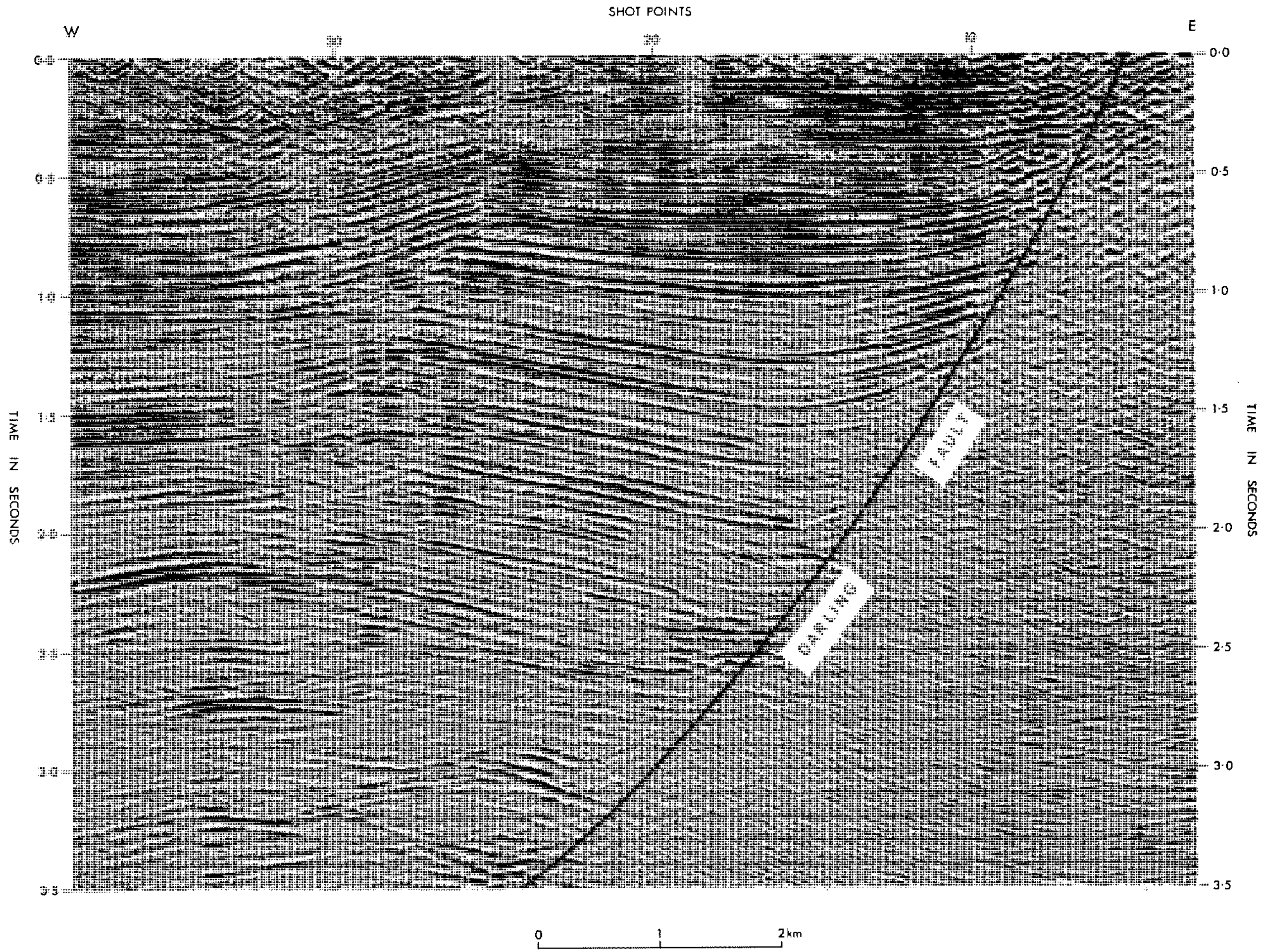


Figure 52. Seismic record section of part of line P72-34L across the Darling Fault about 13 km south of Moora, from lat. 30° 42′ 15″S, long. 116° 00′ 30″E, to lat. 30° 42′ 15″S, long. 115° 56′ 15″E. Record section by courtesy of West Australian Petroleum Pty Ltd.

or soon after the time of the last major period of movement in this area along the Darling Fault, which lies immediately to the west.

The exact position of the Darling Fault in the *Warren River area* is uncertain owing to the lack of reliable outcrop and geophysical control. However, the evidence suggests that in this area there is a prominent swing to the east in the fault. If this is correct it is the most abrupt change in the strike of the fault throughout its length. Alternatively, if the fault in this area really continues in its usual north-trending direction without the abrupt swing, Upper Jurassic Yarragadee Formation must extend some 5 to 7 km east of the fault.

NATURE OF THE FAULT

The Darling Fault is a high-angle fault, dipping to the west. Seismic evidence shows that the dip ranges from 80° off the south coast and near Pinjarra to 75° east of Rockingham, 60° near Moora, 55° near Bullsbrook, and 50° near Dandaragan (Wapet, written comm., 1973). The most accurate of these dip determinations are on seismic lines near Pinjarra and Moora (Fig. 52). The other determinations are said to have fair reliability, with the exception of that near Bullsbrook, which is poor.

There has been no definite record of any seismicity along the Darling Fault in historic times. However, a moderate amount of seismicity, generally of only low magnitude, has been recorded along the South West Seismic Zone (also known as the Yandanooka-Cape Riche Lineament) east of the Darling Fault (Everingham, 1968; Doyle, 1971; Gordon, 1972). This zone strikes north-northwest and it meets the Darling Fault near Yandanooka. The largest earthquake in the zone occurred in 1968 at Meckering, 90 km east of the Darling Fault; it had a magnitude of 6.9 on the Richter scale. The earthquake had a shallow focus (less than 10 km) and it resulted in an arcuate fault scarp at the surface showing reverse dextral displacement. The maximum reverse movement amounted to about 1.85 m, while the dextral displacement averaged about 0.5 m and reached a maximum of 1.17 m (Gordon, 1971). Gordon and Wellman (1971) suggest that the South West Seismic Zone marks a sinistral shear zone and that the Meckering faulting represented the response to movement along this shear acting on a thin cap of granitic rock having the shape of the base of a sphere. However, we believe that the faulting could be a response to localized stresses associated with continuing epeirogenic upwarping of the Yilgarn Block.

Gordon (1972) has suggested that although there is no record of modern movement along the Darling Fault the compressive faulting at Meckering raises the possibility of contemporary reverse or transcurrent movement. He cites some evidence from stream courses near the scarp which he believes, could indicate Holocene transcurrent displacements.

Prider (1972) also cites the Meckering faulting as evidence for the Yilgarn Block being in a state of compression. He hypothesizes that the Darling Fault is a reverse (east-dipping) fault and that the Perth Basin is being held down by the overthrust continental block, an idea that was first put forward by Vening Meinesz (1948). Prider suggests that this interpretation would explain the fact that the Perth Basin is isostatically imbalanced (as shown by the large minimum gravity anomaly) while being seismically inactive.

However, the Darling Fault is not known to have moved in historic times, and there is no evidence that it bears any relationship to the presently active South West Seismic Zone. The stress situation responsible for movement along the Darling Fault (which had its main activity in the Mesozoic) was probably quite different from that which is responsible for modern seismicity along the South West Seismic Zone. Moreover, there is no geophysical or outcrop evidence that the Darling Fault has reverse displacement in the Phanerozoic rocks. Seismic data indicate that the fault dips to the west, and clearly the west block has moved down. In other words, the data are consistent with normal down-to-the-west movement along the fault.

History of the fault

The Precambrian history of the Darling Fault, or of the zone which localized this fault, is uncertain. A structural discontinuity could have been present along this zone during the Archaean or Early Proterozoic, but there is no evidence that the Darling Fault as such was in existence at that time. However, there is evidence that compressive movements took place along the line of the present fault in Late Proterozoic or (more likely) early Palaeozoic times. It is not sure whether this compression resulted in transcurrent or reverse faulting, or simply in linear flexuring. Our preferred hypothesis is that a transcurrent fault developed at that time close to the line of the present Darling Fault, but there is some conflicting evidence as to the sense of the postulated strike-slip displacement. In the Wooderarrung River area the evidence strongly indicates reverse dextral movement.

Later regional pull-apart stress resulted in development of the normal Darling Fault. This may have first occurred in Silurian times, when deposition of the Tumblagooda Sandstone began in the northern Perth Basin. Displacement along the fault may also have occurred during the Permian, but the greatest movements took place from Middle Triassic to earliest Cretaceous times, when the area east of the active fault scarp shed great quantities of detritus into the subsiding Perth Basin. Major movement along the fault came to an end about the middle of the Neocomian, but some activity probably continued in the area of the present Darling Scarp during the Cretaceous and part of the Cainozoic. No movement is known to have occurred in historic times.

OTHER FAULTS AND FAULTED AREAS

Urella Fault

The Urella Fault is another very large fault in the basin. It is over 240 km long and its maximum throw may exceed 11 000 m. The Urella Fault developed parallel to the Darling Fault, probably branching from that fault south of Coorow.

From there it continues to north of the Greenough River. No evidence for the position of the fault can be seen at the surface at its southern end, where it is mapped solely on geophysical evidence. Further north it can be traced at the surface near Mingenew, where the Yarragadee Formation is displaced against Permian sediments. North of Mingenew surface mapping, geophysics, and drillhole data show that the throw of the fault diminishes progressively, while that of the Darling Fault increases. The diminishing throw of the Urella Fault is associated with thinning of the Jurassic sequence; the Jurassic finally pinches out near Kockatea Gully, and north of there the Urella Fault throws Permian against Permian and splits into a number of branches before dying out several kilometres north of the Greenough River.

The Urella Fault is thought to have operated as a normal fault from the Middle Triassic to the early Neocomian. It may have been in existence during the Permian (there is some weak outcrop evidence of coarsening of the High Cliff Sandstone as the fault is approached), but there are no known thickness changes in the Permian units on opposite sides of the fault that would substantiate faulting during the period. The parallelism between the Darling and Urella Faults suggests that they are likely to have had similar origins, but there is no evidence in outcrop or from geophysics of any Proterozoic or early Palaeozoic movement on the Urella Fault.

Beagle Fault

The Beagle Fault defines the eastern margin of the Beagle Ridge for a distance of some 130 km. It is believed to be a high-angle east-dipping normal fault having a maximum throw of some 1 800 m. The fault may have first developed during or prior to the Early Permian, but the strongest period of activity was probably during the early Neocomian. Since then it appears to have been quiescent.

Dunsborough Fault

The Dunsborough Fault marks the eastern margin of the Leeuwin Block. It is believed to be a steeply east-dipping normal fault, and has a maximum throw of between 3 000 and 4 000 m. The fault probably last operated in earliest Cretaceous times; it is overlapped by Neocomian sediments of the Warnbro Group.

Yandi Fault

The Yandi Fault marks the contact between the Tumblagooda Sandstone and the granitic rocks on the eastern side of the Northampton Block in the Murchison River area. The maximum throw of the fault near Yandi homestead may be as much as 1 000 m, but it dies out rapidly to the south, and only 25 km south of the river the Tumblagooda Sandstone is known to onlap the Northampton Block without a faulted contact.

The attitude of the Yandi Fault has not been determined, but it is presumed to be a steep east-dipping normal fault.

HARDABUT FAULT

A gravity survey carried out by Wapet in the Northampton-Ajana area pointed to the presence of a large down-to-the-west fault (presumably normal) having a maximum throw of at least 2 000 m, along the western margin of the Northampton Block. The steep gravity gradient coincides with a small thrust fault between the Tumblagooda Sandstone and the granitic rocks on the Murchison River near Hardabut Pool. This was named the Hardabut Fault by Johnstone and Playford (1955). However, in the Hutt River area (further south) the Tumblagooda Sandstone is not displaced where it crosses the steep gravity gradient, and it unconformably overlaps the granitic rocks. Therefore, the postulated down-to-the-west normal fault in this area would need to have operated prior to deposition of the Tumblagooda Sandstone or during an early stage of its deposition.

The fault near Hardabut Pool dips west-northwest at about 20° to 30°, and a small anticline has developed in the Tumblagooda Sandstone over the fault. The formation is believed to have been thrust upwards over the granitic rocks during the period of compression which affected the coastal parts of the Carnarvon Basin during the late Tertiary (late Miocene) to Pleistocene. It is thought to have been localized by the postulated pre-existing down-to-the-west fault. Such reversal of movement localized by older normal faults also occurs in other parts of the Carnarvon Basin (Playford and Johnstone, 1959; Playford and others, 1975). Uplift of the block of Tumblagooda Sandstone associated with this movement caused the Murchison River to cut down into its bed to form the spectacular gorge which commences at the fault and continues downstream for more than 80 km.

NOLBA-NORTHERN GULLY AREA

A number of small faults, which appear to be normal, have been found along the contact between the Tumblagooda Sandstone and the Precambrian rocks in the Nolba and Northern Gully areas, on the east side of the Northampton Block. These faults strike north-northwest, and none seem to have large displacements. In some parts of the area the Tumblagooda Sandstone rests unconformably on the Precambrian rocks, in others the contact is faulted. Some of the faulting also occurs within the Tumblagooda Sandstone.

The faults are believed to dip to the east at high angles. They form part of a zone of minor faulting along the east side of the Northampton Block that extends from south of the Yandi Fault to near Northern Gully.

NORTHAMPTON BLOCK

Faulting within the Precambrian rocks of the Northampton Block has been described by Prider (1958) and Jones and Noldart (1962). Prider mapped a number of sinistral transcurrent faults with northwest trends, cutting the Precambrian rocks along the Murchison River valley. The displacement of dolerite dykes by the faults indicates the amount of lateral movement, the maximum in the area mapped by Prider being 0.8 km. These faults are believed to be of early Palaeozoic age, as they do not cut the Silurian Tumblagooda Sandstone but are younger than the dolerite dykes and associated lead orebodies that have been dated as 500 m.y. old (Prider, 1954).

Jones and Noldart (1962) state that there are also a number of small northeast-trending faults within the Northampton Block. Dolerite dykes have been intruded along these small faults; other dykes follow joints having the same trend.

Small faults cutting both the Jurassic sediments and the Precambrian rocks of the Northampton Block in the western part of the Bringo cutting have been illustrated by Playford (1953, 1959). They are normal faults, throwing down to the west, and having northwesterly trends. The average dip of the faults at the western end of the cutting is 63°, and the average strike is 135°. The largest displacement on any one fault is 1.2 m. Although these faults are very small, they display many of the features that are characteristic of the normal faulting pattern in the Perth Basin. Thus the faults in the cutting dip to the west, while the individual fault blocks are tilted to the east (Fig. 53). The

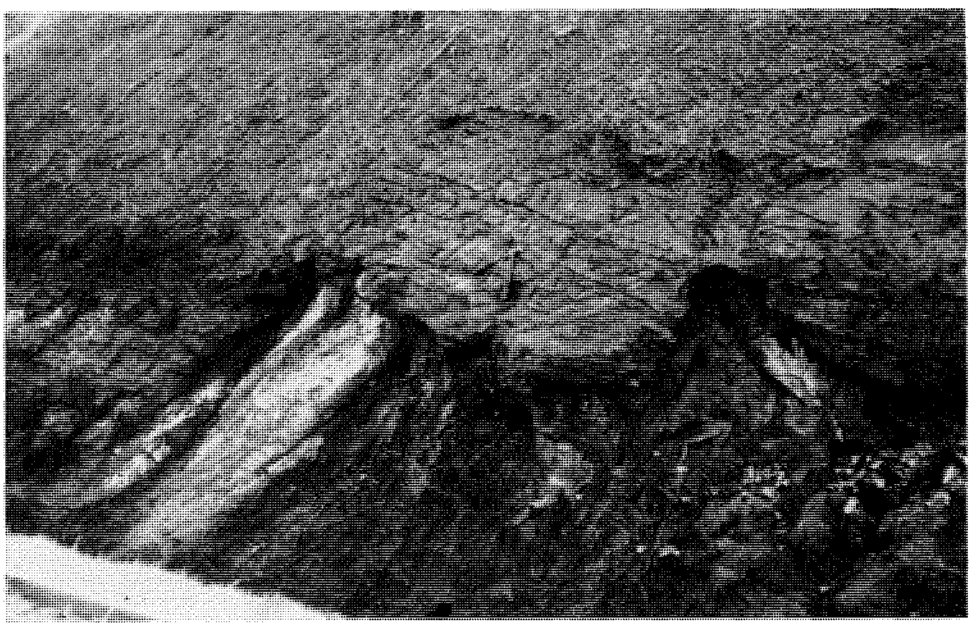


Figure 53. Normal faults cutting weathered Precambrian granitic rocks and Jurassic sediments (Moonyoonooka Sandstone, Colalura Sandstone, and Bringo Shale) on the north wall of the Bringo cutting (photograph taken in 1952). Each fault has a throw of about 1 m in the Moonyoonooka Sandstone, and they die out progressively in the incompetent Bringo Shale, passing into weak folds.

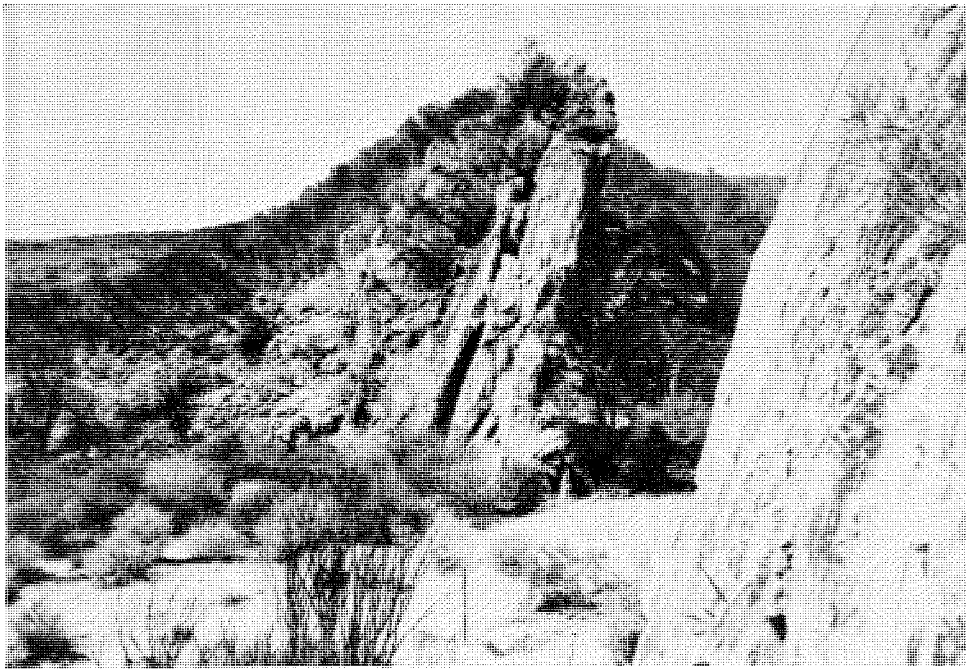


Figure 54. Silicified fault zone, dipping east, cutting the Tumblagooda Sandstone on Bindoo Hill.

sediments show small drag structures adjacent to the faults, and the faults tend to die out upwards into flexures in the sediments. The age of these faults is probably Late Jurassic or Early Cretaceous; they cut the Middle Jurassic sediments and pre-date lateritization in this area. One small pre-Jurassic fault also occurs in the cutting displacing a vein in the Precambrian rocks.

Unfortunately the faults in the Bringo cutting are no longer as well exposed as when they were illustrated by Playford (1959), as the cutting has since been widened, the slopes of the walls have been decreased, and the exposures are now largely covered with loose sediment.

BINDOO HILL

The Tumblagooda Sandstone exposed on Bindoo Hill is extensively faulted. The faults form strongly silicified zones, many of which crop out as walls running along the sides of the hill (Fig. 54). Most of the faults trend north-northwest and dip steeply to the east, but there are others that trend west-northwest to nearly west. Several faults bifurcate, and all appear to have normal displacements. Some of the fault planes exhibit well-developed slickensides which are either parallel to the dip direction of the fault or at a small angle (up to 25°) to it, thus showing that the movements were predominantly vertical.

Most of the exposed faults around Bindoo Hill are within the Tumblagooda Sandstone, but some also displace the Nangetty Formation. Several small faults exposed on the west bank of the Greenough River cut the Nangetty Formation, but are truncated at the unconformity with the overlying Kojarena Sandstone. These faults are therefore post-Sakmarian and pre-Bajocian in age.

IRWIN RIVER AREA

The Permian sediments of the Irwin River area are exposed between the Darling and Urella Faults (Plate 6, Fig. 51). They are also cut by a number of smaller faults, most of which have throws of less than 20 m. Some have been detected only on air-photographs.

The biggest of these faults is present just east of Mount Melara. This fault throws the Carynginia Formation against the Holmwood Shale and is believed to have a maximum displacement of more than 100 m. It is an antithetic fault, dipping to the east (whereas the principal faults in the area are west dipping).

A west-dipping normal fault, which appears to dip at less than 45°, cuts the Holmwood Shale at its type section along Beckett Gully. It displaces the Beckett Member and shows clearly on air-photographs. The total displacement is believed to be about 80 m.

HILL RIVER AREA

The Jurassic and Triassic sediments of the Hill River area east of the Beagle Fault are cut by a network of northerly trending faults (Plate 9, Fig. 55). All are believed to have normal displacements, and most of them dip to the east. The Lesueur Fault-Peron Fault system branches to the north, and the total displacement of the system (down to the east) exceeds 2 000 m. The Warradarge Fault, further to the east, has a throw of about 1 000 m.

Although exposures are very poor in the Hill River area, many of the faults can be detected on the ground owing to ferruginization that has occurred in the sandstones alongside the faults. The pattern of faulting in this area is very similar to that mapped by seismic methods in early Neocomian and older rocks throughout much of the basin.

BUSSELTON-AUGUSTA AREA

The Perth Basin between the Leeuwin and Yilgarn Blocks forms a graben defined on the east by the large Darling Fault and on the west by the smaller Dunsborough Fault. Between these there are a number of other normal faults, including the east-dipping Alexandra Bridge, Schroeder, Wirring, and Busselton Faults, and the west-dipping Darradup Fault (Lowry, 1967). The Busselton Fault-Wirring Fault system is the largest of these, with a total throw of up to 4 000 m.

