DEPARTMENT OF
NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1978/66

A REVIEW OF PETROLEUM EXPLORATION
AND PROSPECTS IN THE PERTH BASIN

by

C.S. Robertson, E. Nicholas and D.G. Townsend

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SUMMARY

Petroleum exploration carried out in the Perth Basin up to August 1975 has been reviewed to provide a current assessment of knowledge of the basin and to determine the need for future exploration.

The Perth Basin is in the form of a half-graben which developed as a result of movement along the major Darling-Urella fault system which forms the eastern boundary of the basin. It contains very large thicknesses of post-Cambrian sediments known to include source, reservoir and cap rocks suitable for petroleum accumulation. The tectonic forces which have moulded the basin have been predominantly tensional and faulting is prevalent throughout the basin.

A considerable amount of petroleum exploration has been done both onshore and offshore and some commercially exploited gas fields have been discovered onshore in the northern part of the basin. The prospectivity of the basin varies from area to area, but overall it is regarded as fair. There is considerable scope for future exploration, particularly offshore where the number of wells drilled is small considering the large area involved.

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1. INTRODUCTION

This Record is a summary of petroleum exploration and prospects in the Perth Basin, which is located both onshore and offshore along the southwest coast of Australia extending from the south coast northwards for over 900 km. It covers an area of 62 000 km^2 onshore, and an area of 52 000 km^2 on the continental shelf (to the 200 m bathymetric contour).

The summary is based on published and non-confidential unpublished information available up to August 1975. Much of the unpublished information is derived from the final reports on petroleum exploration company operations subsidised by the Australian Government under the Petroleum Search Subsidy Act 1959-73. Under the terms of that Act the final reports on individual geophysical or drilling operations are available to the public. Basic data from operations in some areas relinquished by exploration companies have been released to the public by the Department of Mines of Western Australia.

2. GEOLOGY

General

Geological work has been carried out in the Perth Basin area since the latter part of the nineteenth century.

A general description of the geology of the basin was published in Teichert (1947), and the first detailed review of the stratigraphy was published in McWhae et al. (1958). A Bulletin on the geology of the Perth Basin by the West Australian Geological Survey is in press (Playford et al.) and the basin is reviewed in a recent monograph published by the Australasian Institute of Mining and Metallurgy (Jones, 1976). A memoir on the geology of Western Australia has recently been published (Geological Survey of Western Australia, 1975). A review of the geological history of the basin is included in Johnstone et al. (1973). A bibliography of the Perth Basin has been published by BMR (Raine & Smith, 1972).

BMR initiated geophysical exploration in the basin with gravity surveys carried out between 1949 and 1951 (Chapter 3), and drilled the first deep well, (Beagle Ridge) BMR No. 10 in 1959.

Since 1960, petroleum exploration activity by West Australian Petroleum Pty Ltd and its farmout partners has made a major contribution to the understanding of the geology of the basin. To date (August 1975) 96 petroleum exploration wells including 10 offshore have been drilled. Forty-two of these wells were subsidised by the Australian Government under the terms of the Petroleum Search Subsidy Act 1959-73.

Geological mapping at 1:250 000 scale has been carried out by the Geological Survey of Western Australia. A first-edition map of the Augusta-Busselton Sheet area has been published (Lowry, 1967) and preliminary editions of five Sheet areas which lie wholly or partly within the basin (Lowry, 1972 a, b, c, d, e) have also been issued. The geology of the Perth Basin is shown at 1:2 500 000 scale on the geological map of Western Australia published by the Geological Survey of Western Australia in 1974.

The drilling operations are listed in Appendix 1, and a map showing simplified geology and the location of petroleum exploration wells and BMR stratigraphic holes is presented in Plate 1. The bibliography contains a selection of the more important references, and is not intended to be comprehensive.

Structural setting

The Perth Basin (Fig. 1) is a long narrow trough bounded on the east by the major Darling-Urella fault system along which basin sediments are downthrown against Archean metamorphic rocks and Proterozoic sediments of the Yilgarn Block. The northern boundary with the Carnarvon Basin is formed onshore by the Hardabut Fault, the Precambrian Northampton Block, and the Ajana Ridge, which is regarded as a subsurface extension of the Northampton Block. Offshore, the northern boundary is taken as a geophysically defined basement ridge (Spence, 1962; BP, 1971; Continental Oil of Australia, 1973), which Continental described as a 'westward plunging nose coming off the Northampton Block, and named the 'Easter Ridge'. The western and southern boundaries of the basin lie offshore and have not been defined.

Structural subdivisions

The major structural subdivisions recognised in the Perth Basin are shown in Figure 1. The following descriptions are based on the work of Jones & Pearson (1972), Playford et al. (1975), and other workers as indicated.

Yilgarn Block: The Precambrian Yilgarn Block is the oldest part of the Western Australian Shield, and the major nucleus of the present Australian continent. It is predominantly composed of gneisses and granite which give an Rb/Sr age of 2667 ± 27 m, but infolded metasediments contain boulders dated at 3000 m.y. The younger figure is thought to represent the time of stabilisation of the radiogenic elements of the shield Compston & Arriens, 1968; Johnstone et al., 1973). Unmetamorphosed Proterozoic sediments occur on the western margin of the Yilgarn Block, unconformably overlying the Archaean, and Proterozoic high-grade metamorphic rocks (garnet granulites) underlie the Perth Basin and crop out on the Northampton Block in the north and the Leeuwin Block in the south. The granulites on the Northampton Block have been dated at 1040 ± 50 m.y. and those on the Leeuwin Block at 670 ± 25 m.y. (Compston & Arriens, 1968).

Darling Fault: The north-trending Darling Fault is a major crustal feature along the western margin of the Yilgarn Block; it has been active since at least the Proterozoic. It can be traced from north of the Murchison River to the southern Continental shelf - a distance of about 960 km, and the maximum throw is at least 10 500 m. Displacement of the Perth Basin sediments is believed to have been by normal faulting but the Darling Fault may have developed originally as a transcurrent fault, as there is evidence that Proterozoic rocks immediately east of the fault have been affected by compressive movements. North of the Murchison River little or no movement has occurred along the fault since the Early Permain. Farther south, although the fault was probably active during the Permian, the main period of activity was from the Middle Triassic to the Early Cretaceous.

Dandaragan Trough: The Dandaragan Trough contains more than 14 000 m of sediments, the thickest sedimentary section in the onshore Perth Basin. The trough was a major depocentre from Triassic to Lower Cretaceous time, the maximum deposition occurring in the Upper Jurassic and Neocomian. The sediments deposited during this time thin both eastwards and westwards away from the axis of the trough. Faulting increase in intensity eastwards towards the Darling Fault, and westwards towards the Beagle Ridge. Two cross-sections through the central part of the Dandaragan Trough are illustrated in Plate 7.

Beagle Ridge: The Beagle Ridge is a basement ridge which forms the western boundary of the Dandaragan Trough north of Perth. Basement has been intersected on the ridge at depths as shallow as 1006 m below sea level. The western flank lies offshore and is not well-defined. There is evidence of uplift since the Late Palaeozoic, but the greatest movement occurred during the Neocomian. Along the axis of the ridge, erosion has removed all but the Permian and lowermost Triassic part of the sedimentary section.

Harvey Ridge: The Harvey Ridge is a major basement ridge which separates the Dandaragan and Bunbury Troughs. From the Darling Fault, it strikes northwesterly to the coast, then north-northwesterly along the coast where it becomes indistinguishable in a zone of complex faulting.

Bunbury Trough: The Bunbury Trough was a major depocentre from Permian to Lower Cretaceous time (Plate 8). More than 9000 m of sediment occurs on its deep eastern side adjacent to the Darling Fault. The trough shallows to the south and near the southern continental margin contains about 3000 m of Permian and Triassic sediments resting on basement. The southward continuations offshore of the Dunsborough Fault and the Darling Fault have been mapped seismically. A fault block, the Vasse Shelf, lies between the Bunbury Trough and the Leeuwin Block adjacent to the Dunsborough Fault. West of the Leeuwin Block, basement dips gently beneath the Indian Ocean and is onlapped by a Tertiary and ?Cretaceous section.

Turtle Dove Ridge: The Turtle Dove Ridge is a northwest-trending basement ridge lying offshore to the west of the Beagle Ridge. Depth to basement along the crest of the ridge is believed to be as shallow as 1200 m below sea level. The ridge is strongly faulted on both flanks and merges to the south with the Beagle Ridge to form the Edwards Island Block which also appears, from magnetic evidence, to be an area of shallow basement. The greatest uplift on the Turtle Dove Ridge is thought to have occurred during the Neocomian.