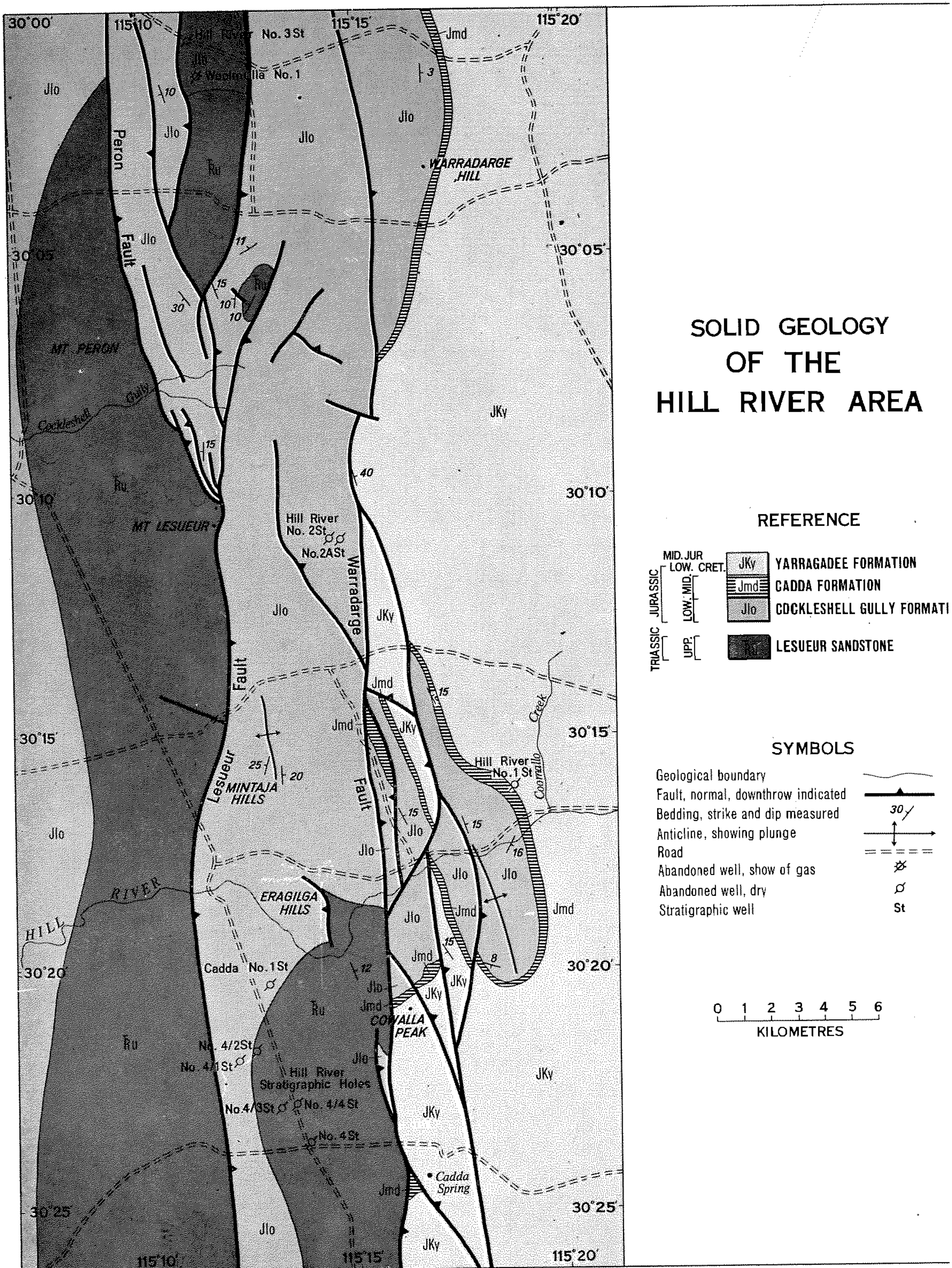

SOLID GEOLOGY
OF THE
HILL RIVER AREA
REFERENCE
MID. JUR
LOW. CRET.
JURASSIC
LOW. MID.
TRIASSIC
UPP.
JKy YARRAGADEE FORMATION
Jmd CADDA FORMATION
Jlo COCKLESHELL GULLY FORMATI
LESUEUR SANDSTONE
SYMBOLS
Geological boundary
Fault, normal, downthrow indicated
Bedding, strike and dip measured
Anticline, showing plunge
Road
Abandoned well, show of gas
Abandoned well, dry
Stratigraphic well
St
0 1 2 3 4 5 6
KILOMETRES
30°00'
115°10'
115°15'
115°20'
30°05'
30°10'
30°15'
30°20'
30°25'
Hill River No. 3 St
Woolmulla No. 1
Peron
Fault
MT PERON
Cockleshell Gully
WARRADARGE HILL
MT LESUEUR
Hill River No. 2St
No. 2ASt
Warradarge
Lesueur
Fault
MINTAJA HILLS
Hill River No. 1 St
Coomallo Creek
HILL RIVER
ERAGILGA HILLS
Cadda No. 1 St
COWALLA PEAK
No. 4/2St
No. 4/1St
Hill River Stratigraphic Holes
No. 4/3St
No. 4/4 St
No. 4 St
Cadda Spring
Jlo
Jmd
JKy

Figure 55.

FOLDING

As previously discussed, the Phanerozoic structure of the Perth Basin is characterized by faulting rather than folding. Normal faulting in response to regional tension and subsidence has apparently prevailed since the middle or late Palaeozoic. There has been some flexuring in association with this faulting, but compressional tectonics in the basin seem to have been restricted to Proterozoic rocks.

NATURE OF FOLDS

The Proterozoic sediments in and adjoining the Perth Basin are believed to have been involved in large-scale folding. The Yandanooka Group apparently occupies a huge syncline west of the Darling Fault, and this could only have developed in response to major regional compression, possibly associated with the initial development of the Darling Fault. The steeply dipping Wenmillia Formation and Cardup Group, which are exposed immediately adjacent to the Darling Fault, are also believed to form limbs of flexures developed at that time.

Figure 56. Small anticline exposed in Yarragadee Formation in the Bringo cutting. The fold has probably resulted from differential compaction over a sandstone lens.

The most conspicuous folding in the Phanerozoic rocks of the basin occurs in association with faults. Synclines are commonly developed on the downthrown sides of faults, while anticlines occur on the upthrown sides. The best developed structures are associated with grabens (synclines) and horsts (anticlines). The cause of the folding has commonly been assumed to be dragging on the faults or incompetent flexuring over them (as can be seen with the small faults in the Bringo cutting). However, as pointed out by Cope (1972), differential compaction could be a major cause of such structures.

Folding on a small scale is common in the Yarragadee Formation, and has apparently resulted from differential compaction of shale and siltstone over sandstone lenses in this continental sequence. A good example of such a fold is exposed in the Bringo cutting (Fig. 56).

FOLDS AND FAULTED AREAS

Many faulted folds have been delineated by seismic methods in the Perth Basin, and some of these have been drilled as petroleum prospects. Economically the most important of these is the *Dongara Anticline*, which contains the largest gas field found in the Perth Basin. This fold is developed in Jurassic, Triassic, and Permian sediments on the upthrown side of the Mountain Bridge Fault, and is itself strongly faulted. Closure of the anticline is largely dependent on faulting.

The *Gingin Anticline* was the first large anticlinal structure to be located in the basin by seismic methods. The early seismic records were poor, but they suggested the presence of a large anticline more than 30 km long and 6 km wide, with about 450 m of closure. Subsequent seismic work has demonstrated that the structure is faulted, and that the structural trend continues for some 65 km to the Bullsbrook area. Drilling has shown that the anticline is developed in Jurassic sediments to depths of at least 4 500 m.

The main Phanerozoic folds exposed at the surface are in the Irwin River area. A large anticlinal nose (the Nangetty Anticline) is developed over the Mullingarra Ridge, on the upthrown side of the Urella Fault. This anticline may have resulted largely from differential compaction over the buried ridge, combined with the effects of large-scale drag associated with movements along the Urella Fault zone.

A large faulted syncline is developed in the Irwin River area immediately west of the Darling Fault. Again, this flexure could have resulted from the combined effects of differential compaction and drag along the fault.

The Northampton Block is onlapped by the Lower Silurian Tumblagooda Sandstone, which dips away from the block on both its east and west sides. On the west dips range from about 15° near the contact to 1° some 30 km west, while on the east the dips are higher, averaging about 40° near the block and 25° some 6.5 km to the east. The Northampton Block is thus essentially the core of a huge anticlinal uplift. Most of this uplift took place after deposition of the Tumblagooda Sandstone and prior to the Early Permian, although the block continued to be a positive feature from the Permian through to the present.

A small structure, believed to be anticlinal, is exposed some 20 km north-northeast of Dandaragan. It is named the *Muthawandery Structure*. Exposures are poor in this area, but an inlier of Yarragadee Formation crops out in the core of the structure, surrounded by younger Cretaceous units (Dandaragan Sandstone and Coolyena Group). It is very conspicuous on the solid geology map (Plate 3).

Dips in the Yarragadee Formation and Dandaragan Sandstone on the east side of the Muthawandery Structure are up to 5° east, but no dips have been observed on the poorly exposed west side. Drilling on the Watheroo line of exploratory water bores 22 km north of the structure has shown that a gentle anticline is developed in the Yarragadee Formation. The Muthawandery Structure may be a southern culmination on the same anticlinal trend. However, seismic work indicates that no anticlinal structure persists at depth along this trend. The origin of the structure is unknown, but the possibility that it has resulted from unrecognized faulting rather than folding cannot be discounted.

Folding in the southern part of the Perth Basin is described by Cope (1972), who interpreted the subsurface folds as being caused by differential compaction across, and in association with, growth faults. He suggested that there is a correlation between the present topography and the subsurface structure and that this has resulted from continuing differential compaction over the various fault blocks. Cope (1972) also postulated that a broad, very gentle anticlinal uplift developed in the Blackwood Plateau area during middle to late Tertiary times, and introduced the name *Jarrahwood Axis* for this feature.

CHAPTER 6

Geophysics

Geophysical work in the Perth Basin was pioneered by the Dutch geophysicist Vening Meinesz in 1935 (Vening Meinesz, 1948). He made several gravity readings along a traverse from Merredin to the coast and out to sea by submarine, and showed that a very large gravity minimum anomaly existed over the Perth Basin. This was the first indication that the basin contains a great thickness of sediments. Since then a great deal of geophysical exploration (gravity, magnetic, and seismic) has been carried out in the basin by oil exploration companies and the Bureau of Mineral Resources.

GRAVITY

The Bureau of Mineral Resources has conducted a regional gravity survey in the Perth Basin. The work began with a short gravity traverse near Bullsbrook by Thyer (1951) and was extended to cover the whole of the basin (Thyer and Everingham, 1956). This survey defined the major structural elements of the basin for the first time. The lowest gravity readings, amounting to a minimum gravity anomaly of −130 milligals, were obtained west of Watheroo. As a result of this work Thyer and Everingham suggested that the throw on the Darling Fault might exceed 9 000 m.

West Australian Petroleum Pty Ltd has carried out more detailed gravity surveys over much of the Perth Basin. Reports that have been made public are by Felcman and Lane (1963), Reynolds and Kramer (1962), Ingall (1967), and Lane and Reynolds (1963). These results have been incorporated in the Bouguer gravity anomaly contour map of the basin shown as Plate 10.

MAGNETIC

The Bureau of Mineral Resources has carried out an aeromagnetic survey of the Perth Basin and has published 1 : 253 440 contour maps of observed total magnetic intensity. These have been used to compile Plate 11, which covers the whole of the basin at a scale of 1 : 1 000 000.

Newman (1959) and Quilty (1963) described the results of the Bureau's survey, and Quilty prepared a basement contour map. Additional magnetic surveys have been carried out in the basin by oil exploration companies, and include aeromagnetic and magnetic surveys. One of the most useful of these covered the area around the Houtman Abrolhos (St. John, 1971); this area had not been fully covered by the B.M.R. aeromagnetic work.

SEISMIC

A great deal of seismic work has been carried out in the Perth Basin, mainly by West Australian Petroleum Pty Ltd and its associated companies, supplemented by several profiles across the basin by the Bureau of Mineral Resources.

The complex structure of the Perth Basin is difficult to map accurately by seismic methods, because of poor record quality associated with energy-absorbing superficial deposits (particularly the Tamala Limestone; Taylor, 1969) and the lack of strong velocity contrasts through most of the section. The only reliable seismic mapping horizons in the basin are the Cattamarra Coal Measures Member of the Cockleshell Gully Formation (over a large area of the basin) and the Quinns Shale Member of the Yarragadee Formation in the offshore area opposite Perth. Other horizons, such as the Permian-Triassic unconformity, are locally useful as mapping horizons, but they are difficult to correlate reliably across faults.

Everingham (1965) has made a study of the deep crustal structure of the southwestern part of Western Australia based on seismic recordings obtained at the Mundaring Geophysical Observatory and various outstations and temporary field stations operated by the Bureau of Mineral Resources. Data were obtained from distant earthquakes and from explosive sources. These showed that the crustal thickness beneath the Perth Basin is as much as 46 km, and suggested that the Darling Fault could have a throw as great as 20 km, and may extend into the mantle.

CHAPTER 7

Geological History

In the first part of this chapter the geological history of the Perth Basin itself is summarized with the aid of a series of palaeogeographic maps (Figs. 57-60). This is followed by an attempt to broadly integrate this history with that of the hypothetical Gondwanaland supercontinent.

PERTH BASIN

PRECAMBRIAN

The granulites of the Northampton and Leeuwin Blocks are believed to represent the metamorphosed equivalents of the earliest sedimentary rocks in the area of the Perth Basin. They are thought to have been deposited originally as geosynclinal greywackes and other arenites, and were metamorphosed to granulite facies some 1 040 m.y. ago (Northampton Block) and 670 m.y. ago (Leeuwin Block).

The oldest unmetamorphosed sediments in the area are very thick siltstone, sandstone, chert, and carbonate rocks (believed to be marine) and minor associated volcanics laid down in Middle to Late Proterozoic times on either side of the present Darling Fault line. There is no evidence to indicate that the Perth Basin as such was in existence at that time, but some authorities believe that a reverse or transcurrent fault had already developed along the line of the present Darling Fault. However, it may be more likely that such a fault was initiated in early Palaeozoic (or possibly Late Proterozoic) times in response to the regional compression that also folded the Proterozoic rocks in and adjoining the basin.

PALAEOZOIC

The Phanerozoic history of the Perth Basin is illustrated in a series of palaeogeographic maps (Figs. 57-60). It began with deposition of the Tumblagooda Sandstone during Early Silurian (or Late Ordovician) times and probably coincided with the commencement of block faulting in the northern part of the basin. The initial period of normal fault movement along the Darling Fault line may have occurred at that time.

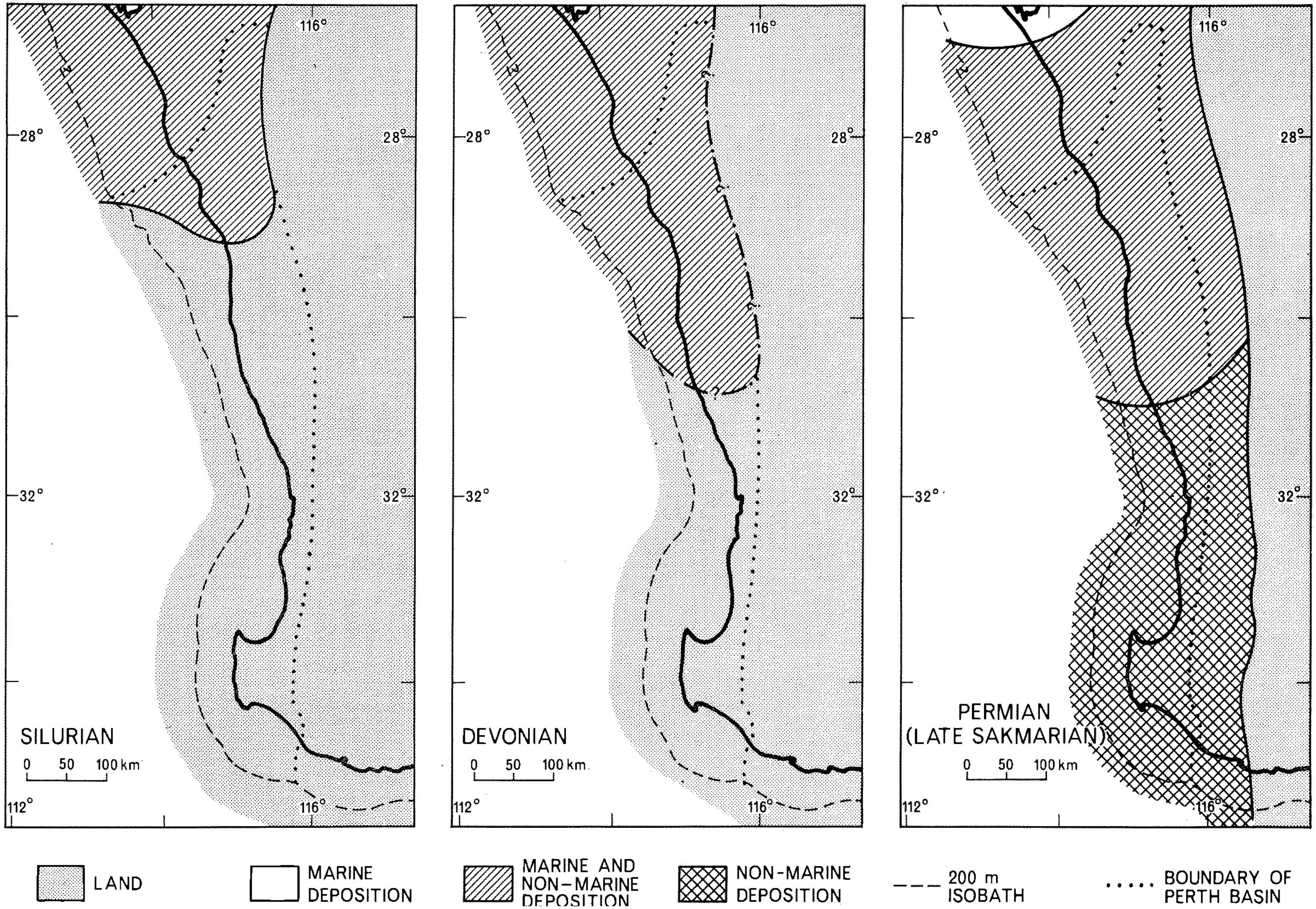


Figure 57. Palaeogeographic maps: Silurian, Devonian, Permian (late Sakmarian).

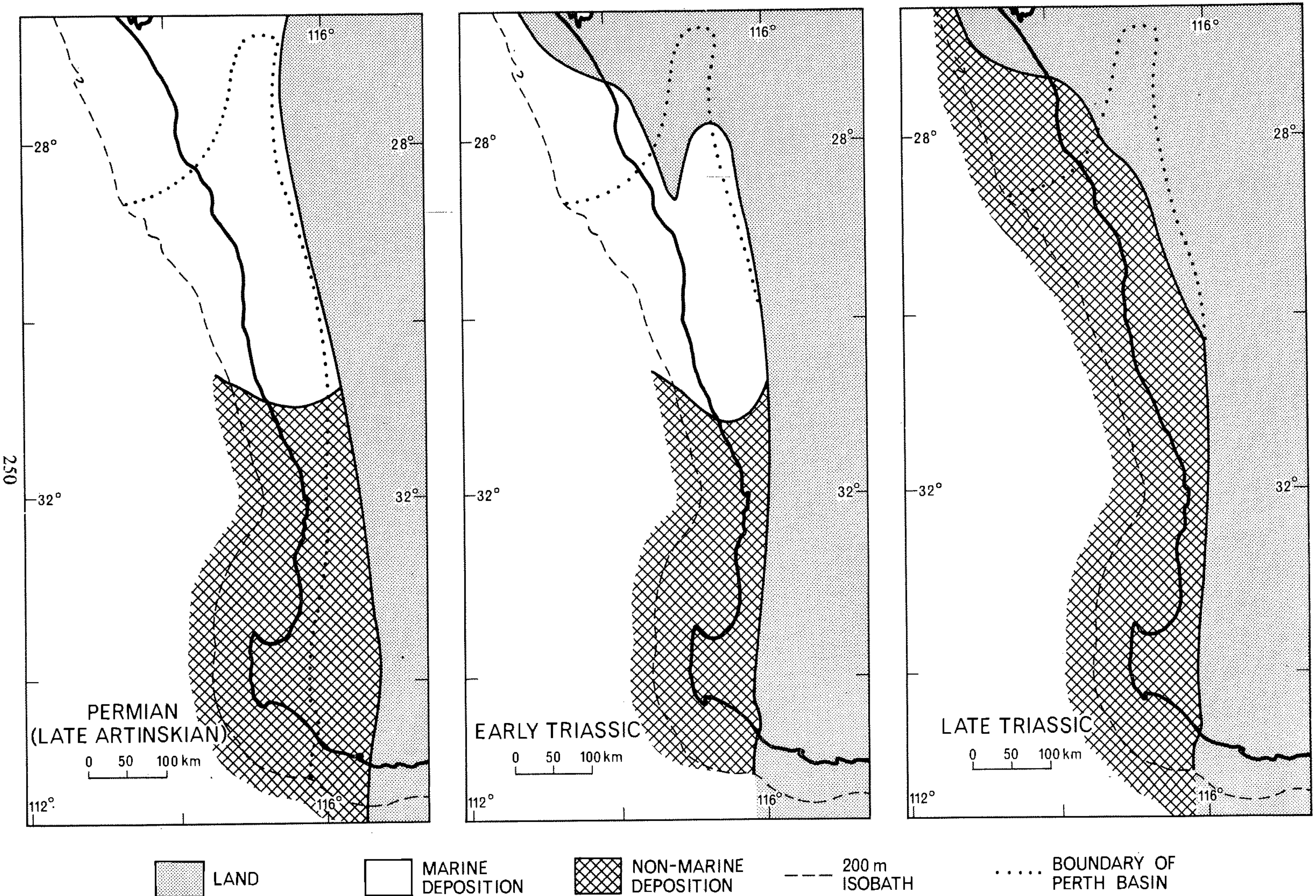


Figure 58. Palaeogeographic maps: Permian (late Artinskian), Early Triassic, Late Triassic.