Abrolhos Sub-basin: The Abrolhos Sub-basin contains up to 9000 m of Phanerozoic sediments of which 4000 m are Jurassic and younger. The sub-basin is thought to have developed contemporaneously with the Dandaragan Trough, but separated from it by the rising Beagle Ridge. It was well established by the Late Jurassic, and during the Tertiary it was linked with the Carnarvon Basin to the northwest of the Northampton Block. The basin is V-shaped, widening to the north-northwest and bounded by the Beagle Ridge on the east and the Turtle Dove Ridge on the west.

Vlaming Sub-basin: The Vlaming Sub-basin developed as a separate entity in the Late Jurassic and Early Cretaceous during the climax of tectonism in the Perth Basin. Maximum deposition was to the west of Rottnest Island, where more than 15 000 m of fluvial and estuarine sediments occur. An intra-Neocomian unconformity separates the strongly folded and faulted Late Jurassic to Early Cretaceous sequence from thick marine Cretaceous and Tertiary sediments which infilled the irregular erosion surface and have been subjected to relatively gentle deformation.

During the tectonism the Rottnest Trench, a north-trending graben 16 km wide, was formed in the northern part of the sub-basin by the collapse of a regional arch. The sea entered this fiord-like structure which opened southwards into a broad basin with an east-west axis which seems to have communicated with the open ocean across a silled region southwest of Warnbro No. 1.

To the south the sub-basin overlaps the north-tilted pre-Cretaceous rocks of the Bunbury Trough. In the southwest, aeromagnetic anomalies indicate that the Precambrian Leeuwin Block extends out to sea to the northwest along the line of the Dunsborough Fault. Geophysical data also suggest that a fault system extends southwest from the Edwards Island Precambrian Block (Fig. 1) to form the northwest margin of the sub-basin. It appears likely that these two structural elements merge to form the western boundary. The eastern boundary is associated with major faults located close to the present coastline (WAPET, 1974).

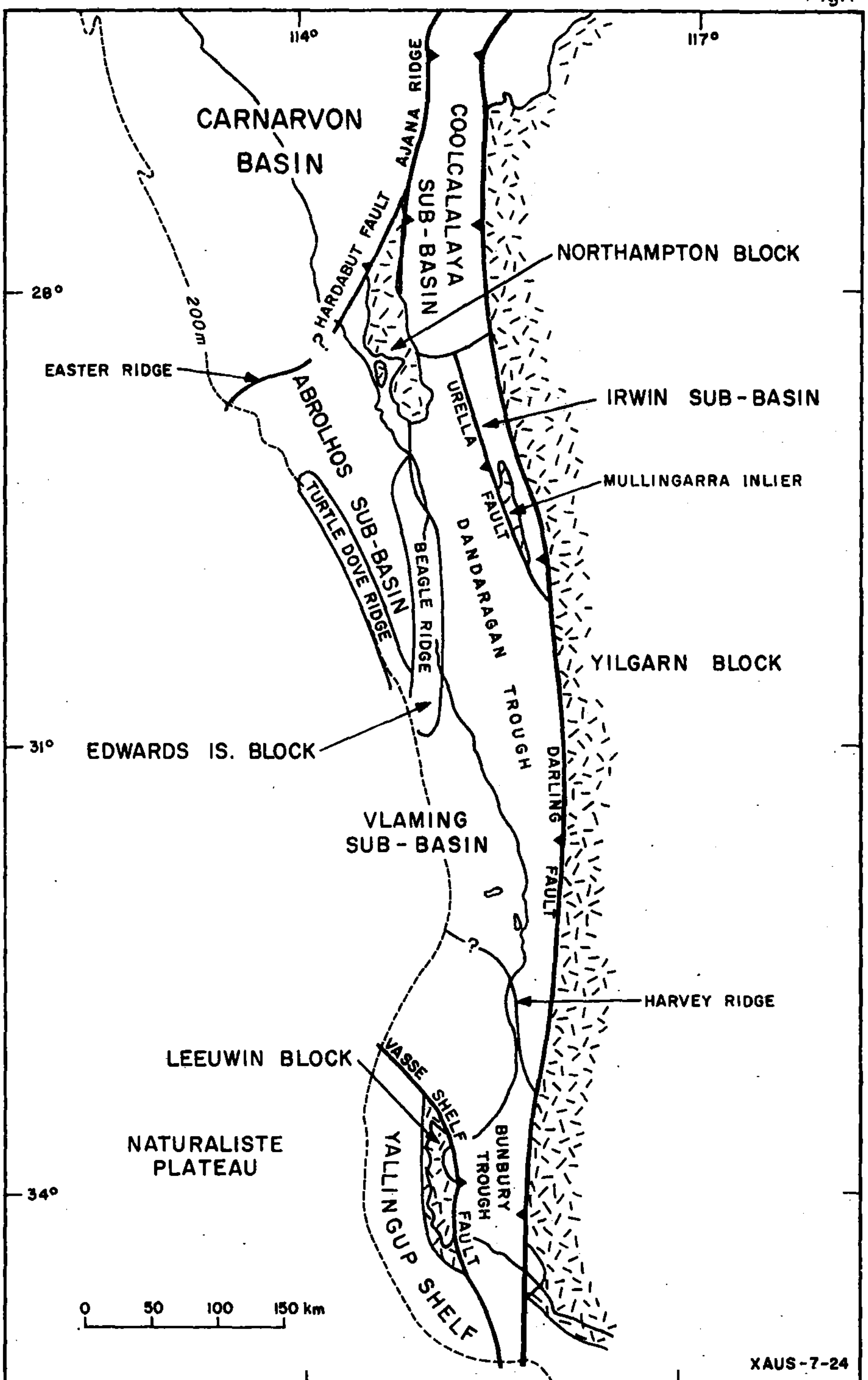
Yallingup Shelf: The Yallingup Shelf lies offshore from the Leeuwin Block, and contains a wedge of sediments that thickens gradually westwards to about 1000 m. There is no stratigraphic control in this area but extrapolation of seismic sections (WAPET, 1969c) indicates that the sequence comprises westerly-dipping Tertiary and possibly Cretaceous sediments overlying basement. The seismic work delineated a graben west of Cape Naturaliste, containing about 1500 m of sediment.