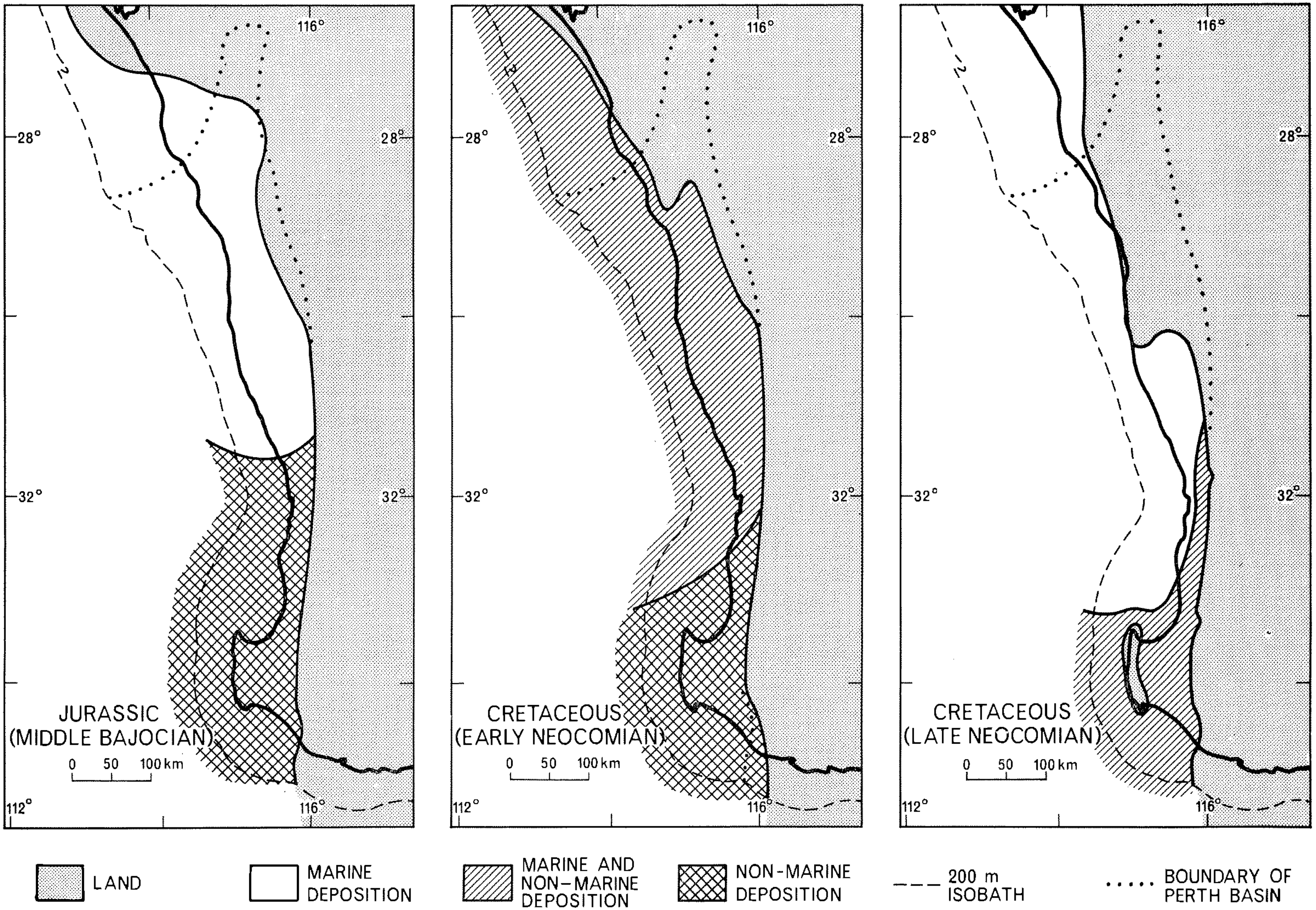


Figure 59. Palaeogeographic maps: Jurassic (Middle Bajocian), Cretaceous (early Neocomian), Cretaceous (late Neocomian).

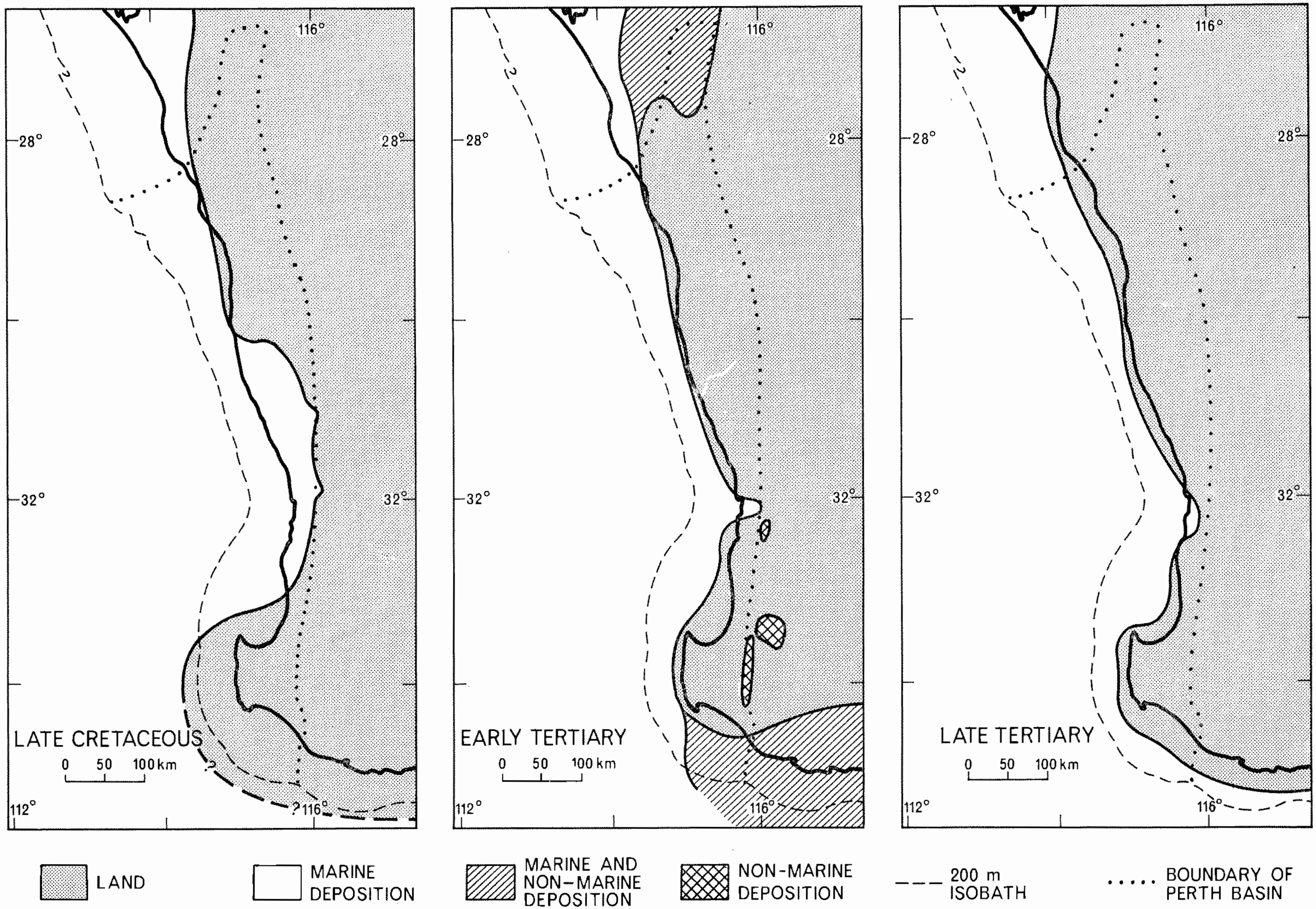


Figure 60. Palaeogeographic maps: Late Cretaceous, early Tertiary, late Tertiary.

No sediments of Devonian or Carboniferous age have yet been found in the Perth Basin, and it is likely that most or all of the basin was a land area during those periods. However, there is indirect evidence (remanié Devonian spores in a Cretaceous unit) that some Devonian sedimentation occurred in the basin.

During Permian times conditions of marine and continental sedimentation prevailed in the northern part of the basin, but the sea failed to reach the southern part, where continental sedimentation continued throughout the period. The Darling Fault was probably weakly active during the Permian, but sedimentation is believed to have extended east of the fault line. Other faults in the basin may have been intermittently active during this period. The Beagle Ridge, Northampton Block, and part of the southern Perth Basin were positive features (possibly emergent) during the early Sakmarian, but the Beagle Ridge and the southern Perth Basin subsided with the rest of the basin during the late Sakmarian and Artinskian.

Glacial conditions prevailed during the early Sakmarian, and the area of the northern Perth Basin ranged from a coastal plain with glacial lakes and meltwater streams to a shallow sea with floating icebergs. The Archaean rocks of the Yilgarn Block, the Proterozoic sediments in and adjoining the Perth Basin, and the Tumblagooda Sandstone were eroded by ice action during this period, the main direction of ice movement being towards the north-northwest.

The climate ameliorated somewhat during the late Sakmarian, and a sea with a few icebergs covered the northern Perth Basin. Anaerobic conditions prevailed on the sea floor for much of the time, but a varied benthonic invertebrate fauna was able to develop periodically, giving rise to thin fossiliferous limestone beds and lenses in the prevailing black shale and siltstone.

A regression of the sea took place in the northern Perth Basin during early Artinskian times, and cross-bedded shallow-marine to shoreline sands were spread over the area, followed by a fluviatile and paludal coal-measures sequence. Later in the Artinskian shallow-marine conditions returned to the northern part of the basin, resulting in deposition of dark shale and siltstone within thin beds of sandstone.

In the southern Perth Basin non-marine conditions with fluviatile and coal-swamp deposition prevailed continuously from the late Sakmarian through the Artinskian and into the Late Permian. However, in the north (where mixed marine and continental sedimentation occurred in the Early Permian) a period of tectonism with associated uplift and erosion took place at some time around the middle of the Permian. Conditions of fluviatile sedimentation, with some coal-measures deposition, returned to this area during the Late Permian.

At the end of the Permian Period another interval of uplift and erosion occurred in the northern Perth Basin, but in the south conditions of continental sedimentation continued through to the Triassic.

MESOZOIC

Sea transgressed the northern Perth Basin during the Early Triassic, the shoreline being situated somewhere south of the Beagle Ridge. Continental sedimentation continued in the southern part of the basin and gradually spread northwards, so that by late Middle Triassic times fluviatile sedimentation prevailed throughout the Perth Basin, associated with strong movement along the Darling and Urella Faults. Movement continued along these faults without major interruption from Middle Triassic to middle Neocomian times. A great thickness of fluviatile sediments was deposited in the Perth Basin in front of the rising fault scarps. Variegated sediments, followed by mixed coal-swamp and fluviatile deposits, were laid down in the Early Jurassic. They were succeeded in the northern part of the basin by a brief marine incursion during the Middle Jurassic, bringing with it a rich marine invertebrate fauna in some areas, especially around the Northampton Block (which remained a positive feature throughout the Mesozoic). Fluviatile sedimentation prevailed through the Late Jurassic into the early Neocomian, with some marine and paralic influence in the early Neocomian in the northern and central Perth Basin.

Uplift and erosion of the whole of the Perth Basin area occurred during the middle Neocomian. The last major faulting in the basin occurred at that time. Basaltic lava flows were extruded over the erosion surface in the Bunbury Trough. Subsidence recommenced over much of the central and southern parts of the basin during the late Neccomian, and a marine transgression occurred from the west. Shallow-marine clastic sediments, passing eastwards into continental deposits, were laid down, the maximum thickness being deposited in the central part of the basin. At about this time terrigenous clastic deposits extended over the Darling and Dunsborough Faults, onlapping the Yilgarn and Leeuwin Blocks.

After a brief interval of erosion, marine sedimentation occurred in the central part of the Perth Basin from late Albian through much of Late Cretaceous times. The deposits consisted mainly of greensand and chalk. Uplift and erosion again occurred in Late Cretaceous to early Tertiary times throughout the basin.

CAINOZOIC

A westerly trending steep-sided channel (possibly the head of a submarine canyon which preceded the present-day Perth Canyon) in the central part of the Perth Basin was filled with marine fine-grained clastic sediments during the Late Paleocene and Early Eocene. At that time marine carbonate sedimentation was occurring in the northwestern part of the basin, and continental sedimentation in the northeastern part. Carbonate sedimentation became widespread along the western side of the basin (approximately coincident with the area of the present continental shelf) in mid-Tertiary times. Over the remainder of the basin the Tertiary was a period of erosion and/or lateritization. Epeirogenic uplift of the

Yilgarn Block, amounting to some 300 to 400 m, and of parts of the Perth Basin has occurred since the Eocene, and may still be continuing. Some movement may also have occurred along the Darling Fault in the Perth area, but it has been inactive in historic times.

The Pleistocene was marked by several brief advances and retreats of the sea, with the development of extensive shoreline and coastal-dune deposits on the Swan Coastal Plain. These were probably associated with eustatic sea-level oscillations, but a partial tectonic control also seems likely. Alluvial and colluvial deposits were also laid down, and extensive lateritization occurred during periods of high precipitation.

There has probably been little active faulting in the basin during the Cainozoic other than movement resulting from differential compaction on opposite sides of existing faults. However, there may have been some minor Cainozoic activity along the Darling Fault in the Darling Range area.

PERTH BASIN AND GONDWANALAND

INTRODUCTION

The concept of an ancient supercontinent that once embraced the present landmasses of the southern hemisphere and the Indian peninsula originated some 100 years ago, when the significance of the distribution of the Permian *Glossopteris* flora was first pointed out by Blanford (1875). Suess (1885) introduced the name "Gondwana-Land" for this hypothetical giant landmass. As now understood, the term Gondwanaland refers to the hypothetical Palaeozoic and Mesozoic landmass that has since been fragmented by continental drift to form the present areas of South America, Africa, Australia, Antarctica, India, and probably part of Southeast Asia.

Teichert (1958) summarized the status of the Gondwanaland hypothesis prior to the development of modern ideas on plate tectonics. Since then there has been increasing acceptance of the concept among geologists, but there is considerable debate as to how the pieces of the "jig-saw" once fitted together. Several models that have been proposed are shown on Figure 61.

While all models of Gondwanaland are in agreement as to the fit of South America with Africa, there is wide variance in piecing together the other landmasses. There is a general consensus of opinion that the gap between India and Australia shown on the reconstructions of Smith and Hallam (1970) and Smith and others (1973) must have been occupied by continental crust. However, it is uncertain whether this crustal material was an extension of peninsular India that was destroyed during formation of the Himalayas, as stated by McElhinny and Embleton (1974) and implied by Johnstone and others (1973), or is a separate piece of crust now represented by the Tibetan Plateau, as suggested by Crawford (1974).

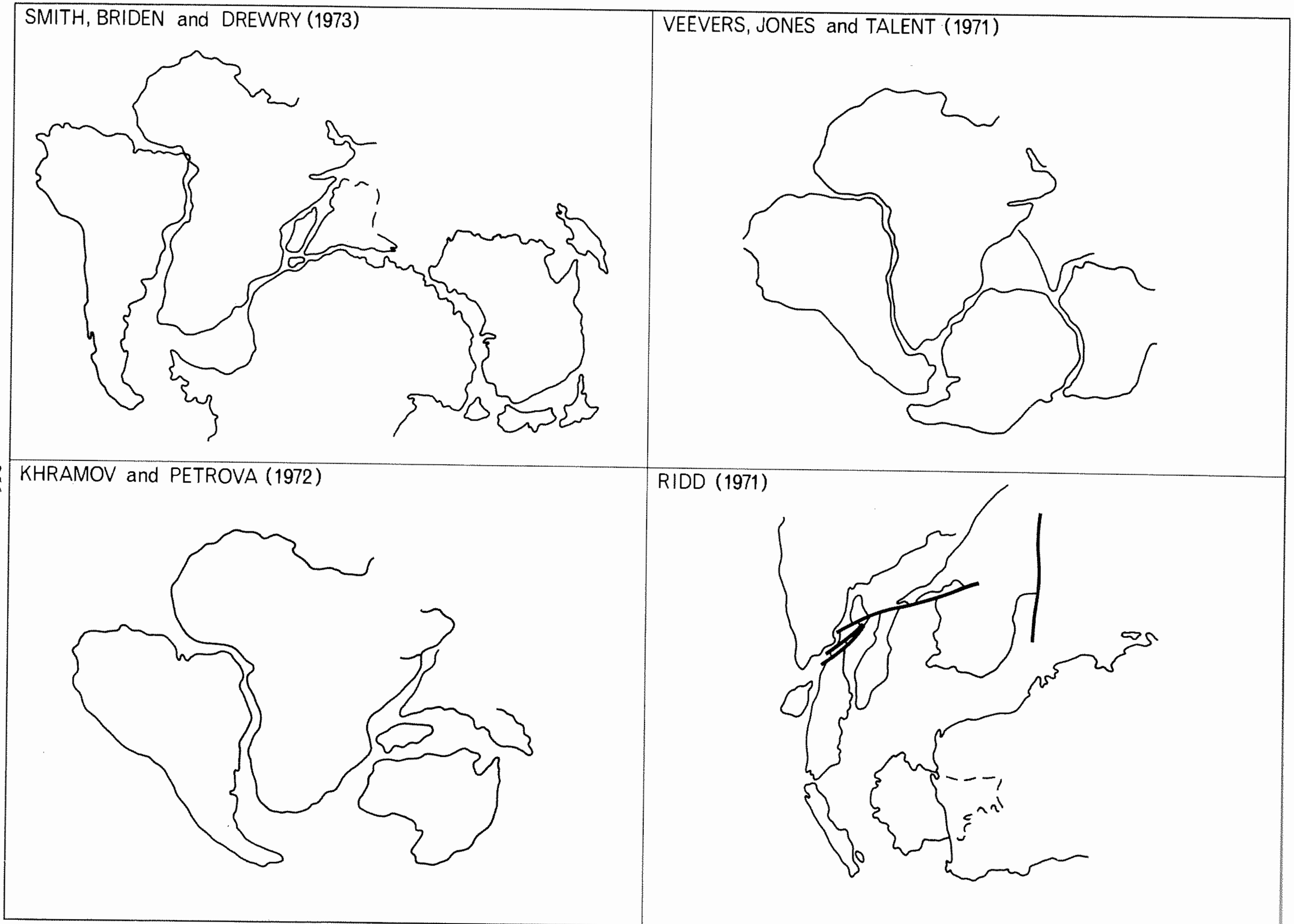


Figure 61. Reconstructions of Gondwanaland according to various authors.

The Precambrian and early Palaeozoic history of Gondwanaland is obscure. For example, a recent series of maps shows the supercontinent essentially unchanged from the Cambrian to Cretaceous (Smith and others, 1973), whereas Embleton (1972) suggested that Australia and Antarctica were separated from the rest of Gondwanaland in the early Palaeozoic, and Dewey and Horsfield (1970) have speculated that Gondwanaland (as well as Laurasia and Pangaea) was only a transitory stage in a continuing history of collision and separation of continental plates.

During the late Palaeozoic each of the areas thought to have constituted Gondwanaland was subjected to continental glaciation, and the characteristic *Glossopteris* flora was developed. These events are well recorded in the Permian of the Perth Basin. The main fragmentation of Gondwanaland, associated with activation of spreading centres, is believed to have taken place in the Cretaceous and to have been completed in the early Tertiary, with the South Atlantic, Indian, and Antarctic Oceans forming between the displaced continental fragments. The history of development of the Indian Ocean from the Cretaceous to the present day has been analyzed by McKenzie and Sclater (1971).

The history of the Perth Basin in relation to the Gondwanaland hypothesis can be discussed conveniently in three phases: the Proterozoic (pre-Gondwanaland), Palaeozoic to Early Cretaceous (Gondwanaland), and Early Cretaceous to Holocene (post-Gondwanaland) phases.

PROTEROZOIC

The notable features of this phase in the Perth Basin are the great thickness of apparently marine sediments, the associated volcanism, and the occurrence of high-grade metamorphism in some areas. Apparently an extensive sea was present on the western side of the Yilgarn Block during the Proterozoic. The seaway was closed and the Proterozoic sediments were folded in the Late Proterozoic or Early Palaeozoic, and this may represent the welding together of two crustal plates to form Gondwanaland.

The Proterozoic is accordingly thought to represent the pre-Gondwanaland phase of the history of the Perth Basin area. Embleton (1972), on the basis of palaeomagnetic evidence, has suggested that Gondwanaland originally existed as two separate plates, but he differs from the present interpretation in placing the time of plate joining after the Ordovician.

PALAEOZOIC TO EARLY CRETACEOUS

Palaeozoic sedimentation began in the northern Perth Basin with deposition of the thick Tumblagooda Sandstone during the Silurian (or possibly Late Ordovician), probably in response to the beginning of normal movement along the northern part of the Darling Fault. The Permian to Early Cretaceous (early Neocomian) sequence is characterized by continental sedimentation, with periodic

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marine incursions from the north. The section in the southern part of the basin is almost entirely continental, whereas in the north mixed marine and continental conditions prevailed. This suggests that from the Permian to early Neocomian the Perth Basin lay at the southern end of a marine embayment extending into Gondwanaland—possibly a rift valley (the Westralian Rift Valley of Warris, 1973). The Darling Fault defines one side of the Perth Basin rift; the other side may now lie to the north of peninsular India, or it may have been destroyed during formation of the Himalayas.

The waters of the hypothetical marine embayment north of the Perth Basin were in direct communication with Tethys and the Pacific Ocean. The faunas that accompanied marine incursions in the northern part of the basin during the Permian, Triassic, and Jurassic include genera that are common in other parts of the world. The marine Permian faunas are basically Tethyan (Teichert, 1971), the Early Triassic marine forms are part of a widespread world fauna (Dickins and McTavish, 1963), while the Middle Jurassic marine fauna includes ammonites belonging to the Pacific faunal realm (Arkell, 1956). Despite this, there are indigenous elements in the faunas (especially in the Permian and Middle Jurassic) which suggest comparative isolation of the Perth Basin area. The Permian *Glossopteris* flora contains a northern Euramerican element (*Sphenophyllum*), which possibly indicates the presence of a migration route from the northern continents.

Normal faulting in the Perth Basin probably began in the Silurian (or possibly Late Ordovician), and from that time through to the early Neocomian the Perth Basin was a fault-controlled trough.

EARLY CRETACEOUS TO HOLOCENE

The main break-up of Gondwanaland in the Perth Basin area apparently began during the Neocomian, as pointed out by Jones and Pearson (1972) and Johnstone and others (1973). Stratigraphically, the separation of the Perth Basin from the rest of Gondwanaland is believed to be marked by the unconformity at the base of the Warnbro Group and the extrusion of the Bunbury Basalt. The post-Gondwanaland or drift phase after the middle Neocomian is marked by marine sedimentation from the west in the central and western parts of the Perth Basin, in contrast to the earlier marine incursions which came from the north.

Since the middle Neocomian the Perth Basin has also been tectonically quiet, with little active faulting. This contrasts strongly with the intense faulting of the earlier rift phase.

The Antarctic and Australian plates are thought to have separated during the Eocene, although rifting along the future plate boundaries had commenced during the Jurassic or earlier. The final rupture which gave rise to the southern Indian Ocean occurred during the Eocene. It was followed by epeirogenic uplift of the Yilgarn Block and of at least some parts of the Perth Basin.

On the other hand, in the Carnarvon, Canning, and Browse Basins of northwestern Australia continental breakup began in the Middle Jurassic (Powell, 1976). It thus seems that separation of Australia from the rest of Gondwanaland took place over a considerable period of time, the main break-up commencing during the Middle Jurassic in the northern basins and in the Neocomian in the Perth Basin, and being completed during the Eocene in the Bremer and Eucla Basins.

CHAPTER 8

Economic Geology

PETROLEUM

INTRODUCTION

The first significant exploration for petroleum in the Perth Basin was commenced in 1954 by Wapet. However, the prospects in the basin generally were not very favourably regarded, and the company did not drill its first exploratory well (Eneabba No. 1) until 1961. Since then more than 90 oil-test and stratigraphic wells have been drilled, and several gas fields have been found, the first being at Yardarino in 1964, followed by Gingin in 1965, Dongara in 1966, Mondarra in 1968, and Walyering in 1971 (Playford, 1975). Wells that have been drilled to the end of 1973 are listed by Low (1974). A diagram showing correlation of selected wells in the basin is shown as Figure 62.