Coolcalalaya Sub-basin: The sub-basin, which contains Lower Palaeozoic and Permian sediments, is a northward extension of the Perth Basin (Condon, 1968). It is bounded on the east by the Darling Fault, and on the west and north by the Precambrian Northampton Block and the Ajana Ridge, on which basement crops out. Poor-quality seismic results in the southern part of the sub-basin indicate a sediment thickness of more than 4000 m to the west of the Darling Fault. The inclusion of the Coolcalalaya Sub-basin in the Perth Basin (Condon, 1968; GSWA, 1974) is supported by magnetic and gravity evidence (Chapter 3). However, Thomas & Smith (1974) of WAPET included it with the Byro Sub-basin as part of the Carnarvon Basin, but did not specify the nature of the southern boundary.

Irwin Sub-basin: The Irwin Sub-basin (Clark et al., 1951) lies between the Urella and Darling Faults, with the deepest part adjacent to the Darling Fault. It contains about 1500 m of Permian sediments overlying a very thick sequence of Proterozoic sediment - the Yandanooka Group.

Naturaliste Plateau: The Naturaliste Plateau, west of the southern Perth Basin, lies in relatively deep water beyond the 200 m bathymetric contour. It is at least partly separated from the Perth Basin by the Leeuwin Block and its extensions offshore to the northwest and south. Until there is better geological control on the sediments on the Naturaliste Plateau it is probably inappropriate to re-define the limits of the Perth Basin to

Fig. I



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Structural subdivisions Perth Basin
(after Playford et al., 1975)

include the Plateau within that basin. However, the geographic proximity of the Plateau to the much better known Perth Basin makes it appropriate to briefly consider here existing knowledge of the Naturaliste Plateau as an important structural element in the region.

The plateau (Figures 2 and 3) is a relatively flat feature covering an area of 120 000 km^2 in water depths from 2200 to 2500 m. BMR's geophysical survey of the continental margins included 13 profiles across the plateau totalling about 5000 km, and the Glomar Challenger Deep Sea Drilling Project Sites 258 and 264 were located near the northern and southern margins respectively. Details of the DSDP data are given in Luyendyk et al. (1973), and Hayes et al. (1973). Two metres of Upper Cretaceous (Turonian) sediments were obtained in an earlier coring operation (Burckle et al., 1967).

The combined results from the DSDP and the BMR continental margin survey have been studied by Branson (1974) and Petkovic (1975). The western half of the plateau is characterised by shallow seismic basement and intense magnetic anomalies, and the eastern by a thick sedimentary sequence and less intense magnetic anomalies. The thickest sedimentary sequence (at least 2 km) is present in a basin on the eastern side of the plateau, and about 1 km of sediment occurs in a smaller basin in the northeastern corner. The southern margin and parts of the western margin are characterised by steep scarp-like features suggestive of faulting in the basement. Seismic data indicate that the sediments elsewhere on the plateau are undisturbed.