A 14-inch gas pipeline from Dongara (the largest field) to Perth and its neighbouring industrial complexes was opened in 1971. Production from the smaller Mondarra Field is also being fed into this line, and minor production has been utilized from Walyering and Gingin. Current production (April, 1975) amounts to about 2.1 x 10^6 m^3/day.

PROSPECTIVE SECTION

The producing section in the Dongara Gasfield is of Triassic and Permian age (Early Triassic Dongara Sandstone Member of the Kockatea Shale, Late Permian Yardarino Sandstone Member of the Wagina Sandstone, and Early Permian Carynginia Formation and Irwin River Coal Measures). In the Mondarra and Yardarino Fields the producing interval is probably entirely within the Yardarino Sandstone Member.

The Gingin and Walyering Gasfields have produced from the Cattamarra Coal Measures Member of the Cockleshell Gully Formation. Other reservoirs in the basin having potential for hydrocarbon accumulations are the Tumblagooda Sandstone (Silurian), the Sue Coal Measures and High Cliff Sandstone (Permian), sandstone beds (including the Bookara Sandstone Member) in the Kockatea Shale (Triassic), the Lesueur Sandstone and Woodada Formation (Triassic), the Eneabba Member of the Cockleshell Gully Formation (Jurassic), and the Gage Sandstone Member of the South Perth Shale (Cretaceous).

The most extensive prospective reservoir within reach of the drill is the Cattamarra Coal Measures Member, but unfortunately this unit has poor reservoir characteristics in the fields found to date. The sandstones have very low permeabilities, so that flow rates declined rapidly when wells were put on production. The best producing reservoirs are the Dongara Sandstone Member and Yardarino Sandstone Member. However, in several wells in the Dongara-Yardarino-Mondarra area the porosity in these units is largely destroyed by silicification (possibly associated with faulting).

Flows of gas were obtained from the Sue Coal Measures in Whicher Range No. 1 and Wonnerup No. 1 wells, and from the Carynginia Formation in Arrowsmith No. 1 well, but production declined rapidly in each owing to the low permeabilities of the reservoir sandstones. Small amounts of oil were recovered from the Kockatea Shale in Mount Horner No. 1 and North Erregulla No. 1 wells, from the Eneabba Member in Erregulla No. 1 well, and from the Gage Sandstone Member in Gage Roads No. 1 well. None of these discoveries is commercial at present.

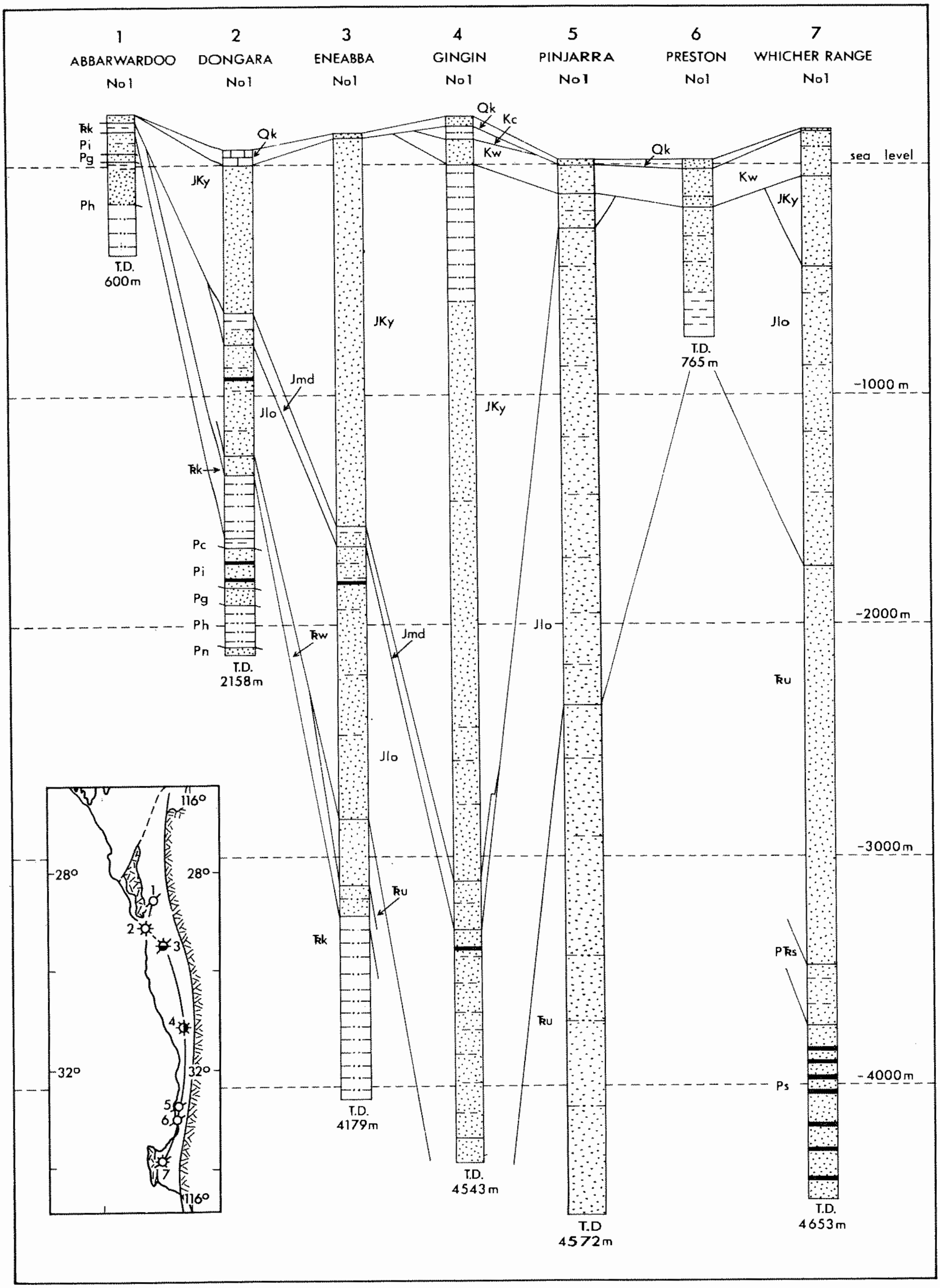
The best potential reservoir in the basin may be the Tumblagooda Sandstone. However, the only area in which it is likely to have prospects for significant hydrocarbon accumulations is in the Abrolhos Sub-basin. In the northern part of this sub-basin the Tumblagooda Sandstone is probably overlain directly by the Kockatea Shale, which could act as a suitable source and cap rock.

The best source rocks for petroleum in the basin are believed to be the Kockatea Shale, Cattamarra Coal Measures Member, Irwin River Coal Measure, Sue Coal Measures, and South Perth Shale. Gas in the Dongara, Mondarra, and Yardarino Fields has probably originated for the most part in the Kockatea Shale, although the Irwin River Coal Measures may also have acted as a source. The source of oil in the Dongara and Yardarino Fields is likely to have been the Kockatea Shale. The gas and condensate at Gingin and Walyering is believed to be derived from the Cattamarra Coal Measures Member, which is also the reservoir unit. The oil recovered from Gage Roads No. 1 well is thought to have originated in the South Perth Shale. Other possible source rocks in the basin include the Holmwood Shale and Carynginia Formation (Early Permian).

Results of exploration to date indicate that the best prospects in the Perth Basin are for gas rather than oil.

STRUCTURE

The structural characteristics of the Perth Basin are not very attractive for the discovery of large hydrocarbon accumulations. The sedimentary section is strongly faulted, and large simple anticlinal traps are unknown. In addition, it is difficult to map the complex structure by seismic methods, owing to the lack of strong velocity contrasts through most of the section.



1
ABBARWARDOO
No 1
2
DONGARA
No 1
3
ENEABBA
No 1
4
GINGIN
No 1
5
PINJARRA
No 1
6
PRESTON
No 1
7
WHICHER RANGE
No 1
sea level
-1000 m
-2000 m
-3000 m
-4000 m
T.D. 600 m
T.D. 2158 m
T.D. 4179 m
T.D. 4543 m
T.D 4572 m
T.D. 765 m
T.D. 4653 m
Qk
Kc
Kw
JKy
Jlo
Jmd
Pc
Pi
Pg
Ph
Pn
Ps

Most of the structures that have been drilled are anticlinal features associated with faults, and any large closure is commonly dependent on one or more of these faults. However, the discoveries that have been made (for example, the Dongara Field) show that combination anticlinal-fault traps can be effective in this basin provided that the fault closing the structure brought a suitable cap rock into juxtaposition with the reservoir at the time of hydrocarbon migration.

With continuing improvements in seismic techniques it is expected that mapping of the subsurface structure in the Perth Basin will become progressively more precise, thus allowing more definitive test wells to be drilled.

COMMERCIAL FIELDS

The Dongara and Mondarra Fields are currently producing gas into the pipeline to Perth and Pinjarra. The Walyering and Gingin Fields also contributed for brief periods, but both of these are now shut in owing to depletion of the reservoirs. Yardarino has not yet been produced commercially, but this field may also be utilized at some time in the future, and is therefore described here.

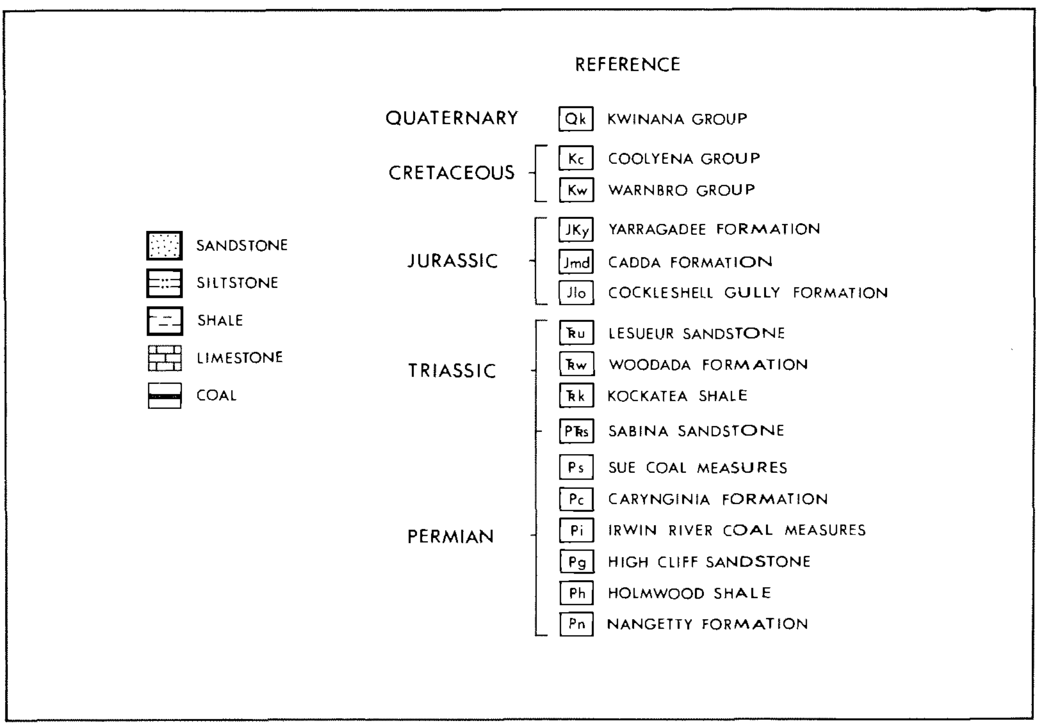


Figure 62 (above and opposite). Correlation of selected wells in the Perth Basin drilled for petroleum exploration.

Dongara Field

The Dongara Gasfield occurs in a faulted anticlinal structure bounded on the east by the Mountain Bridge Fault, which has a down-to-the-east displacement of some 1 000 m. Closure is largely dependent on this fault.

The field covers an area of about 42 km^2, and closure amounts to at least 120 m. The original recoverable gas reserves totalled some 13 x 10^9 m^3. In addition, the field contains small reserves of oil and natural-gas liquids. To the end of 1974 production had amounted to 2 109 x 10^6 m^3 and 73 528 bbl of natural gas liquids. None of the oil in the field has yet been marketed. There are 11 producing wells (out of a total of 20 drilled) and production is obtained at depths of 1 580 to 1 650 m.

The principal producing units are the Dongara Sandstone Member (Lower Triassic) and the Yardarino Sandstone Member (Upper Permian). Some production is also obtained from the Irwin River Coal Measures and the Carynginia Formation (Lower Permian). The source of the hydrocarbons is believed to be the Kockatea Shale and possibly the Irwin River Coal Measures.

Mondarra Field

The Mondarra Field is the only other gas field currently producing in the Perth Basin. It occupies a faulted anticlinal nose, plunging to the north-northwest, and covers a total area of some 14 km^2. Closure totals some 160 m and is controlled largely by faulting, although porosity barriers may also be important. The original recoverable gas reserves of the field probably totalled about 1.6 x 10^9 m^3. Production to the end of 1974 had amounted to 168 x 10^6 m^3 with 20 838 bbl of natural-gas liquids, from the single producing well in the field. Another gas well is shut in, and there have been two dry holes.

The producing unit at Mondarra at depths of 2 620 to 2 680 m is correlated with the Yardarino Sandstone Member of the Wagina Sandstone (McKellar, R. G., pers. comm., 1973). Drilling has shown that at Mondarra this unit has very variable reservoir characteristics, controlled by the degree of silicification.

Yardarino Field

The Yardarino Field occupies a small domal structure covering about 1 km^2 within a strongly faulted area. Closure amounts to about 65 m.

Reserves of the Yardarino Field are smaller than those of Mondarra, and the field has not yet been produced commercially. The field also contains minor oil reserves. Four wells have been drilled at Yardarino, one of which was completed as a potential gas well and one as a potential oil well; the others dry.

The reservoir unit at Yardarino is the Yardarino Sandstone Member of the Wagina Sandstone.

Walyering Field

The Walyering Field is in a faulted anticlinal structure, and the trap may be controlled by both faulting and porosity barriers. The total area covered by the field has not been defined, but it could be about 7 km^2.

Production at Walyering has been obtained from depths of 3 260 to 3 520 m subsea in the Cattamarra Coal Measures Member of the Cockleshell Gully Formation (Lower Jurassic). Three wells were drilled on the field, two of which were abandoned as dry holes, while the other was produced commercially for a short period, yielding 7.4 x 10^6 m^3 of gas and 1 493 bbl of natural-gas liquids. Production declined sharply and the well was abandoned. The reservoir sands have low permeabilities, and the production history shows that they also have only limited lateral extent.

Gingin Field

The Gingin Field occurs in a large faulted anticline. The total closure is unknown, and it is thought that the gas accumulation is partly stratigraphically controlled. The total area of the gas-bearing zone around the two wells drilled on the structure may be about 30 km^2.

Production at Gingin has been obtained from the Cattamarra Coal Measures Member of the Cockleshell Gully Formation at depths of 3 660 to 3 960 m subsea. The producing sands have low porosities and permeabilities and are probably lenticular. Both of the wells drilled were completed as potential producers, but Gingin No. 2 was found on production testing to be non-commercial. Gingin No. 1 was connected to the gas pipeline and yielded 48.5 x 10^6 m^3 of gas and 17 000 bbl of natural-gas liquids before being shut in because of pressure decline.

The gas reserves in place in the Gingin Field are probably very large, but it seems unlikely that further commercial development will occur unless new methods are devised for stimulating production from the poor reservoirs.

GROUNDWATER*

INTRODUCTION

The groundwater resources of the Perth Basin have not yet been investigated on a regional basis. In metropolitan Perth and its environs, a comprehensive investigation into the area's hydrogeology is currently in progress and will be the subject of a detailed report. Elsewhere, hydrogeological information is available from three types of investigation—reconnaissance deep drilling, local water-supply investigations, and bore-census records.

In 1961 the Geological Survey commenced a long-term programme of drilling a series of east-west lines of bores across the Perth Basin to systematically obtain information on its stratigraphy, structure, and hydrogeology (Fig. 63).

*By J. R. Forth, Geological Survey of Western Australia.

These lines, through Byford (Berliat, 1964), Mandurah (Emmenegger, 1964), Pinjar (Whincup, 1966), Gingin Brook (Sanders, 1967), Quindalup (Probert, 1968), and Watheroo (Harley, A. S., written comm., 1974), provide most of the available information on the deeper aquifers outside the Perth metropolitan area.

Detailed investigations for town water supplies have also been made at Wicherina (Swarbrick, 1964), Allanooka (Allen, 1965), Arrowsmith River (Barnett, 1970), Agaton (Balleau and Passmore, 1972), Gnangara (Balleau, 1973), and Mandurah-Pinjarra (Commander, 1974a). At these localities the investigations have provided comprehensive data on all important flow systems.

The third source of information is from bore census records catalogued by the Geological Survey. More than 10 000 bores have so far been recorded in the Perth Basin, but information on water quality, water depth, and lithologies encountered has been recorded for less than half. Further, most of the records are from shallow bores and hence do not provide information relevant to the deeper aquifer systems.

GENERAL HYDROGEOLOGY

Groundwater in the Perth Basin can be classified into two broad groupings: (a) local unconfined flow systems in the superficial, generally Quaternary, sediments; and (b) regional, mostly confined, flow systems in Mesozoic and older sediments.

Local flow systems are found where there is a sufficient thickness of superficial sands. Balleau (1973) has described such a system at Gnangara (Fig. 63) in the Bassendean Sand, and has shown that water quality in such systems is a function of aquifer geometry. Recharge is by direct infiltration of rainfall, and discharge is by evaporation from lakes and soaks, by evapotranspiration, by leakage into underlying sediments, and by discharge to the sea. The main recharge zones are at topographic highs and discharge is at topographic lows. Where there is discharge by evapotranspiration (which is governed by depth to water table) salinities are increased. They are lowest, 300 to 800 ppm TDS (total dissolved solids), in the area of maximum recharge. Recharge on sandplain may be as much as 30 per cent of the annual rainfall.

Much less is known of regional flow systems. Commonly the systems are fully confined (except in the zone of recharge), and are made up of multiple sandy aquifer zones separated by silts and clays. The aquifer zones have a general hydraulic continuity on the macroscopic (though not necessarily on the microscopic) scale.

Water quality generally worsens with depth and distance in the direction of flow. Aquifer through-flows in the regional systems may often be small, but the gross storages of water are very large and major water supply schemes will

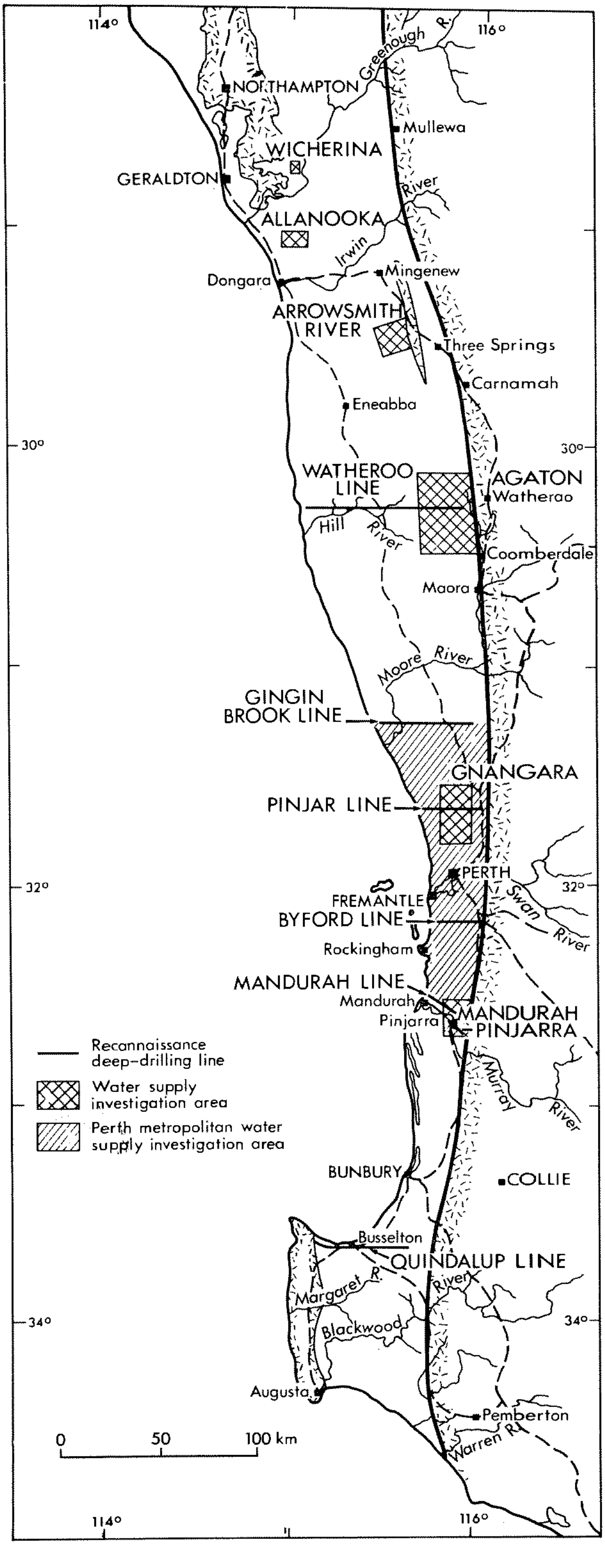


Figure 63. Location map, groundwater investigations in the Perth Basin.

be partly dependent upon this. The electric log of a recently drilled bore on the Quindalup line shows 980 m of saturated Mesozoic sediments containing groundwater the salinity of which is probably less than 1 000 ppm TDS. A petroleum exploration well north of Perth (Eneabba No. 1) intersected 1 700 m of Yarragadee Formation consisting of sandstone with a few claystone and siltstone beds, containing groundwater of less than 1 200 ppm TDS throughout.

Commander (1974b), in an unpublished thesis, has discussed the influence of the major north and north-northwest-trending faults upon flow directions in the Dandaragan and Bunbury Troughs. He shows that within the various fault-bounded blocks, flow directions often locally follow the fault trends. Also, in the southern half of the Perth Basin, recharge is restricted to localized areas where suitable rock types underlie thin Quaternary deposits, whereas in the northern half recharge to the regional aquifer systems occurs over extensive areas where Mesozoic sediments crop out or underlie sandplain. This situation is in contrast to the typical marginal continental basin in which aquifer recharge is restricted to the basin periphery, where successively older sediments crop out as the margin is approached. Because of faulting and subsequent erosion at the continental margin of the Perth Basin, this sequential outcrop pattern does not occur, and the basin margin at the Darling Fault is not the dominant recharge area.

GROUNDWATER OCCURRENCE

Groundwater exploration has so far mostly been based upon the need to develop supplies at a particular location. Only in the drilling of some of the Perth Basin lines has there been systematic investigation into the relationship between geological factors and groundwater occurrence on a broad scale. Consequently, it is impossible at this time to present a complete picture of the hydrogeology of all geologic units encountered in the Perth Basin. The following descriptions are therefore of a general nature and are not intended to be comprehensive. They are confined to the most important units that have been studied from a hydrogeological viewpoint.