Four unconformities, A, B,C, and D, are revealed on BMR seismic sections. The Tertiary/Cretaceous unconformity (A) was detected at sites 258 and 264 and also at Broken Ridge and Wharton Basin DSDP sites. Unconformity B can be identified over the whole plateau. It truncates unconformity C, restricting it to the eastern part of the plateau. Unconformity D separates sediment and acoustic basement and is mostly easily identified in areas of thin sediments in the west. The sequence above unconformity B constitutes about half of the total sedimentary sequence on the plateau and appears to be largely of Cretaceous age indicating that most of the sedimentation on the plateau preceded the separation of Australia from Antarctica in Eocene time.

Tectonic history

The relationship of the development of the Perth Basin to its tectonic history may be summarised as follows (Jones & Pearson, 1972; Johnstone et al., 1973).

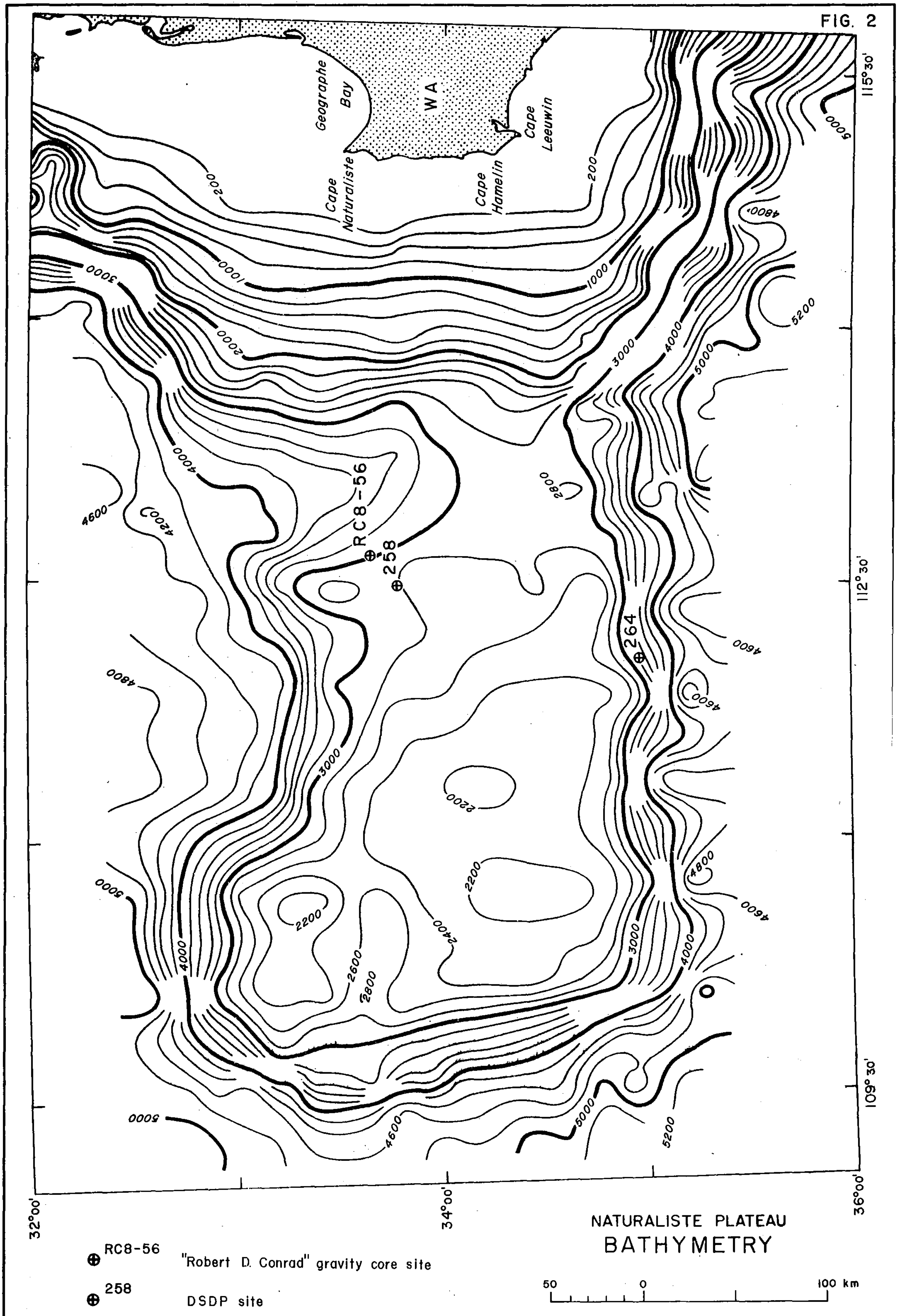
Ordovician?-Silurian Fluviatile sediments were deposited in the northern part of the basin. It is thought that the sequence may be a piedmont deposit associated with uplift on the northern part of the Darling Fault.

Early Permian The Yilgarn Block was uplifted during the Sakmarian and a trough developed down the length of the basin which received sediment throughout the Sakmarian in the north and from late Sakmarian in the south. Sedimentation in the trough continued during the Artinskian and probably extended into the Abrolhos Sub-basin. At this time the northern Perth Basin was linked with the sea via a gulf which connected with the Carnarvon Basin to the east of the Northampton Precambrian block.

Late Permian Minor faulting in the Late Permian in the Dongara area (Hosemann, 1971) marked the initiation of a set of north-northwest-trending faults and rifts which produced the deep graben of the Perth Basin from Late Triassic to Neocomian time. During the Late Permian and Early Triassic the sea entered the northern Perth Basin from the west of the Northampton Block and the easterly link between the Perth and Carnarvon Basins was closed.

Early and Middle Triassic Gentle downwarping of the basin continued. Marine, followed by deltaic, sediments were deposited in the north and dominantly fluviatile sediments were deposited to the south.

Late Triassic The Late Triassic was a period of intense activity on the Darling Fault. Coarse detritus from the uplifted Yilgarn Block was deposited in the rapidly subsiding graben. The Edwards Island Block and the Leeuwin Block are also thought to have been uplifted during this time.



(Based on I49/B8-24A) (From Cameron and Petkovic in prep)

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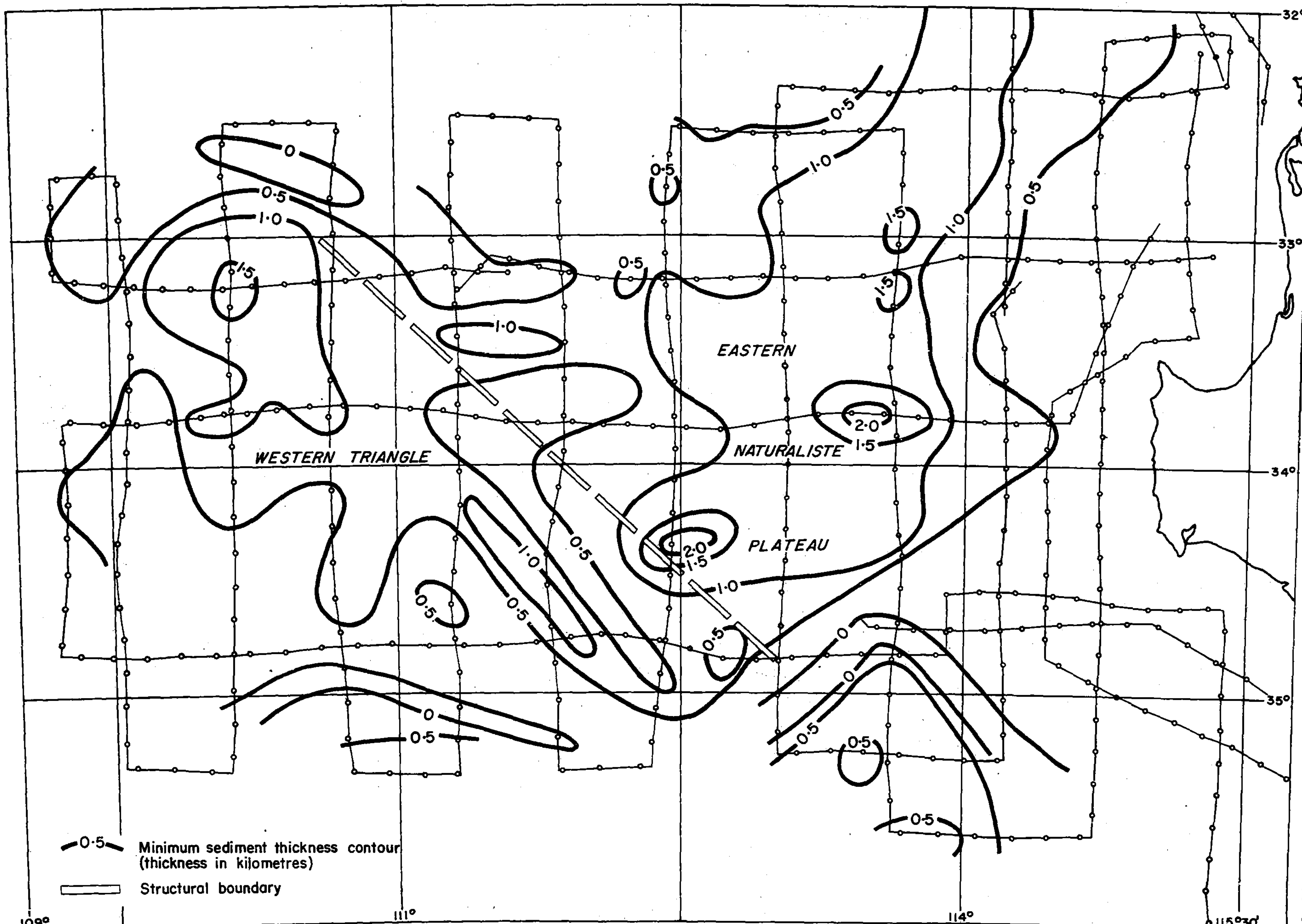