PROTEROZOIC

The Proterozoic rocks, with the exception of the Coomberdale Chert, are not known to be good producers of groundwater. Primary porosity is very low, and if groundwater is to be obtained, sites which take advantage of secondary porosity (for example, joints, fractures) must be selected. In such cases, yields are likely to be low, but may be sufficient for limited farm supplies.

The Coomberdale Chert has local high porosity (generally cavernous), and parts have moderately good permeability. It is successfully exploited for town supplies at Moora, Watheroo, and Coomberdale. At Watheroo, water with a salinity as low as 490 ppm TDS is obtained from depths of 30 to 40 m. Yields from individual bores range up to 1 000 m^3/d.

At Carnamah (Whincup, 1968a) yields were high (for example, 3 000 m^3/d were pumped from a water-filled cave) but salinities were too high (up to 11 000 ppm TDS) for the water to be used for domestic purposes. The reason for the water at Carnamah being of poorer quality than elsewhere has not yet been determined.

SILURIAN

The Tumblagooda Sandstone is an important aquifer in parts of the northern Perth Basin. It is coarse grained and well lithified, and it commonly yields most water from vertical and horizontal (bedding-plane) joints. Yields are normally low but are sufficient for stock supplies. Recharge is by direct infiltration of rainfall on areas of outcrop, and the best quality water is found in these areas. Salinities as low as 350 ppm TDS have been recorded, but 1 000 to 3 000 ppm TDS is more normal (Whincup, 1968b). Salinities increase in the direction of flow, but the aquifer normally contains water suitable for stock.

PERMIAN

Nangetty Formation: The Nangetty Formation generally has poor permeability, and salinities are high. Where sandstones are encountered in the formation, stock-quality water may be obtained.

Holmwood Shale: The Holmwood Shale normally has very low permeability and is of greater importance as an aquiclude than as an aquifer. At Arrowsmith River, Barnett (1970) reported the presence of a poor aquifer with only 1 100 to 3 400 ppm TDS. Elsewhere salinities are generally higher.

High Cliff Sandstone: At Wicherina the High Cliff Sandstone is an important aquifer. Excessive pumping, though, has led to the influx of saline water from the Greenough River (Swarbrick, 1964). The aquifer zone is about 20 m thick and where recharged by percolation, the water quality is good and is suitable for domestic use.

Wagina Sandstone: Swarbrick (1964) found varying quality groundwater within the Wagina Sandstone at Wicherina. Where recharge is from surface flows salinities are high, but where the formation occurs at shallow depth and is recharged by percolating rainfall small potable supplies can sometimes be obtained.

Farm water supplies are also obtained from this formation near the Darling Fault in the Irwin River area.

Sue Coal Measures: The most westerly bore of the Quindalup line (Probert, 1968) penetrated the Sue Coal Measures. The sediments are generally of low permeability, but are capable of yielding water suitable for stock purposes (1 300 to 2 800 ppm TDS).

TRIASSIC

Kockatea Shale: The Kockatea Shale is mainly a thick body of silty shale with little potential for yielding water in useful quantities or of good quality. Its main importance is as a regional aquiclude.

Lesueur Sandstone: The Lesueur Sandstone has been little explored, but it may prove to be an important aquifer. During drilling of the Watheroo line (Harley, A. S., written comm., 1974) unconfined water with TDS of less than 500 ppm was located. Recharge is by direct percolation from rainfall and discharge is probably into the Tamala Limestone.

JURASSIC

Cockleshell Gully Formation: The Cockleshell Gully Formation is thick and widespread in the Perth Basin, and as it is both porous and permeable it is of considerable importance as an aquifer. The aquifer zones are sandstones interbedded with siltstones and claystones. The groundwater is mostly confined, and near the outcrop areas water quality is of domestic standard. Salinities increase with depth and in the direction of flow. Stock-quality water (1 000 to 5 000 ppm TDS) can almost always be obtained from the unit.

Chapman Group: A sandstone aquifer within the Chapman Group was intersected by a Geological Survey exploratory bore in the area between Allanooka and Wicherina. The water was potable with 690 to 940 ppm TDS, and yields were good, 600 m^3/d (Allen, 1965). The total extent of this aquifer is not known.

Cadda Formation: Sandstones of the Cadda Formation are porous and permeable, and water-table aquifers with potable water are found in outcrop areas. In general, supplies are fairly small.

Yarragadee Formation: Hydrologically the Yarragadee Formation is probably the most important formation in the Perth Basin. Perth has been drawing approximately 10 per cent of its water requirements from aquifers in this unit, while Geraldton and Busselton and some smaller towns obtain most of their supplies from it.

Aquifer systems having very large storages were located in the Yarragadee Formation during the drilling of the Quindalup, Pinjar, Gingin Brook, and Watheroo lines; the Agaton, Arrowsmith River, and Allanooka projects; and in the Perth metropolitan investigation (Fig. 63). The formation is a thick sequence consisting mainly of interbedded sandstone and siltstone.

Where the sediments crop out or are covered by a thin surface veneer of sands, water-table aquifers may be found. This particularly applies to the Victoria Plateau, where there are extensive unconfined aquifers, although confined aquifers also occur there.

The more general case in the Perth Basin is that of multiple-aquifer fully confined systems found in the Yarragadee Formation, occurring within an interbedded sequence of sands and silts. Recharge is by leakage from other sediments or by direct percolation from the surface, particularly in the eastern parts of the basin. Water quality is very variable, with a general pattern of worsening with depth and distance away from the recharge zones. Domestic quality water (less than 1 000 ppm TDS) has been found at all of the above-listed locations. Artesian flows have been obtained from boreholes in the formation in parts of the Perth metropolitan and Arrowsmith River areas.

CRETACEOUS

Warnbro Group: The *South Perth Shale* is an important aquiclude in the Perth metropolitan area, but at Pinjar (Whincup, 1966) it contains poor aquifers, less than 10 m thick, with variable quality water. In the Mandurah-Pinjarra area (Commander, 1974a) there are laterally continuous sand beds in the unit interbedded with silt and shale, and these are important water sources for stock and domestic use. The quality of this water ranges from less than 1 000 ppm to 35 000 ppm TDS.

The *Leederville Formation*, which consists mainly of sandstone interbedded with siltstone and shale, has important (mostly confined) aquifer systems within the Perth metropolitan area. Water quality is generally in the range 250 to 2 000 ppm TDS. Hydrologically the unit is very similar to the Yarragadee Formation. Aquifers are often thick (up to 300 m at Pinjar), and are capable of supporting high rates of production. In the Perth metropolitan area the presence of iron (10 to 30 ppm TDS) imposes some limitations on its use.

The *Dandaragan Sandstone* has been little explored hydrologically, but at Watheroo (Harley, A. S., written comm., 1974) an aquifer, 40 m thick and confined by argillaceous sediments, was encountered. The water is suitable for domestic use (less than 1 000 ppm TDS) and the aquifer is very permeable. Recharge is by direct rainfall percolation in the western part of the marine basin and by leakage from the overlying Coolyena Group sediments.

Coolyena Group: The *Osborne Formation* is mostly of low permeability, and at Gnangara and Pinjar may locally provide a comparatively impervious base for aquifers within the overlying Quaternary sands. At Gingin Brook (Sanders, 1967) the Osborne Formation performs the same function in relation to aquifers in the overlying *Molecap Greensand*, which contains good aquifers at that locality. At Gnangara the Molecap Greensand is variable, showing good permeability at some sites and very low permeability at others. Water in the Molecap Greensand is generally of very good quality and it is suitable for domestic use.

Bunbury Basalt: The Bunbury Basalt is a distinctive aquiclude between the Yarragadee Formation and Warnbro Group. In the vicinity of Bunbury confined aquifers with domestic quality water are located below the basalt.

QUATERNARY

Hydrologically, the two most important Quaternary rock units are the Bassendean Sand and the Tamala Limestone. Other superficial sand units, where sufficiently thick and extensive, often contain local unconfined flow systems which can be utilized for small supplies.

The *Bassendean Sand* aquifers are of considerable economic importance and will in the future supply a significant proportion of Perth's water supplies. The aquifers are unconfined, recharge directly by rainfall infiltration, and discharge by evapotranspiration, evaporation from lakes, discharge to the sea, and by leakage to underlying and adjacent sediments. At Gnangara 400 km^2 of water-table aquifer (Fig. 63) have been investigated and Balleau (1973) has shown that outflow from the area is 69 600 m^3/d. Net annual recharge varies with depth to the water table, but in the vicinity of the groundwater divide it is as high as 30 per cent of the total rainfall. Hydraulically the sands are very uniform, with an average hydraulic conductivity of 13 m/d.

These properties are likely to be applicable to Bassendean Sands elsewhere.

The *Tamala Limestone* aquifers are successfully exploited along much of the coastline of the Perth Basin. Rainfall readily infiltrates to the water table, where cavernous flow conditions often prevail. Below the water table caverns are not so common, and the intergranular porosity of the formation controls water movement. Because of the cavernous conditions, at or near the water table, flow rates are high, and gradients are very low. The limestone is a coastal deposit, and groundwater discharge is mainly to the sea. Because of the low gradients, sea water can intrude far inland, and fresh groundwater only occurs as a seaward-thinning wedge overlying saline water.

Passmore (1970) has shown that at Rockingham the position of the underlying saline water conforms to the Glyben-Herzberg relation. Tidal changes give fluctuating water levels within the groundwater-flow system, resulting in dispersion of saline water into the overlying fresh water. Consequently, at sites near the coast, despite the ready infiltration of rainfall, only water fit for stock use may be encountered. The best chance for obtaining domestic quality water is where the Tamala Limestone extends furthest inland, or where there is a substantial lateral inflow to the unit from sediments inland and adjacent to it.

Dispersion effects make prediction of water quality, at any specific location near the coast, a hazardous procedure. Where dispersion effects are small, domestic-quality water should be encountered at or near the water table.

Because of its very high permeability, conditions for water abstraction from the Tamala Limestone are good; however, this facility can lead to overpumping and the drawing-in of saline water.

HEAVY-MINERAL SANDS

INTRODUCTION

Heavy-mineral sands occur at a number of localities in the Perth Basin in Holocene to early Pleistocene or late Tertiary shoreline deposits on the Swan and Scott Coastal Plains (Fig. 64).

Three main groups of shorelines are recognized on the Swan Coastal Plain. The eastern shorelines are the oldest. They formed below the scarps defining the eastern margin of the plain (the Darling, Whicher, and Gingin Scarps), probably during the early Pleistocene or late Tertiary. The middle shorelines are believed to be of middle to early Pleistocene age, and only one group of these, the Capel Shorelines, are known to contain significant heavy-mineral concentrations. The western shorelines are late Pleistocene to Holocene and these formed along or close to the modern coastline.

Four main shoreline deposits contain heavy-mineral sands on the Scott Coastal Plain. The northern shoreline is believed to be early Pleistocene (or older), the two central shorelines are Pleistocene, and the fourth shoreline coincides with the present coast.

The original source of the heavy-mineral sands on the coastal plains was the Precambrian shield of the Yilgarn Block. However, most of the heavy minerals in the deposits are thought to have been reworked from Mesozoic sediments during the period of late Tertiary to Pleistocene marine erosion.

This summary is partly based on an unpublished report by Baxter (1974). Other important papers on the heavy-mineral deposits are by Welch (1964), Baxter (1972), and Lissiman and Oxenford (1973).

SWAN COASTAL PLAIN

EASTERN SHORELINES

A series of early Pleistocene or late Tertiary shorelines are recognized along the eastern margin of the Swan Coastal Plain. The deposits of these shorelines are the most extensive of those containing heavy-mineral sands in the Perth Basin.

Yoganup Shorelines: The Yoganup Shorelines are a group of closely spaced, parallel shorelines in front of the Whicher Scarp in the southern part of the Swan Coastal Plain. They are marked by lines of beach, dune, and shallow-marine sandy deposits, which have been mapped as the Yoganup Formation. They occur at elevations extending from 25 to 75 m above sea level. As pointed out earlier, the base of the deposits ranges in elevation from about 47 m in the south to 37 m in the north, and this may be related to upwarping along the Jarrahwood Axis (Cope, 1975).

The heavy-mineral sands have been mined at two pits in the vicinity of Yoganup. Production began in 1959, and up to the end of 1974 they had produced 1 305 588 t of ilmenite, 136 854 t of zircon, 33 950 t of leucoxene, 5 309 t of monazite, and 1 173 t of rutile.

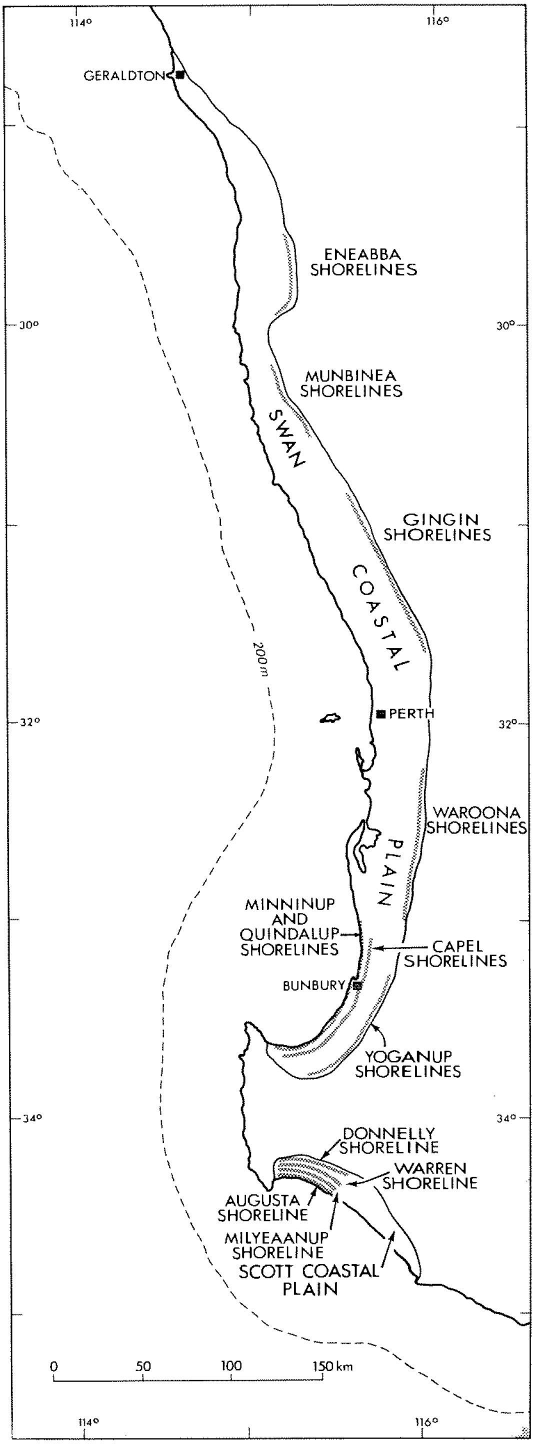


Figure 64. Shoreline deposits containing heavy-mineral concentrations on the Swan and Scott Coastal Plains.

Waroona Shorelines: The group of Waroona Shorelines are equivalent to those at Yoganup. They occur below the Darling Scarp, and are marked by lines of shallow-marine, beach, and dune deposits between 25 and 80 m above sea level. The deposits are best developed between ridges of granite which formed headlands on the ancient coastal scarp.

Concentrations of heavy minerals are irregular and discontinuous along the shorelines and are often buried beneath late Pleistocene to Holocene outwash fans. They have not yet been developed commercially.

Gingin Shorelines: The Gingin Shorelines occur below the Gingin Scarp, north of Perth. The deposits probably correlate with those of Yoganup and Waroona. Plans for their possible development in the near future have recently been announced.

Munbinea Shorelines: The Munbinea Shorelines are a group of four Pleistocene shorelines 33 to 43 m above sea level, at the foot of the Gingin Scarp near Jurien. They may correlate with the Gingin, Waroona, and Yoganup Shorelines; alternatively they may be slightly younger, perhaps correlating with the Capel Shorelines of the central Swan Coastal Plain.

The Munbinea Shoreline deposits are regarded as beach, swale, and dune sediments, and the announced reserves amount to 2 000 000 t proved and 1 000 000 t possible, with an average grade of 8 to 9 per cent heavy minerals. Commercial development of the deposits is expected to begin soon.

Eneabba Shorelines: A series of shorelines defining an early Pleistocene or late Tertiary bay have been recognized south of Eneabba in front of the northern extension of the Gingin Scarp (Baxter, 1972; Lissiman and Oxenford, 1973). The shorelines range from 85 m to 128 m above present sea level, and the deposits consist of shallow-marine, beach, lagoonal, and dune deposits, containing local heavy-mineral concentrations. These shoreline deposits occur at higher elevations, and may be older, than others containing heavy minerals on the eastern margin of the Swan Coastal Plain. They could correlate with the Ridge Hill Sandstone of the Darling Scarp east of Perth.

A total of some 30 000 000 t of heavy minerals occur in the deposits, which are the largest yet found in Western Australia. The heavy minerals consist primarily of ilmenite, and include a high proportion of rutile—up to 15 per cent. Production from two pits began in 1974, and to the end of that year had amounted to 30 179 t of ilmenite, 4 835 t of zircon, 7 462 t of rutile, and 325 t of leucoxene.

Middle Shorelines

Only one group of the early to middle Pleistocene shoreline deposits in the central Swan Coastal Plain has been found to contain significant concentrations of heavy minerals. These are the Capel shoreline deposits in the middle of the coastal plain east of Busselton.

Capel Shorelines: Sediments of the Capel Shorelines include beach and dune deposits forming part of the Bassendean Sand. Some are apparently associated with an ancient low sea cliff that was cut into the Bunbury Basalt. They have been dated as early Pleistocene.

Production from the Capel deposits began in 1956, and to the end of 1974 it amounted to 5 162 454 t of ilmenite, 390 161 t of zircon, 48 362 t of leucoxene, 24 251 t of monazite, 18 018 t of rutile, and 71 t of xenotime.

WESTERN SHORELINES

The western shoreline deposits include those of the Holocene coast and closely adjacent late Pleistocene shorelines.

Minninup Shoreline: The Minninup shoreline deposits consist of beach and dune sediments near the modern coast, forming part of the late Pleistocene Tamala Limestone. They contain accumulations of heavy minerals at Minninup, south of Bunbury, but have not yet been developed.

Quindalup Shoreline: The Quindalup shoreline deposits are the Holocene beach, dune, and swale accumulations along the coast north and south of Bunbury. The shoreline is rapidly prograding in this area.

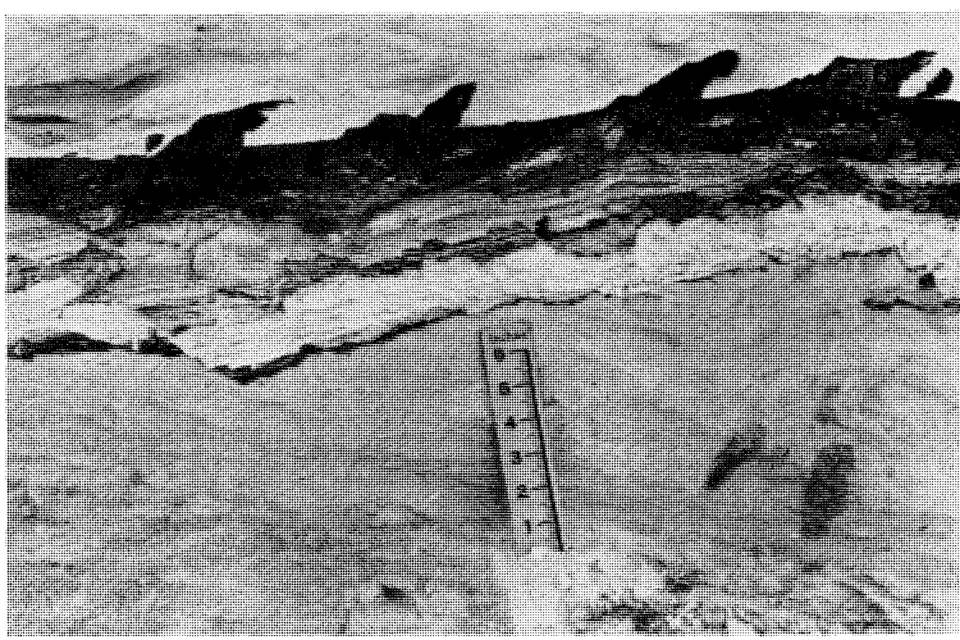


Figure 65. Small faults and flame structures in heavy-mineral sands at Wonnerup (Quindalup Shoreline). These intraformational structures have apparently resulted from minor slippage of the foredune sands.

The deposits have been mined at Koombana Bay and Wonnerup (Fig. 65). Production began in 1956, and ceased in 1967. It amounted to 422 244 t of ilmenite, 3 481 t of zircon, and 99 t of monazite.

The modern coastline bordering other parts of the Swan Coastal Plain also contains some small heavy-mineral concentrations, notably near Perth and north of Jurien, but there are no plans for their development at this time.

SCOTT COASTAL PLAIN

Several Pleistocene to Holocene belts of shoreline deposits containing heavy minerals have been found on the Scott Coastal Plain, but none have been developed so far. In addition there are some heavy-mineral concentrations in the modern estuarine sediments of Hardy Inlet.

Donnelly Shoreline: The Donnelly Shoreline is situated along the northern margin of the Scott Coastal Plain. It is believed to be of early Pleistocene or late Tertiary age, equivalent to the Yoganup Shorelines and others along the eastern edge of the Swan Coastal Plain.

Warren Shoreline: The Warren Shoreline may correlate with the Capel Shorelines of the middle Swan Coastal Plain. It is probably of early or middle Pleistocene age.

Milyeaanup Shoreline: The Milyeaanup Shoreline is thought to be late Pleistocene, correlating with the Minninup Shoreline of the Swan Coastal Plain.

Augusta Shoreline: The Augusta Shoreline forms the present coast bordering the Scott Coastal Plain. The modern beach and dune deposits in this area include some concentrations of heavy minerals, which may be economically significant in the future.

COAL

Coal has been found in several areas of the Perth Basin, but none of the discoveries have yet proved to be economic. The coal occurs in Permian, Jurassic, and Cretaceous sediments, and the main areas of interest have been around Irwin River (Irwin River Coal Measures), Eradu (Wagina Sandstone), Busselton-Augusta (Sue Coal Measures), Beagle Ridge (Irwin River Coal Measures), and Eneabba-Hill River (Cattamarra Coal Measures Member). Several other minor occurrences of coal or lignitic material have been reported from the Yarragadee and Leederville Formations, but none of these are likely to have economic significance.

PERMIAN

IRWIN RIVER

The first discovery of coal in Western Australia was made in 1846 on the North Branch of the Irwin River by the Gregory brothers (Gregory and Gregory, 1884). It was confirmed by the Government Geologist, F. von Sommer, in 1847, although he was not impressed by the coal's potential. Since that time interest has been stimulated from time to time in the commercial prospects of the area, but on each occasion investigations have shown the coal to be uneconomic.

The history of the various investigations is summarized by Campbell (1910) and Johnson and others (1954).

The coal occurs in lenticular seams up to 3.7 m thick in the Irwin River Coal Measures, of Artinskian (Early Permian) age. The coal crops out in both branches of the Irwin River. In the Woolaga Creek area, 30 km to the south, the equivalent section contains beds of carbonaceous shale, but no coal.

In 1944 an adit was driven 55 m down the dip of the thickest seam (1.8 m thick) beside the North Branch of the Irwin River. Samples taken from the end of the adit showed a range of 21 to 29 per cent volatiles, 28 to 43 per cent fixed carbon, and 15 to 41 per cent ash. Other samples from the seam showed a range of 20 to 32 per cent moisture and a range in calorific values from 12.56 to 17.25 MJ/kg on an "as received" basis. Several other adits and shafts have been dug in the area, and a number of exploratory bores have been drilled. They have demonstrated that the seams are very lenticular, and that the coal in all cases has a high ash content. Full details are given by Johnson and others (1954), who concluded that the coal is considerably inferior to Collie coal and is to be regarded as uneconomic.

Eradu

Coal occurs in the Eradu area in the Upper Permian Wagina Sandstone. The economic potential of the seams has been investigated on a number of occasions since they were first discovered in 1906 in a Government calyx bore, but on each occasion they have been judged to be uneconomic.

There has been a considerable amount of drilling and some shaft sinking around Eradu, which has disclosed the presence of several seams up to 5.7 m thick (Johnson and others, 1954). The coal has a high ash content and low calorific value. One of the thickest seams (5.3 m), reached at a depth of 44 m in Morrow's Shaft, had an average calorific value of 14.1 MJ/kg with 20.67 per cent volatiles, 31.63 per cent fixed carbon, and 17.70 per cent ash when analyzed on a 30 per cent moisture basis.

Beagle Ridge

The Irwin River Coal Measures are known to occur in the subsurface on the Beagle Ridge, where they have been penetrated in two wells drilled for petroleum exploration, Jurien No. 1 and B.M.R. No. 10.

In Jurien No. 1 well (Pudovskis, 1963) 9 seams were intersected between depths of 680 and 888 m. The seams ranged from 0.6 to 1.5 m in thickness, the aggregate being 8.8 m.

Examination of the coal by the Government Chemical Laboratories (*in* Pudovskis, 1963) showed that it is a coking non-swelling type with higher calorific values than Collie coal. Analyses of three samples, gave moisture values ranging from 1.2 to 3.8 per cent, ash from 13.8 to 22.7 per cent, volatiles from 15.1 to 18.4 per cent, and fixed carbon from 57.3 to 66.6 per cent. The calorific value "as received" ranged from 26.42 to 30.74 MJ/kg, while dry and ash free it ranged from 35.29 to 36.4 MJ/kg.

Exploration is in progress to determine whether the coal seams are sufficiently thick and close to the surface to permit economic development in any part of this area.

Busselton-Augusta area

Coal has been penetrated in a number of exploratory bores for petroleum and water in the Busselton-Augusta area. The coal occurs in the Sue Coal Measures (Permian), and the type section of the formation in Sue No. 1 well contains about 85 m of coal in some 70 seams over an interval of 1 626 m. The coal is sub-bituminous, and the better seams are similar in quality to Collie coal.

An analysis of a seam cored from 612.6 to 615.0 m in Alexandra Bridge No. 1 stratigraphic well showed 20.8 per cent moisture, 8.5 per cent ash, 26.7 per cent volatiles, and 44.0 per cent fixed carbon, the calorific value being 20.84 MJ/kg on an "as received" basis. Dry and ash free the calorific value of this coal is 29.47 MJ/kg. For other analyses see Cockbain (1974b).

The shallowest known occurrence of the coal measures is at a depth of 111 m in Quindalup No. 2 water bore. Some coal exploration was carried out in the area south of Busselton by Griffin Coal Mining Company, and this organization drilled a number of holes there without success (Utting, 1966). However, it is possible that faulting could have brought the coal close enough to the surface to allow economic development somewhere in the area of the Vasse Shelf. Companies are currently exploring for coal in the area.

JURASSIC

Coal seams are known to occur in the Cattamarra Coal Measures Member of the Cockleshell Gully Formation over a wide area of the Perth Basin, from Wicherina No. 1 well in the north to Blackwood No. 1 well in the south. The seams are strong seismic reflectors, and seismic data show that they extend down to depths of more than 5 000 m in the central part of the basin. Prospecting has been carried out in two areas where they come close enough to the surface for possible economic development, near Eneabba and Hill River.

Eneabba

Eneabba No. 1 well, drilled in 1961, encountered 22 seams of coal totalling some 12.2 m in thickness in the Cattamarra Coal Measures Member between 1 942.4 and 1 963.2 m (Johnstone, 1964). Analysis of this coal showed that it has a similar calorific value (18.6 to 20.9 MJ/kg, assuming 20 per cent moisture) to that of coal from Collie, the State's only commercial coal field. In addition, the coal in Eneabba No. 1 possesses weak coking properties.

The Cattamarra Coal Measures Member is known to subcrop in a block-faulted area extending for a few kilometres south of Eneabba township. Exploratory drilling for coal has recently been carried out in this area and has disclosed the occurrence of a number of thin seams of sub-bituminous coal close to the surface. The future economic viability of the deposit is still uncertain.

Hill River

An exploratory drilling programme for coal was carried out in the Hill River area, where the Cattamarra Coal Measures Member is known to crop out. The area is structurally complex, and although coal was encountered at shallow depths in a number of holes, the individual seams were commonly found to be less than 0.6 m thick, and the greatest aggregate thickness of coal discovered in any of the holes was only 3.3 m. Although the calorific value of the coal at Hill River is similar to that from Eneabba No. 1 well, none of the Hill River coal showed coking properties. Johnstone (1964) concluded that coal in this area is uneconomic.

QUARTZ SAND

Quartz sand is perhaps the most abundant mineral deposit in the Perth Basin. It has been worked at a number of localities for use in iron and steel moulding, glass manufacture, lime-silica brick manufacture, and building purposes.

The Bassendean Sand of the Swan Coastal Plain is the unit that has been most used, especially in the area around Perth. It is generally thoroughly podsolized, and consists almost wholly of quartz sand. Much of it is ideally suited to steel and cast-iron moulding.

The white sand deposits around the shores of Lake Gnangara are well graded and are suitable for high-quality glass manufacture. On ignition this sand is pure white, and has the following typical percentage composition: silica 99.8 per cent, ferric oxide 0.04 per cent, alumina 0.14 per cent, titania 0.007 per cent, a trace of potash, and nil lime and magnesia.

LIMESTONE AND LIME SAND

Limestone of the Tamala Limestone is quarried at various localities in the Perth Basin for road-making materials. It is also used, especially in the vicinity of Perth, as a building stone. In addition, this limestone, and lime sand of the Safety Bay Sand, have been used on a small scale as a source of industrial and builders' lime and for agricultural purposes.

Capstone on the Tamala Limestone is used for making cement and builders' lime. Large reserves having 70 to 80 per cent $CaCO_3$ are available (de la Hunty, 1966), and these are likely to have increasing industrial importance in the future.

Extensive sub-Holocene shell beds (mainly made up of the oyster *Ostrea angasi*) of the Swan River estuary were worked in the past as a source of lime for cement manufacture, but production ceased in 1957. The Gingin Chalk and Muchea Limestone have also been used for agricultural purposes and for making builders' lime.

BUILDING STONE

Building stone is quarried at a number of localities in and adjoining the Perth Basin. The principal sources are the Tamala Limestone, Donnybrook Sandstone, laterite, Greenough Sandstone, and granitic rocks of the Darling Scarp. Other minor sources have been utilized in some areas, including the Tumblagooda Sandstone and the basal sandstone member of the Kockatea Shale around Northampton, and the Mokadine Formation around Moora.

LATERITE GRAVEL

Laterite gravel is used extensively for surfacing roads in the Perth Basin. It is obtained from gravel pits in many localities.

BAUXITE

No economic bauxite deposits are known in the Perth Basin itself, but extensive deposits have been developed in the Darling Range, immediately east of the basin margin. Bauxite ore occurs as local concentrations in the bauxitic laterite overlying the Archaean igneous-metamorphic complex (Tomich, 1964; Geidans, 1973). It ranges from 1 to 9 m in thickness, and from 30 to 45 per cent in alumina content. Total reserves amount to at least 850 x 10^6 t, and the production of alumina to the end of 1974 had amounted to 9 575 747 t.

PEAT

Peat is being mined from small swamps some 9 km west of Bullsbrook. It is used to improve soils in the Perth metropolitan area for gardening purposes.

CLAY AND SHALE

Ceramic and brick clays occur in the Pleistocene Guildford Formation in the valleys of the Swan and Helena Rivers, and they have been extensively developed at a number of localities, especially around Guildford.

Shale suitable for brick making occurs in the Cretaceous Osborne Formation 4 km east of Muchea, where it is currently being mined. However, the largest production of shale for brick manufacture is obtained from the Proterozoic Armadale Shale, immediately east of the Darling Fault, near Byford, Cardup, and Mundijong (Lord, 1948, 1950; Noldart, 1956).

Montmorillonite-bearing clays occur in a number of salt lakes in the basin Their potential as a source of bentonite for use in drilling muds has been investigated, but none have been found to be commercial.

COPPER ORE

A few hundred tonnes of low-grade copper ore have been extracted from the Proterozoic Arrowsmith Sandstone at Baxter's Copper Mine, 4 km south of Arrino. The deposits have no present economic value.

PHOSPHATE

Deposits of guano and rock phosphate were worked for many years on the Houtman Abrolhos. The first recorded production, amounting to 65 t, was in 1878, but the deposits had been exploited for some years previously when no records were kept. Between 1883 and 1915 some 57 000 t were extracted, mainly from West Wallabi, Rat, Gun, and Pelsart Islands, and in 1944 and 1945 the British Phosphate Commission obtained 10 869 t of guano and rock phosphate from Pelsart Island. The economic reserves of the islands are now exhausted.

The Middle Jurassic Bringo Shale and Colalura Sandstone near Geraldton and the Cretaceous Molecap Greensand near Dandaragan contain phosphatic horizons, but these deposits are regarded as uneconomic (Matheson, 1948; Russell, 1966).

DIATOMITE

Extensive deposits of diatomaceous peat occur in swamps on the Swan Coastal Plain. The best known of these is at Lake Gnangara, about 20 km north of Perth, and large deposits have recently been reported from south of Dongara.

Diatomite is obtained from the deposits by calcining the peat. It is a high-quality product having several potential industrial uses, especially as a filtering agent and as a filler for paints and other products. In the past the diatomite was extracted on a limited scale for use as an abrasive and heat insulator. Plans for more extensive development of the deposits have recently been announced.

TALC

A deposit of high-quality talc has been developed in the Dudawa Beds at Coodawa, 9 km east-northeast of Three Springs. It is thought to be derived from dolomites within the Dudawa Beds by metasomatism associated with the intrusion of adjoining dolerite dykes. Total production to the end of 1974 amounted to 314 379 t.

GREENSAND

Some 32 500 t of greensand were mined from the Molecap Greensand at Molecap Hill between 1932 and 1960, and from this some 6 570 t of glauconite concentrate were exported to England for use as a water softener. The operation ceased when artificial products replaced glauconite for this purpose.

GYPSUM

A few tonnes of gypsum have been produced from the Dooka and Cliff Head deposits near the coast south of Dongara. These are small Quaternary salt-lake deposits in interdunal depressions, and total reserves amount to some 90 000 t (de la Hunty and Low, 1958).

Very much larger reserves (about 10 x 10^6 t according to de la Hunty and Low) occur in the Yarra Yarra Lakes. However, these have not been developed, and seasonal flooding of the lakes and the presence of interbedded clays could make extraction difficult.

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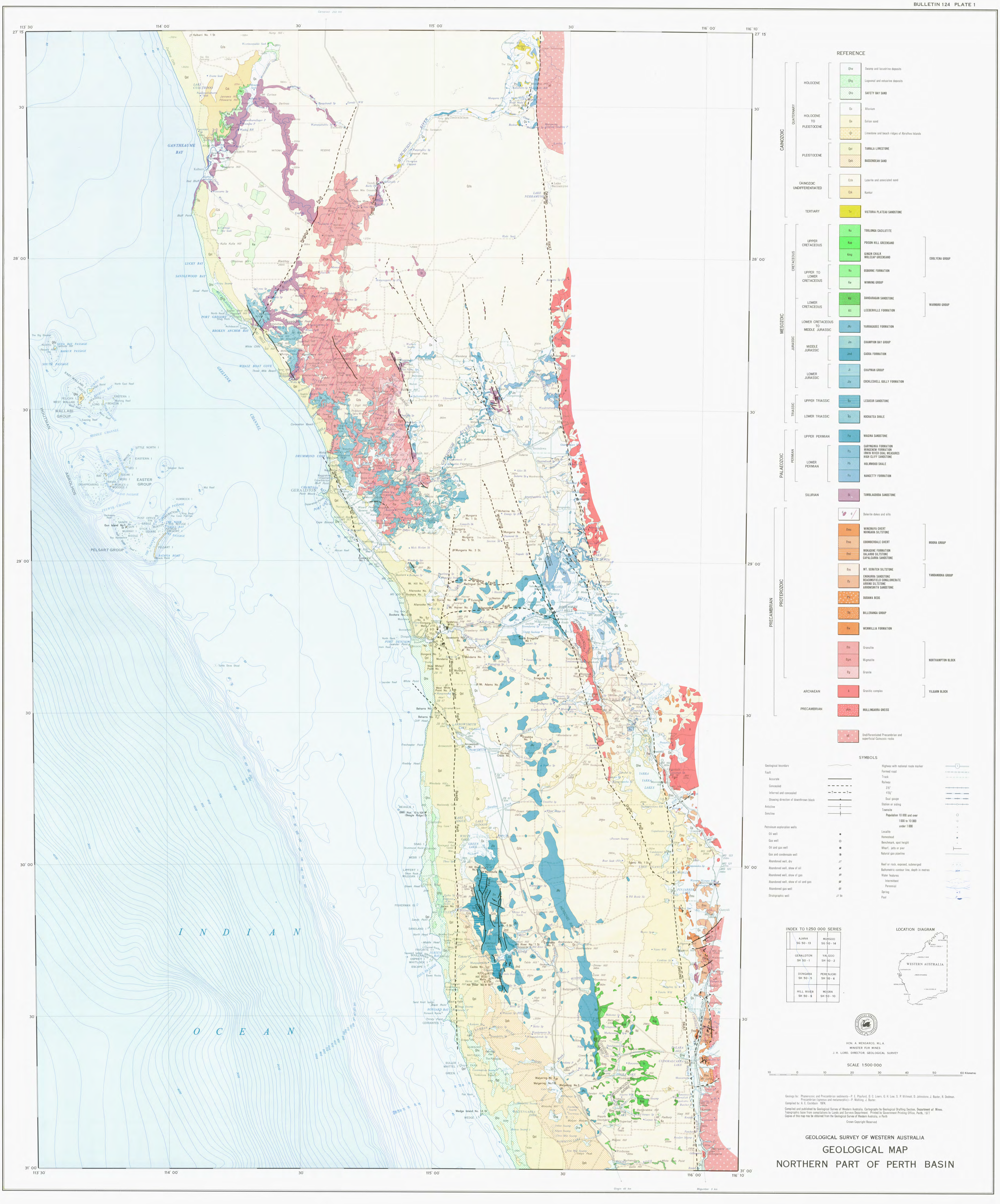
(11)—53419

ISBN 0 7244 6043 8

53419/1/76—1250 WILLIAM C. BROWN, Government Printer, Western Australia



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP
NORTHERN PART OF PERTH BASIN

REFERENCE

CAINOZOIC	QUATERNARY	HOLOCENE	Qhw	Swamp and lacustrine deposits	
			Qhg	Lagoonal and estuarine deposits	
			Qho	Shell beds of Rottnest Island	
			Qhs	SAFETY BAY SAND	
		HOLOCENE TO PLEISTOCENE	Qa	Alluvium	
		PLEISTOCENE	Qpt	TAMALA LIMESTONE	
			Qpb	BASSENDEAN SAND	
			Qpg	GUILDFORD FORMATION	
			Qpy	RIDGE HILL SANDSTONE and YOGANUP FORMATION	
		CAINOZOIC UNDIFFERENTIATED	Czls	Laterite and associated sand	
			Czh	HARVEY BEDS	
MESOZOIC	CRETACEOUS	UPPER CRETACEOUS	Kup	POISON HILL GREENSAND	COOLYENA GROUP
			Kmg	GINGIN CHALK MOLECAP GREENSAND	COOLYENA GROUP
		UPPER TO LOWER CRETACEOUS	Ko	OSBORNE FORMATION	COOLYENA GROUP
		LOWER CRETACEOUS	Kll	LEEDERVILLE FORMATION	WARNBRO GROUP
			Klb	BULLSBROOK BEDS	
			Kn	DONNYBROOK SANDSTONE	
			Km	MAXICAR BEDS	
			Kb	BUNBURY BASALT	
		LOWER CRETACEOUS TO MIDDLE JURASSIC	JKy	YARRAGADEE FORMATION	
PRECAMBRIAN	PROTEROZOIC		Ꞓc	CARDUP GROUP	
			Ꞓlm	Granulite	LEEUWIN BLOCK
			Ꞓlg	Granite gneiss	LEEUWIN BLOCK
			Ꞓag	Granite and gneiss	ALBANY-FRASER PROVINCE
	ARCHAEAN		A	Granitic complex	YILGARN BLOCK
			pЄ	Undifferentiated Precambrian and superficial Cainozoic rocks	

SYMBOLS

Geological boundary
Fault
- Accurate
- Concealed
- Inferred and concealed
- Showing direction of downthrown block

Anticline
Syncline
Petroleum exploration wells
- Oil well
- Gas well
- Oil and gas well
- Gas and condensate well
- Abandoned well, dry
- Abandoned well, show of oil
- Abandoned well, show of gas
- Abandoned well, show of oil and gas
- Abandoned gas well
- Stratigraphic well (St)

Highway with national route marker
- Major road
- Minor road

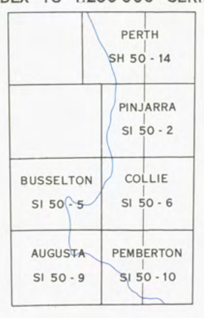
Railway
- 3′6″
- 4′8½″
- Dual gauge
- Station or siding

Townsite
- Population 10 000 and over
- 1 000 to 10 000
- under 1 000

Locality
Homestead
Benchmark, spot height
Natural gas pipeline
Reef or rock, exposed, submerged
Wharf jetty or pier
Bathymetric contour line, depth in metres
Water features
- Intermittent
- Perennial

Spring
Pool

INDEX TO 1:250 000 SERIES



LOCATION DIAGRAM

HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 500 000

10 0 10 20 30 40 50 60
KILOMETRES

Geology by: Phanerozoic and Precambrian sediments—D. C. Lowry, G. H. Low, and R. W. Lake.
Precambrian (igneous and metamorphic)—R. C. Horwitz, I. Gemuts, and J. J. G. Doepel.
Compiled by: A. E. Cockbain, 1974

Compiled and published by Geological Survey of Western Australia. Cartography by Geological Drafting Section, Department of Mines.
Topographic base from compilations by Lands and Surveys Department. Printed by Government Printing Office, Perth, 1977
Copies of this map may be obtained from the Geological Survey of Western Australia, in Perth.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP
SOUTHERN PART OF PERTH BASIN

REFERENCE

CAINOZOIC	CAINOZOIC UNDIFFERENTIATED	Czh	HARVEY BEDS
CAINOZOIC	TERTIARY UNDIFFERENTIATED	T	Tertiary below **HOUTMAN ABROLHOS**
CAINOZOIC	TERTIARY	Tv	VICTORIA PLATEAU SANDSTONE
CAINOZOIC	TERTIARY	Tk	KINGS PARK FORMATION
MESOZOIC — CRETACEOUS	UPPER CRETACEOUS	Ku	TOOLONGA CALCILUTITE
MESOZOIC — CRETACEOUS	UPPER TO LOWER CRETACEOUS	Kc	COOLYENA GROUP
MESOZOIC — CRETACEOUS	UPPER TO LOWER CRETACEOUS	Kw	WINNING GROUP
MESOZOIC — CRETACEOUS	LOWER CRETACEOUS	Kr	WARNBRO GROUP, DONNYBROOK SANDSTONE, BULLSBROOK BEDS AND MAXICAR BEDS
MESOZOIC — CRETACEOUS	LOWER CRETACEOUS	Kb	BUNBURY BASALT
MESOZOIC	LOWER CRETACEOUS TO MIDDLE JURASSIC	JKy	YARRAGADEE FORMATION
MESOZOIC — JURASSIC	MIDDLE JURASSIC	Jm	CHAMPION BAY GROUP
MESOZOIC — JURASSIC	MIDDLE JURASSIC	Jmd	CADDA FORMATION
MESOZOIC — JURASSIC	LOWER JURASSIC	Jl	CHAPMAN GROUP
MESOZOIC — JURASSIC	LOWER JURASSIC	Jlo	COCKLESHELL GULLY FORMATION
MESOZOIC — TRIASSIC	UPPER TRIASSIC	Ru	LESUEUR SANDSTONE
MESOZOIC — TRIASSIC	LOWER TRIASSIC	Rk	KOCKATEA SHALE
PALAEOZOIC — PERMIAN	UPPER PERMIAN	Pw	WAGINA SANDSTONE
PALAEOZOIC — PERMIAN	LOWER PERMIAN	Pa	CARYNGINIA FORMATION, MINGENEW FORMATION, IRWIN RIVER COAL MEASURES, HIGH CLIFF SANDSTONE
PALAEOZOIC — PERMIAN	LOWER PERMIAN	Ph	HOLMWOOD SHALE
PALAEOZOIC — PERMIAN	LOWER PERMIAN	Pn	NANGETTY FORMATION
PALAEOZOIC	SILURIAN	St	TUMBLAGOODA SANDSTONE
PRECAMBRIAN — PROTEROZOIC		Ec	CARDUP GROUP
PRECAMBRIAN — PROTEROZOIC		Emu	WINEMAYA CHERT, NOINGARA SILTSTONE (MOORA GROUP)
PRECAMBRIAN — PROTEROZOIC		Emc	COOMBERDALE CHERT (MOORA GROUP)
PRECAMBRIAN — PROTEROZOIC		Eml	MOKADINE FORMATION, DALAROO SILTSTONE, CAPALCARRA SANDSTONE (MOORA GROUP)
PRECAMBRIAN — PROTEROZOIC		Eys	MT. SCRATCH SILTSTONE (YANDANOOKA GROUP)
PRECAMBRIAN — PROTEROZOIC		Ey	ENOKURRA SANDSTONE, BEACONSFIELD CONGLOMERATE, ARRINO SILTSTONE, ARROWSMITH SANDSTONE (YANDANOOKA GROUP)
PRECAMBRIAN — PROTEROZOIC		Eu	DUDAWA BEDS
PRECAMBRIAN — PROTEROZOIC		Eb	BILLERANGA GROUP
PRECAMBRIAN — PROTEROZOIC		Ew	WENMILLIA FORMATION
PRECAMBRIAN — PROTEROZOIC		En	Igneous and metamorphic rocks of **NORTHAMPTON BLOCK**
PRECAMBRIAN — PROTEROZOIC		El	Igneous and metamorphic rocks of **LEEUWIN BLOCK**
PRECAMBRIAN	ARCHAEAN	A	Granitic complex of **YILGARN BLOCK**
PRECAMBRIAN	PRECAMBRIAN UNDIFFERENTIATED	pEm	MULLINGARRA GNEISS