50 0 100 Kilometres

Naturaliste Plateau Sediment Thickness And Structural Elements

(Based on I49/B8-39A) (From Cameron & Petkovic, in prep.)

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FIG. 3

<u>Early and Middle Jurassic</u> Faulting along the Darling-Urella Faults continued but was less intense and had ceased by the Middle Jurassic when a minor rise in sea level occurred and the sea entered the northern part of the basin from the northwest.

<u>Late Jurassic</u> The Late Jurassic was a time of intense block-faulting in the basin. Both the Yilgarn Block, and the Edwards Island Block were sources of great thicknesses of sediment.

<u>Cretaceous (Neocomian)</u> Tectonism reached a climax in the Neocomian. Major vertical movement continued on the block faults. The Beagle and Turtle Dove Ridges were uplifted and, as a result, tilting and major faulting occurred in the adjacent Abrolhos Basin and Dandaragan Trough. Major subsidence occurred offshore in the Vlaming Sub-basin. During this time the last significant movement took place on the Darling Fault, the present form of the Beagle Ridge was established, and most of the major faults in the basin were produced. In the south, sediments of Neocomian age overlap the Darling Fault, and the Bunbury Basalt was extruded at this time. The western structural boundary of the Bunbury Trough against the Leeuwin Block developed along the Dunsborough Fault.

<u>Cretaceous (Aptian-Santonian)</u> This was a period of tectonic stability. There was no further subsidence in the fault-bounded troughs which had been subsiding since the Permian, and the block-faulted uplands had been reduced to near-base level.

<u>Tertiary and Quaternary</u> Tectonically stable conditions continued. Clastic sediments were deposited near Perth during marine incursions in the Palaeocene and Miocene and shelf limestones were laid down in the Vlaming and Abrolhos Sub-basins.

The development of the Perth Basin has been related to the break-up of Gondwanaland and the drift of 'India' away from the present southwest margin of Australia.

Veevers et al., (1971), and Veevers (1971, 1972) present a reassembly of Australia in Gondwanaland which places the Perth Basin in the interior of the continent, alongside peninsular India, and the Carnarvon Basin facing a gulf of the Tethyan sea. This interpretation is based on the progressive facies change from non-marine sedimentary rocks in the southern Perth Basin, through correlatives of paralic and marine origin in the north, to predominantly marine correlatives in the Carnarvon Basin.

On the basis of the ridge and rift structure of the two basins it is postulated that southwest Australia was arched in the Late Carboniferous, and that the arch collapsed by rifting in the Permian, Triassic, and Jurassic with the deposition of thick sequences of mainly non-marine sediments (Perth Basin), and marine sediments (Carnarvon Basin) in the developing grabens. The intense tectonism in the Perth Basin in the Neocomian marks the change from continental 'rifting' to 'drifting', and is marked by the eruption of the Bunbury Basalt. Sea-floor spreading commenced in the late Neocomian and 'India' is postulated to have moved away from Western Australia along the Wallaby-Perth transform fault (Johnstone et al., 1973).