SYMBOLS

Geological boundary
Fault
- Accurate
- Concealed
- Showing direction of downthrown block

Anticline
Syncline

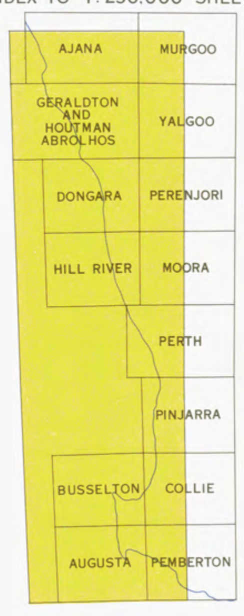
Highway
Main Road
Railway
- 3'6"
- 4'8½"

Station or siding — Dwellingup

Townsite
- Population 10 000 and over — BUNBURY
- 1 000 to 10 000 — MANDURAH
- under 1 000 — Chittering

Bathymetric contour line, depth in metres — 200
Watercourse
- Perennial
- Intermittent

INDEX TO 1:250,000 SHEETS



LOCALITY MAP

HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1:1 000 000

20 0 20 40 60 80 100 120 KILOMETRES

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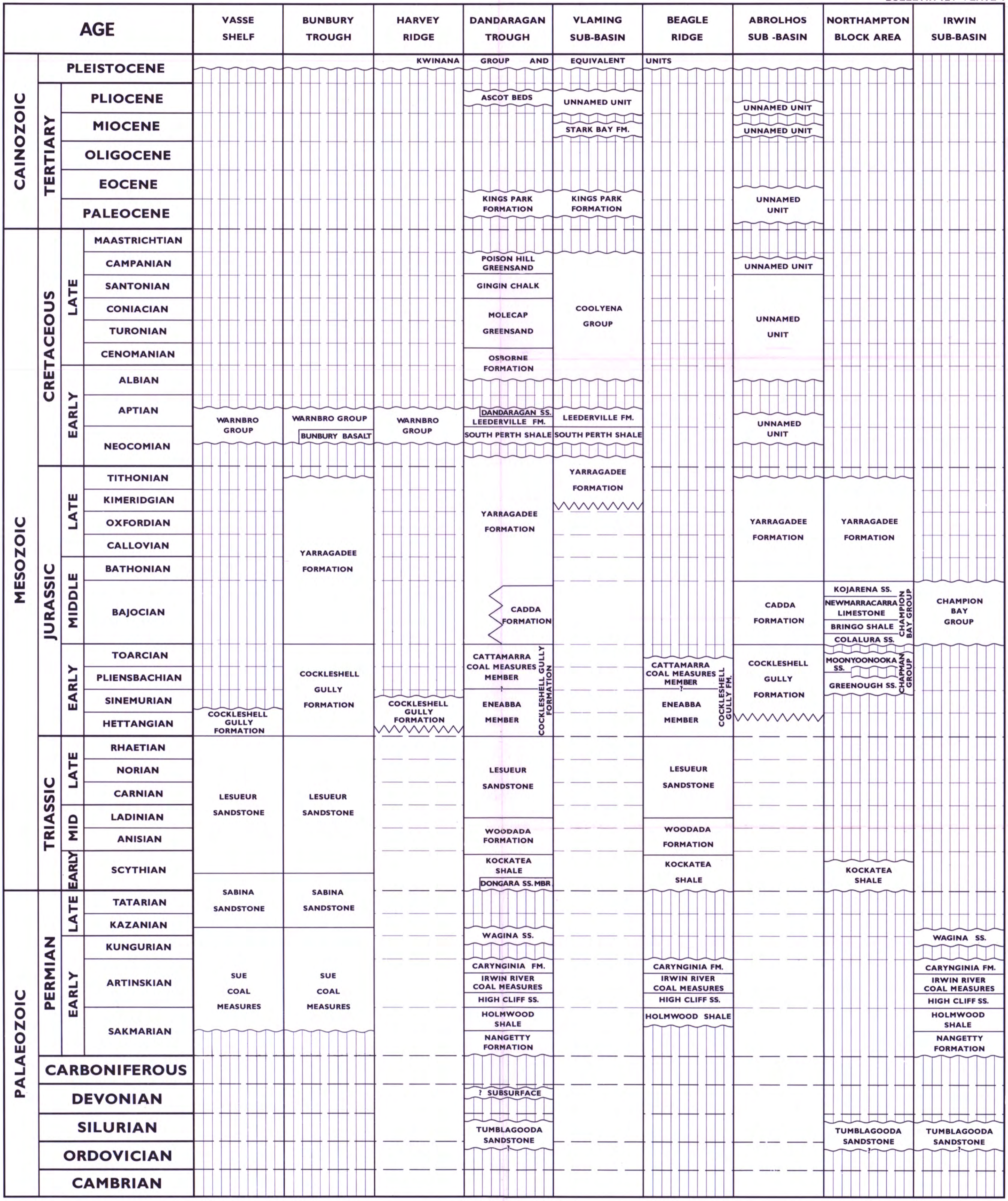
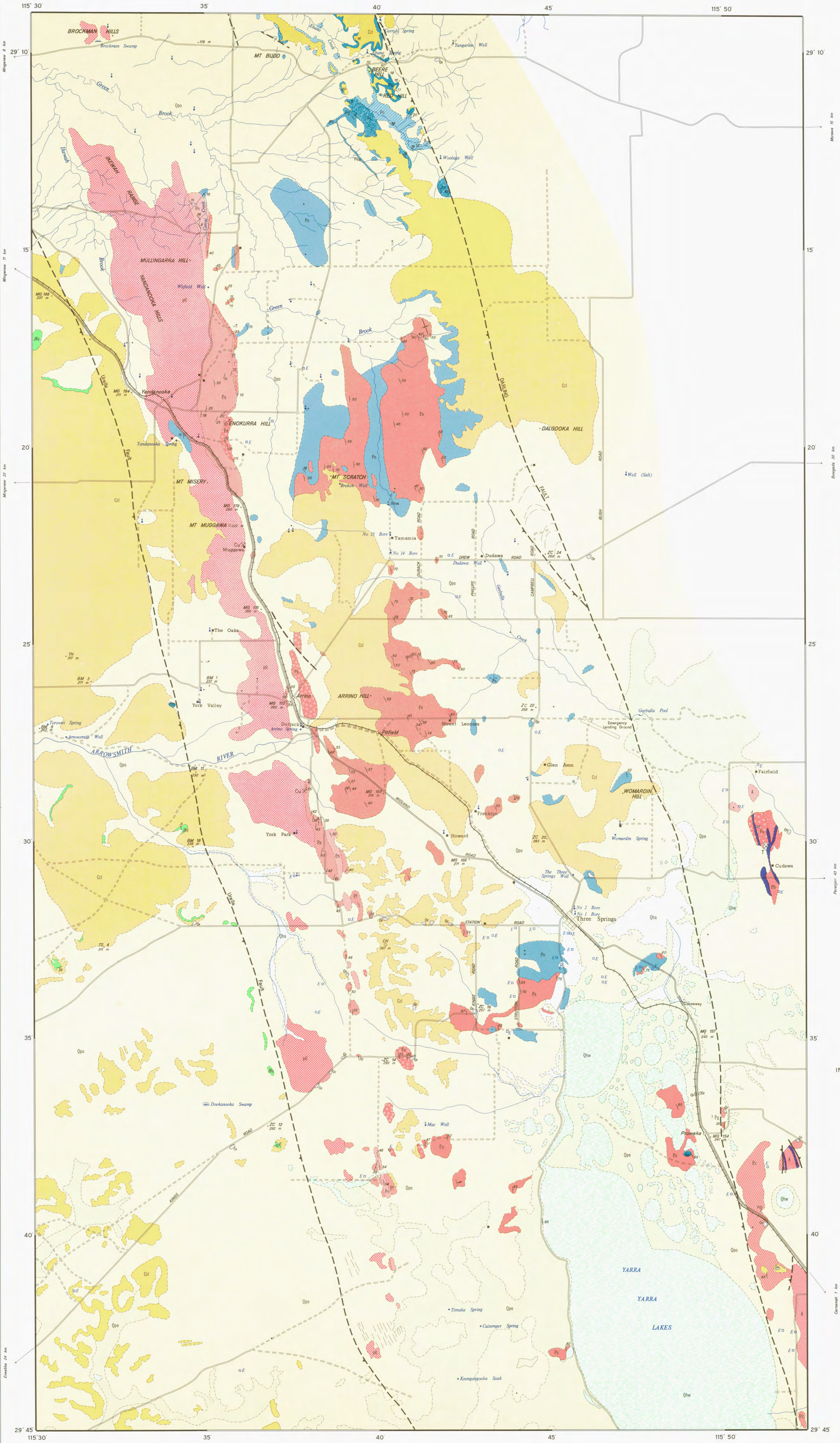
Compiled and published by Geological Survey of Western Australia. Cartography by Geological Drafting Section, Department of Mines. Topographic base from compilations by Lands and Surveys Department. Printed by Government Printing Office, Perth, 1977

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PERTH BASIN SOLID GEOLOGY


AGE
VASSE SHELF
BUNBURY TROUGH
HARVEY RIDGE
DANDARAGAN TROUGH
VLAMING SUB-BASIN
BEAGLE RIDGE
ABROLHOS SUB -BASIN
NORTHAMPTON BLOCK AREA
IRWIN SUB-BASIN
CAINOZOIC
TERTIARY
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
MESOZOIC
CRETACEOUS
LATE
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
EARLY
ALBIAN
APTIAN
NEOCOMIAN
JURASSIC
LATE
TITHONIAN
KIMERIDGIAN
OXFORDIAN
CALLOVIAN
MIDDLE
BATHONIAN
BAJOCIAN
EARLY
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
TRIASSIC
LATE
RHAETIAN
NORIAN
CARNIAN
MID
LADINIAN
ANISIAN
EARLY
SCYTHIAN
PALAEOZOIC
PERMIAN
LATE
TATARIAN
KAZANIAN
EARLY
KUNGURIAN
ARTINSKIAN
SAKMARIAN
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
KWINANA GROUP AND EQUIVALENT UNITS
ASCOT BEDS
UNNAMED UNIT
STARK BAY FM.
UNNAMED UNIT
UNNAMED UNIT
KINGS PARK FORMATION
KINGS PARK FORMATION
UNNAMED UNIT
POISON HILL GREENSAND
UNNAMED UNIT
GINGIN CHALK
COOLYENA GROUP
MOLECAP GREENSAND
UNNAMED UNIT
OSBORNE FORMATION
WARNBRO GROUP
WARNBRO GROUP
BUNBURY BASALT
WARNBRO GROUP
DANDARAGAN SS.
LEEDERVILLE FM.
SOUTH PERTH SHALE
LEEDERVILLE FM.
SOUTH PERTH SHALE
UNNAMED UNIT
YARRAGADEE FORMATION
YARRAGADEE FORMATION
YARRAGADEE FORMATION
YARRAGADEE FORMATION
YARRAGADEE FORMATION
CADDA FORMATION
CADDA FORMATION
KOJARENA SS.
NEWMARRACARRA LIMESTONE
BRINGO SHALE
COLALURA SS.
CHAMPION BAY GROUP
CHAMPION BAY GROUP
COCKLESHELL GULLY FORMATION
CATTAMARRA COAL MEASURES MEMBER
ENEABBA MEMBER
COCKLESHELL GULLY FORMATION
CATTAMARRA COAL MEASURES MEMBER
ENEABBA MEMBER
COCKLESHELL GULLY FM.
COCKLESHELL GULLY FORMATION
MOONYOONOOKA SS.
GREENOUGH SS.
CHAPMAN GROUP
COCKLESHELL GULLY FORMATION
COCKLESHELL GULLY FORMATION
LESUEUR SANDSTONE
LESUEUR SANDSTONE
LESUEUR SANDSTONE
LESUEUR SANDSTONE
WOODADA FORMATION
WOODADA FORMATION
KOCKATEA SHALE
DONGARA SS. MBR
KOCKATEA SHALE
KOCKATEA SHALE
SABINA SANDSTONE
SABINA SANDSTONE
WAGINA SS.
WAGINA SS.
SUE COAL MEASURES
SUE COAL MEASURES
CARYNGINIA FM.
IRWIN RIVER COAL MEASURES
HIGH CLIFF SS.
HOLMWOOD SHALE
NANGETTY FORMATION
CARYNGINIA FM.
IRWIN RIVER COAL MEASURES
HIGH CLIFF SS.
HOLMWOOD SHALE
CARYNGINIA FM.
IRWIN RIVER COAL MEASURES
HIGH CLIFF SS.
HOLMWOOD SHALE
NANGETTY FORMATION
? SUBSURFACE
TUMBLAGOODA SANDSTONE
TUMBLAGOODA SANDSTONE
TUMBLAGOODA SANDSTONE



REFERENCE

CAINOZOIC	QUATERNARY — HOLOCENE	Qhw	Swamp and lacustrine deposits—sand and clay
		Qha	Alluvium—sand, silt, clay
	QUATERNARY — PLEISTOCENE AND HOLOCENE	Qpe	Eolian sand—quartz sand
		Qpc	Colluvium—quartz sand and soil
	TERTIARY	Czl	Laterite and associated sand. In places underlain by the ? Tertiary Victoria Plateau Sandstone (not differentiated in mapping)
MESOZOIC	MID. JURASSIC TO LOWER CRETACEOUS	JKy	YARRAGADEE FORMATION: sandstone, siltstone, shale and conglomerate
PALAEOZOIC	PERMIAN — UPPER	Pw	WAGINA SANDSTONE: clayey sandstone with minor conglomerate, shale and siltstone
	PERMIAN — LOWER — ARTINSKIAN	Pm	MINGENEW FORMATION: sandstone, siltstone
		Pc	CARYNGINIA FORMATION: siltstone with interbedded sandstone and minor conglomerate
		Pi	IRWIN RIVER COAL MEASURES: sandstone, conglomerate, siltstone, claystone and minor coal
		Pg	HIGH CLIFF SANDSTONE: sandstone with minor siltstone and conglomerate
	PERMIAN — LOWER — SAKMARIAN	Ph	HOLMWOOD SHALE: shale, siltstone and minor limestone
		Phw	Woolaga Limestone Member: fossiliferous limestone
		Pn	NANGETTY FORMATION: tillite, shale, sandstone and conglomerate
PRECAMBRIAN	UPPER OR MIDDLE PROTEROZOIC — YANDANOOKA GROUP		MOUNT SCRATCH SILTSTONE: siltstone with minor sandstone and conglomerate
			ENOKURRA SANDSTONE: sandstone often conglomeratic and minor conglomerate
			BEACONSFIELD CONGLOMERATE: sandy and silty volcanic—pebble conglomerate
			ARRINO SILTSTONE: siltstone with minor sandstone
			ARROWSMITH SANDSTONE: sandstone with minor conglomerate towards base
			Dolerite dykes and ? sills
	UPPER OR MIDDLE PROTEROZOIC — MOORA GROUP		NOINGARA SILTSTONE: siltstone, with minor arkose, sandstone and chert
			COOMBERDALE CHERT: chert, orthoquartzite, with minor siltstone, sandstone and claystone
			DUDAWA BEDS: chert and orthoquartzite
			BILLERANGA GROUP (undifferentiated): sandstone, arkose, conglomerate, orthoquartzite, chert and shale
	PRECAMBRIAN UNDETERMINED		MULLINGARRA GNEISS: granitic gneiss with basic intrusives and metasediments
ARCHAEAN		A	Granitic complex—undifferentiated

SYMBOLS

Geological boundary
- Accurate
- Approximate

Fault
- Accurate
- Inferred
- Concealed
- Normal, downthrow indicated

Syncline

Bedding
- Strike and dip measured
- Trend line from air photos
- Air photo interpretation
- Dip > 45°

Highway
Formed road
Track
Railway
Horizontal control, major, minor
Benchmark, height accurate
Watercourse
Pool
Spring
Bore
Well, with windmill
Dam, earth
Homestead
Building
Gravel Pit
Mineral occurrence
- Copper
- Talc

INDEX TO ADJOINING 1:250 000 SHEETS

GERALDTON SH 50-1	YALGOO SH 50-2
DONGARA SH 50-5	PERENJORI SH 50-6 (Area Mapped)
HILL RIVER SH 50-9	MOORA SH 50-10

LOCALITY MAP

WESTERN AUSTRALIA
Perth

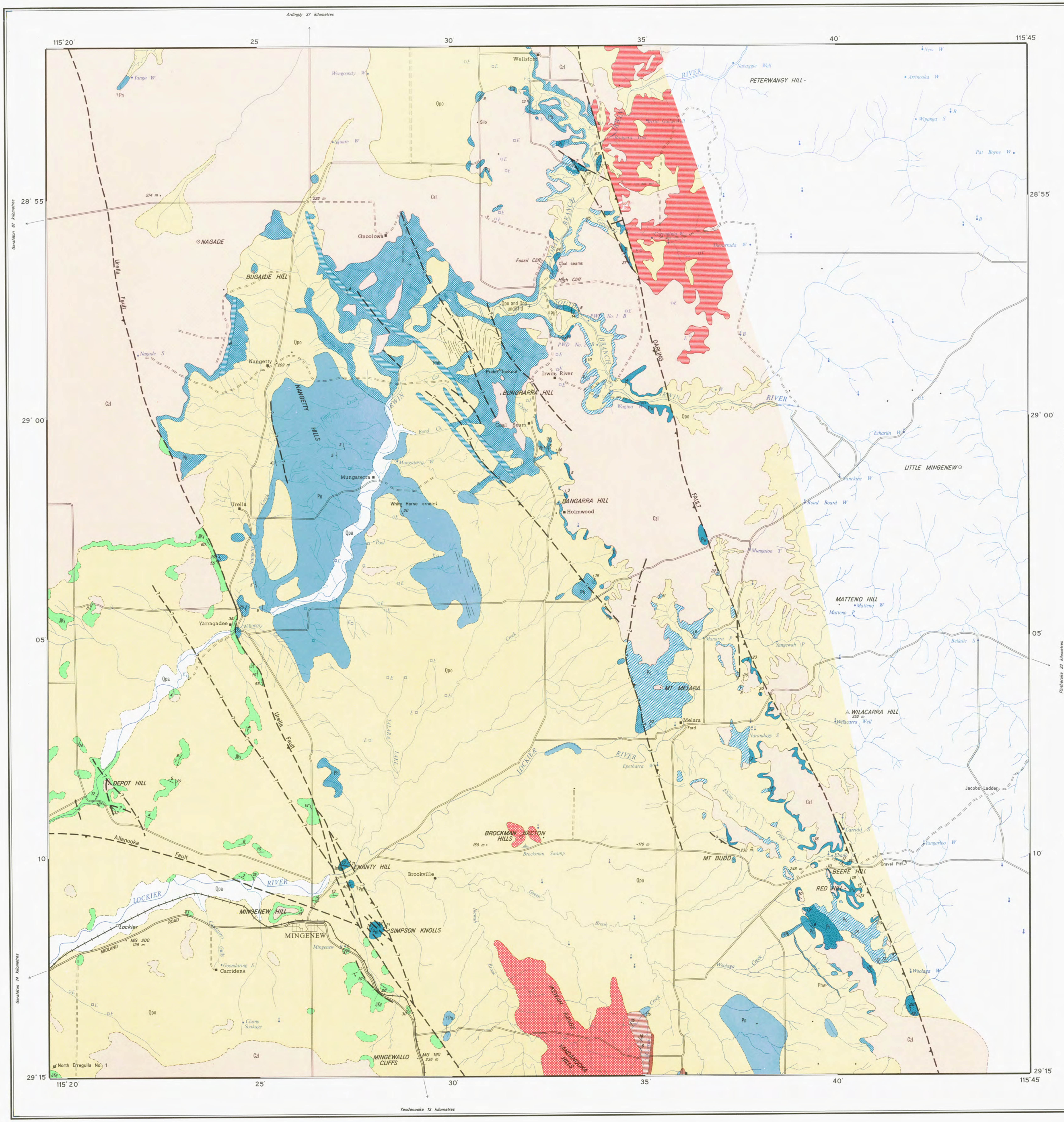
HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1:100 000

2 0 2 4 6 8 10
KILOMETRES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE YANDANOOKA AREA



REFERENCE

CAINOZOIC	PLEISTOCENE AND HOLOCENE	Qpo	Colluvium—quartz sand and soil
	PLEISTOCENE	Qpa	Alluvium—sand, silt, clay
	TERTIARY	Czl	Laterite and associated sand; in places underlain by Victoria Plateau Sandstone (? Early Tertiary)
MESOZOIC	JURASSIC — MID. JURASSIC TO LOW. CRETACEOUS	JKy	**YARRAGADEE FORMATION:** sandstone, siltstone, shale and conglomerate
	JURASSIC — MIDDLE	Jmd	**CADDA FORMATION:** sandstone, siltstone, shelly limestone
PALAEOZOIC	PERMIAN — UPPER	Pw	**WAGINA SANDSTONE:** sandstone with minor conglomerate, shale and siltstone
	PERMIAN — LOWER — ARTINSKIAN	Pm	**MINGENEW FORMATION:** sandstone, siltstone
		Pc	**CARYNGINA FORMATION:** siltstone with interbedded sandstone and minor conglomerate
		Pi	**IRWIN RIVER COAL MEASURES:** sandstone, conglomerate, carbonaceous shale, siltstone and minor coal
		Pg	**HIGH CLIFF SANDSTONE:** sandstone with minor siltstone and conglomerate
	PERMIAN — LOWER — SAKMARIAN	Ph	**HOLMWOOD SHALE:** shale, siltstone and minor limestone
		Phf	**Fossil Cliff Member:** shale, siltstone and fossiliferous limestone
		Phw	**Woolaga Limestone Member:** fossiliferous limestone
		Phb	**Beckett Member:** shale and limestone
		Pn	**NANGETTY FORMATION:** tillite, shale, sandstone and conglomerate
PRECAMBRIAN	MIDDLE TO UPPER PROTEROZOIC — YANDANOOKA GROUP	Ps	**MOUNT SCRATCH SILTSTONE:** siltstone with minor sandstone and conglomerate
		Pe	**ENOKURRA SANDSTONE:** sandstone and conglomerate
		Pn	**ARRINO SILTSTONE:** siltstone with minor sandstone
	PRECAMBRIAN UNDETERMINED	pC	**MULLINGARRA GNEISS:** granitic gneiss with basic intrusives and metasediments
	ARCHAEAN	A	Granitic complex-undifferentiated, commonly covered by thin Qpo

SYMBOLS

Geological boundary
- Accurate
- Approximate

Fault
- Accurate
- Inferred
- Concealed
- Normal, downthrow indicated with dip

Bedding
- Strike and dip measured

Trend line from air photos

Air photo interpretation
- Dip 15°

Petroleum exploration well
- Show of oil, abandoned

Formed road

Track

Horizontal control, major, minor

Bench mark, height accurate — MG 200 128 m

Watercourse

Pool — P

Spring — S

Bore — B

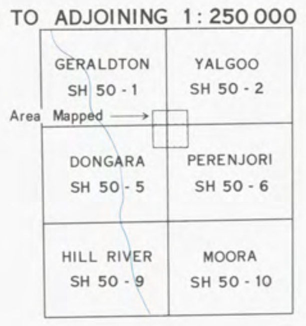
Well, with windmill

Dam, earth — E

Homestead — Halls Creek

Building

INDEX TO ADJOINING 1:250 000 SHEETS



LOCALITY MAP

HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

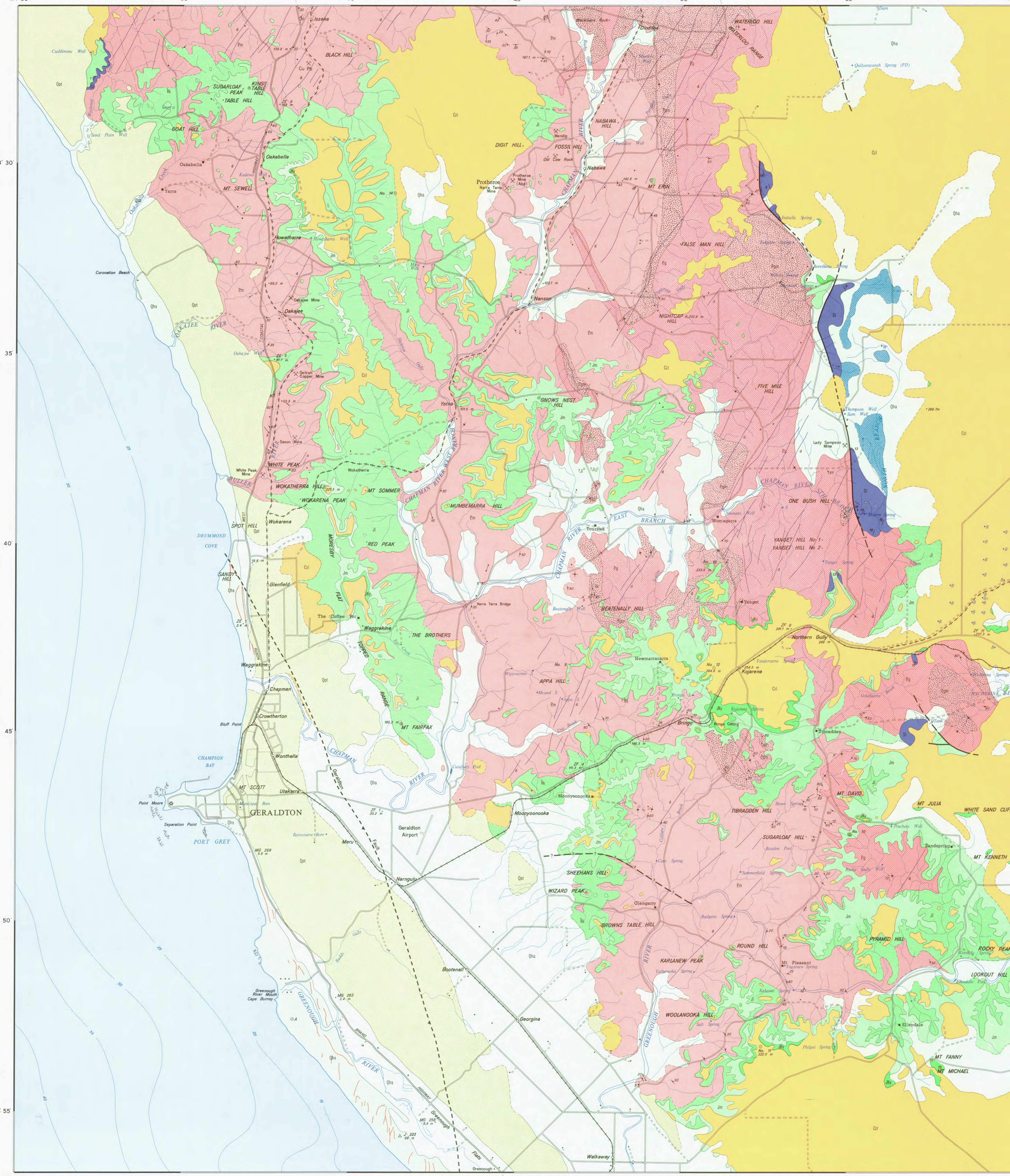
SCALE 1:100 000

2 0 2 4 6 8 10

KILOMETRES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE IRWIN RIVER AREA



REFERENCE

CAINOZOIC

QUATERNARY — HOLOCENE

- **Qha** — Alluvium, colluvium and miscellaneous soils undifferentiated—quartz sand, clay, loam
- **Qhs** — **SAFETY BAY SAND:** white calcareous and quartzose dune and beach sands

QUATERNARY — PLEISTOCENE

- **Qpt** — **TAMALA LIMESTONE** and overlying podsolised sand—eolianite and leached quartz sands

LATE CAINOZOIC

- **Czl** — Laterite with overlying quartz sand and underlying highly weathered rock

MESOZOIC

JURASSIC — MIDDLE TO UPPER JURASSIC

- **JKy** — **YARRAGADEE FORMATION:** variegated sandstone, siltstone, shale and conglomerate

JURASSIC — MIDDLE

- **Jm** — **CHAMPION BAY GROUP:** Kojarena Sandstone (ferruginous sandstone); Newmarracarra Limestone (richly fossiliferous limestone); Bringo Shale (dark grey to black shale); and Colalura Sandstone (ferruginous and phosphatic sandstone, rich in fossil wood)

JURASSIC — LOWER

- **Jl** — **CHAPMAN GROUP:** Moonyoonooka Sandstone (yellow feldspathic sandstone and arkose) and Greenough Sandstone (variegated clayey sandstone). Equals **COCKLESHELL GULLY FORMATION** in subsurface

TRIASSIC — LOWER

- **Rk** — **KOCKATEA SHALE:** yellow and white shale and siltstone with purple ferruginous bands

PALAEOZOIC

PERMIAN — LOWER

- **Ph** — **HOLMWOOD SHALE:** grey-green shale and siltstone with thin beds of limestone

SILURIAN

- **St** — **TUMBLAGOODA SANDSTONE:** red and yellow feldspathic sandstone and conglomerate

LOWER PALAEOZOIC OR UPPER PROTEROZOIC

- **d** — Dolerite dykes

PRECAMBRIAN

MIDDLE PROTEROZOIC

- **Pg** — Porphyritic granite
- **Pgm** — Migmatite—association of Pg and Pm
- **Pm** — Granulite—predominantly metasedimentary origin

SYMBOLS

Geological boundary
- Accurate
- Approximate

Fault
- Accurate
- Inferred
- Concealed
- Normal, downthrow indicated

Bedding
- Strike and dip measured — 15

Foliation
- Inclined — 40
- Horizontal
- Vertical

Folding
- Horizontal plunge
- Plunge of fold axis — 35

Trend line from air photos
Highway
Formed road
Track

Railway
- 3' 6"
- Abandoned

Railway and siding
Homestead — Ellendale
Building
Horizontal control, major, minor
Benchmark, height accurate — ZF 14 • 213 m
Reef
Sand dune
Watercourse
Bathymetric contour line, depth in metres — 5
Pool — P
Spring — S
Bore — B
Well and windmill — W
Mining centre
Gravel pit — Gr
Cutting

INDEX TO ADJOINING 1:250 000 SHEETS

GERALDTON SH 50 - 1	YALGOO SH 50 - 2
DONGARA SH 50 - 5	PERENJORI SH 50 - 6
HILL RIVER SH 50 - 9	MOORA SH 50 - 10

Area Mapped →

LOCALITY MAP

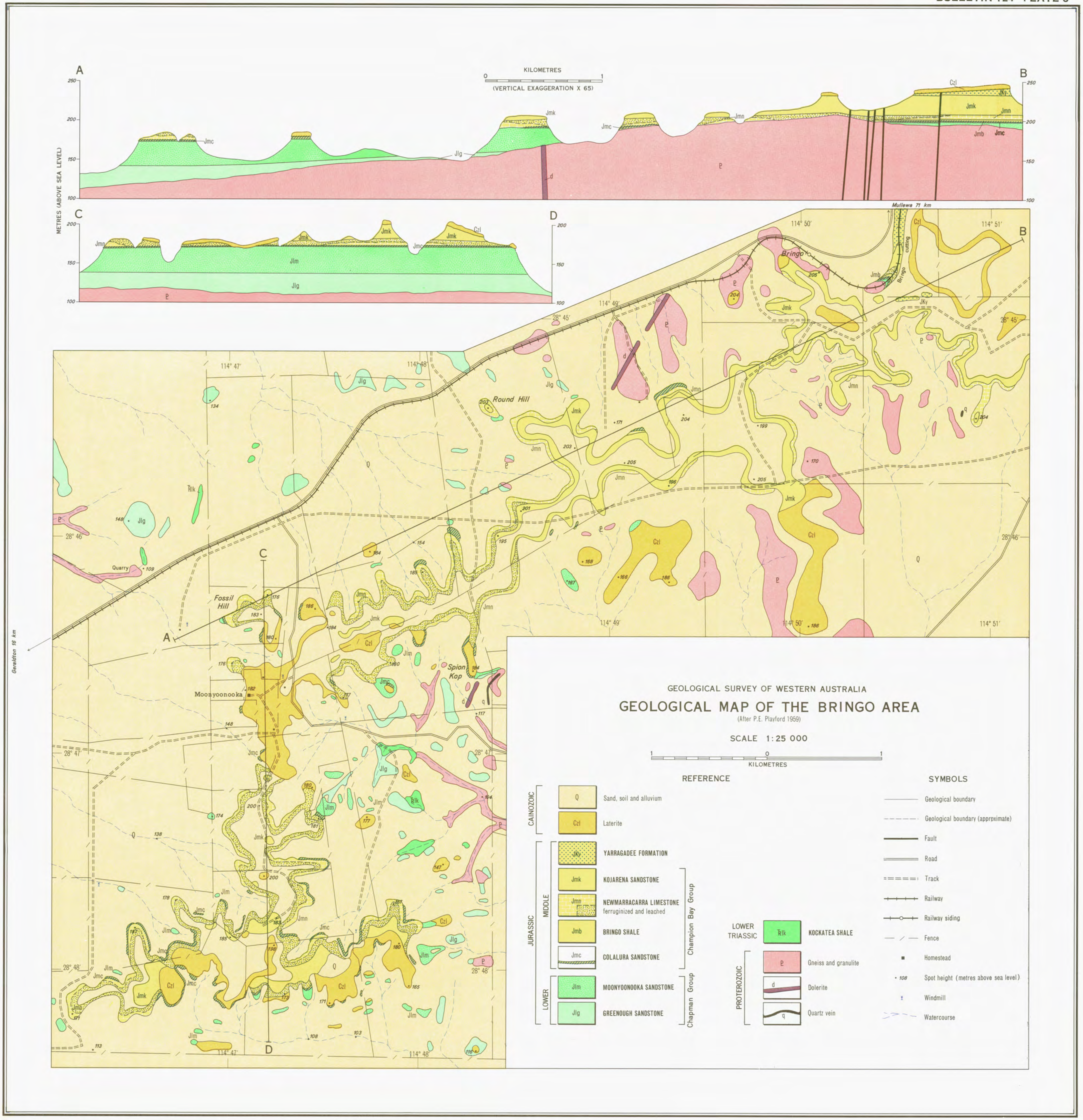
HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

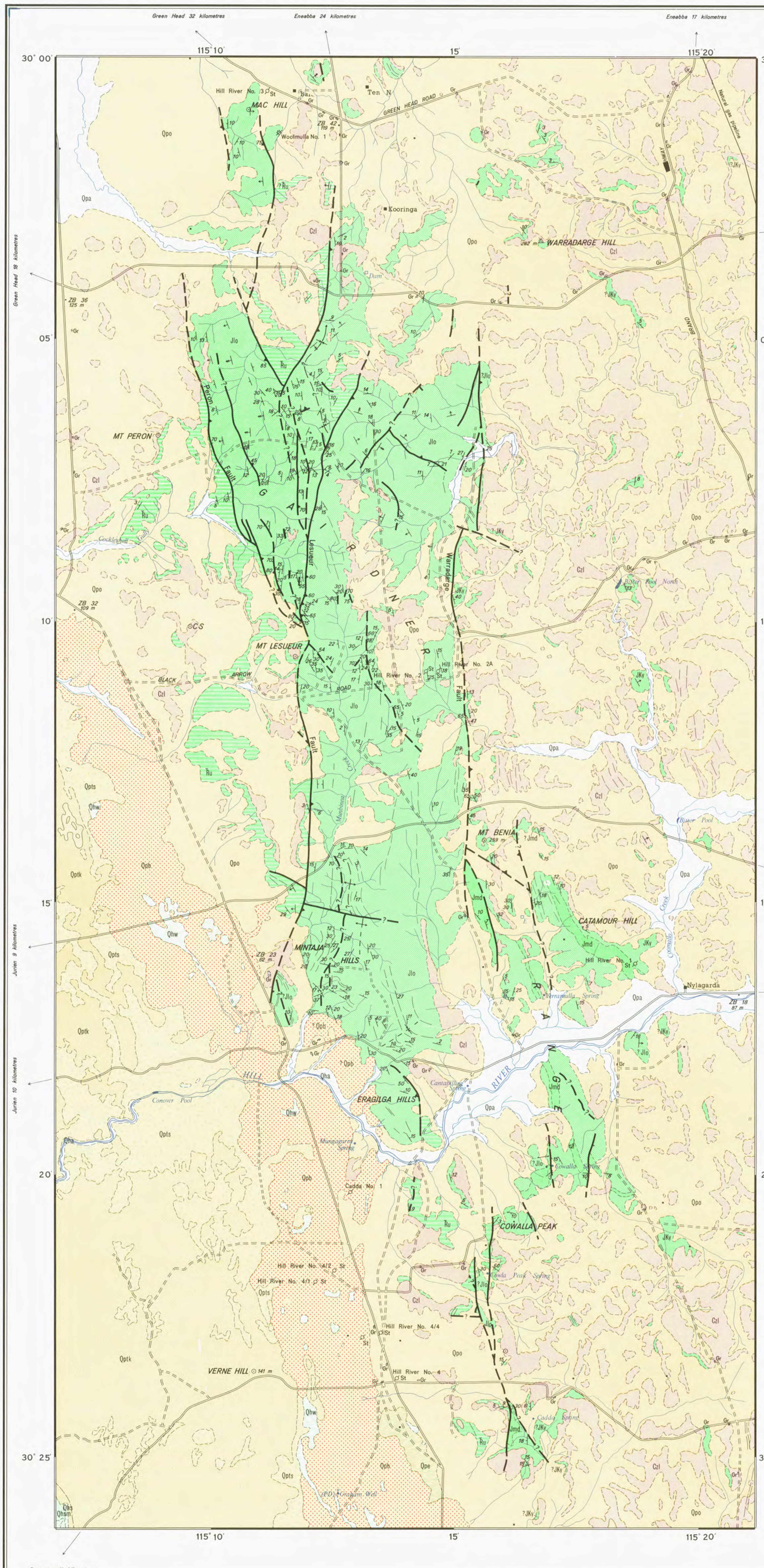
SCALE 1:100 000

2 0 2 4 6 8 10
KILOMETRES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE GERALDTON AREA


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP OF THE BRINGO AREA
(After P.E. Playford 1959)
SCALE 1:25 000
KILOMETRES
REFERENCE
CAINOZOIC
Q Sand, soil and alluvium
Czl Laterite
JURASSIC
MIDDLE
Jky YARRAGADEE FORMATION
Jmk KOJARENA SANDSTONE
Jmn NEWMARRACARRA LIMESTONE ferruginized and leached
Jmb BRINGO SHALE
Jmc COLALURA SANDSTONE
Champion Bay Group
LOWER
Jlm MOONYOONOOKA SANDSTONE
Jlg GREENOUGH SANDSTONE
Chapman Group
LOWER TRIASSIC
Ŧlk KOCKATEA SHALE
PROTEROZOIC
Gneiss and granulite
d Dolerite
q Quartz vein
SYMBOLS
Geological boundary
Geological boundary (approximate)
Fault
Road
Track
Railway
Railway siding
Fence
Homestead
· 108 Spot height (metres above sea level)
Windmill
Watercourse
KILOMETRES
(VERTICAL EXAGGERATION X 65)
METRES (ABOVE SEA LEVEL)
A
B
C
D
Bringo
Round Hill
Fossil Hill
Spion Kop
Moonyoonooka
Quarry
Bringo cutting
Mullewa 71 km
Geraldton 16 km
114° 47'
114° 48'
114° 49'
114° 50'
114° 51'
28° 45'
28° 46'
28° 47'
28° 48'



REFERENCE

CAINOZOIC

QUATERNARY

HOLOCENE

- Qhw — Swamp and lacustrine deposits—sand, clay, diatomite
- Qha — Alluvium—sand, silt, clay
- Qhs — **SAFETY BAY SAND:** calcareous eolian and beach sand, in places weakly lithified
- Qhsm — Safety Bay Sand forming mobile dunes

PLEISTOCENE AND HOLOCENE

- Qpo — Colluvium—quartz sand
- Qpe — Eolian sand—quartz sand derived from ephemeral lakes and swamps

PLEISTOCENE

- Qpa — Alluvium—sand, silt, clay
- Qptk — **TAMALA LIMESTONE:** eolian limestone and kankar
- Qpts — Tamala Limestone covered by residual quartz sand
- Qpb — **BASSENDEAN SAND:** quartz sand forming ancient coastal dunes

UPPER CAINOZOIC

- Czl — Laterite

MESOZOIC

MID. JURASSIC TO LOW. CRET.

- JKy — **YARRAGADEE FORMATION:** sandstone, siltstone, shale

JURASSIC — MIDDLE

- Jmd — **CADDA FORMATION:** sandstone, siltstone, shelly limestone

JURASSIC — LOWER

- Jlo — **COCKLESHELL GULLY FORMATION:** sandstone, siltstone, shale

TRIASSIC — UPPER

- Ru — **LESUEUR SANDSTONE:** medium to coarse—grained sandstone

SYMBOLS

- Geological boundary
  - Accurate
  - Approximate
- Fault
  - Accurate
  - Inferred
  - Concealed
  - Normal, downthrow indicated, with dip
- Anticline
  - Inferred
- Syncline
  - Accurate, showing plunge
  - Inferred
- Bedding
  - Strike and dip measured
- Trend line from air photos
- Air photo interpretation
  - Dip < 15°
  - Dip 15°-45°
- Petroleum exploration wells
  - Dry hole, abandoned
  - Show of gas, abandoned
  - Stratigraphic well (St)
- Formed road
- Track
- Horizontal control, major, minor
- Benchmark, height accurate (ZB 32 109 m)
- Watercourse
- Pool
- Spring
- Building
- Homestead (Barara)
- Gravel pit (Gr)

INDEX TO ADJOINING 1: 250 000 SHEETS

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HILL RIVER SH 50 - 9	MOORA SH 50 - 10

Area Mapped

LOCALITY MAP

HON. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1: 100 000

2 0 2 4 6 8 10

KILOMETRES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE HILL RIVER AREA

SYMBOLS
Petroleum exploration wells
Oil well
Gas well
Oil and gas well
Gas and condensate well
Abandoned well, dry
Abandoned well, show of oil
Abandoned well, show of gas
Abandoned well, show of oil and gas
Abandoned gas well
Abandoned gas and condensate well
Bouguer anomaly contour (milligals)
-50
High anomaly
Low anomaly
Highway
Railway
(3′ 6″)
(4′8½″)
Townsite
Population 10000 and over
1000 to 10000
under 1000
Locality
Homestead
BUNBURY
MANDURAH
Augusta
Yuin
Balline
Bathymetric contours (in metres)
200m
Watercourse
Perennial
Intermittent
Compiled from surveys conducted by the Bureau of Mineral Resources, West Australian Petroleum Pty. Ltd. and BP Petroleum Development Australia Pty. Ltd.
PERTH BASIN BOUGUER GRAVITY ANOMALIES
Contour interval 5 milligals
SCALE 1:1 000 000
20 0 20 40 60 80 100 120 KILOMETRES
TRANSVERSE MERCATOR PROJECTION
112° 30′
113° 00′
113° 30′
114° 00′
114° 30′
115° 00′
115° 30′
116° 00′
116° 30′
26° 00′
26° 30′
27° 00′
27° 30′
28° 00′
28° 30′
29° 00′
29° 30′
30° 00′
30° 30′
31° 00′
31° 30′
32° 00′
32° 30′
33° 00′
33° 30′
34° 00′
34° 30′
35° 00′
35° 30′
INDIAN
OCEAN
HAMELIN POOL
FREYCINET ESTUARY
PERON PENINSULA
WALLABI GROUP
NORTH ISLAND
EASTER GROUP
PELSART GROUP
GERALDTON
Kalbarri
Northampton
Mullewa
Dongara
Carnamah
Moora
Gingin
PERTH
FREMANTLE
ARMADALE
ROCKINGHAM
MANDURAH
PINJARRA
WAROONA
HARVEY
BUNBURY
COLLIE
BUSSELTON
Donnybrook
BRIDGETOWN
MANJIMUP
Augusta
Pemberton
Northcliffe
DARLING RANGE


PERTH BASIN TOTAL MAGNETIC INTENSITY
Compiled from surveys conducted by the Bureau of Mineral Resources, West Australian Petroleum Pty. Ltd. and BP Petroleum Development Australia Pty. Ltd.
SCALE 1:1 000 000
KILOMETRES
TRANSVERSE MERCATOR PROJECTION
SYMBOLS
Petroleum exploration wells
Oil well
Gas well
Oil and gas well
Gas and condensate well
Abandoned well, dry
Abandoned well, show of oil
Abandoned well, show of gas
Abandoned well, show of oil and gas
Abandoned gas well
Abandoned gas and condensate well
Magnetic intensity contours (gammas)
Highway
Railway
Townsite
BUNBURY
MANDURAH
Augusta
Locality
Homestead
Bathymetric contours (in metres)
Watercourse
Perennial
Intermittent
INDIAN
OCEAN
GERALDTON
PERTH
FREMANTLE
BUNBURY
MANDURAH
HARVEY
WAROONA
PINJARRA
ARMADALE
BUSSELTON
BRIDGETOWN
MANJIMUP
MOORA
Augusta
Dongara
Northampton
Kalbarri
Hamelin
Denham
HAMELIN POOL
FREYCINET ESTUARY
PERON PENINSULA
WALLABI GROUP
EASTER GROUP
PELSART GROUP
HOUTMAN ABROLHOS
GEOGRAPHE BAY
DARLING RANGE
112° 30'
113° 00'
113° 30'
114° 00'
114° 30'
115° 00'
115° 30'
116° 00'
116° 30'
26° 00'
26° 30'
27° 00'
27° 30'
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31° 00'
31° 30'
32° 00'
32° 30'
33° 00'
33° 30'
34° 00'
34° 30'
35° 00'
35° 30'