The onset of sea-floor spreading resulted in rapid marginal subsidence, and in deposition in the Late Cretaceous of shallow marine sediments in the Perth Basin, and deep marine sediments in the Carnarvon Basin. Deep-sea sediments were also deposited near the continental edge on the Naturaliste Plateau. (Burckle et al., 1967; Saito in Le Pichon & Heirtzler, 1968).

After Santonian time the Indian Ocean is considered to have reached maturity (Veevers & Johnstone, 1974) and the sedimentary regime which has persisted to the present time, characterised by the deposition of shelf carbonate sequences, was established.

Petkovic (1975) considers that the data from the BMR continental margin survey and the DSDP casts doubt on the validity of the reconstruction of Gondwanaland postulated by Veevers et al., which places the Naturaliste Plateau some 500 km north of its present position. Such a large horizontal movement relative to Australia since the deposition of the sediments on the plateau would have produced deformation in the sediments that would be obvious on the seismic records. The Gondwanaland reconstruction proposed by Sproll & Dietz (1969) places the Naturaliste Plateau against a similar Antarctic bathymetric feature known as the Bruce Plateau, offshore from Knox Coast where Precambrian gneisses and schists of granulite facies crop out. The geophysical evidence suggests that the basement rocks of the Naturaliste Plateau are more likely to be of this type than oceanic igneous rocks. Petkovic therefore suggests that the plateau was part of the Gondwanaland continental shelf abutting the Bruce Plateau and that it broke away from Antarctica during the initial rifting and subsequently remained attached to the Australian crustal plate.

Stratigraphy

The generalised stratigraphy of the Perth Basin is given in Table 1; stratigraphic tables for individual wells from various parts of the basin are presented in Appendix 3. A well correlation chart for onshore wells in the southern part of the basin is given in Plate 8. The main reference for this section is Playford et al. (1975).

Silurian

Tumblagooda Sandstone: The Tumblagooda Sandstone (Clarke & Teichert, 1948) consists of red, yellow, and white quartz and feldspathic sandstone which grades to granule and pebble conglomerate and contains thin siltstone beds. The formation is overlain with angular unconformity by Permian, Triassic, Jurassic, and Cretaceous sediments, and underlain by granitic basement. It crops out on the eastern and western flanks of the Northampton Block and extends northwards into the Carnarvon Basin where it has its most widespread development. The type section is in the lower Murchison River area in the Carnarvon Basin but the thickest measured section of about 1800 m occurs along the Murchison River east of the Northampton Block in the Perth Basin. It is thought that the total thickness in the Perth Basin may be more than 3000 m. Invertebrate tracks and burrows (Opik, 1959) are the only fossils found to date in the Perth Basin and although these were not regarded as definitive for dating the formation, a Middle Cambrian to Early Ordovician age was favoured. However, in the Shark Bay area of the Carnarvon Basin there is evidence from deep wells that the Tumblagooda Sandstone conformably underlies the Late Silurian Dirk Hartog Formation. A microplankton assemblage of possible Late Silurian age has also been found in a Carnarvon Basin well (B.E. Balme, pers. comm. 1973, in Playford et al., 1975). On the basis of this evidence a Silurian age, possibly extending into the Late Ordovician, is now favoured for the Tumblagooda Sandstone. The environment of deposition is considered to be dominantly fluviatile.

Devonian

Sediments of Devonian age have not been definitely identified in the Perth Basin either in outcrop or in the subsurface. Ingram (1967) identified reworked Late Devonian spores in the Early Cretaceous Otorowiri Siltstone Member of the Yarragadee Formation in water-bores west of Arrino. This assemblage had previously been found only in the Devonian Gneudna Formation in the Carnarvon Basin. The presence of the assemblage in the Otorowiri Siltstone Member suggests that during the deposition of this unit, Devonian sediments were being eroded from nearby, perhaps from within the Urella Fault zone. It seems likely therefore that Devonian sediments were deposited in the Perth Basin.

Permian

Permian rocks crop out in the northeastern part of the basin between the Darling and Urella Faults (Irwin Sub-basin, Playford, 1971) and have also been encountered in the subsurface during drilling operations in both the northern and southern parts of the basin. In the northern part of the basin the major formations in ascending order are the Nangetty Formation, the Holmwood Shale, the Irwin River Coal Measures, the Carynginia Formation, and the Wagina Sandstone (Table 1). Two other units, the Fossil Cliff Formation and the High Cliff Sandstone, are recognised between the Holmwood Shale and the Irwin River Coal Measures, and the Mingenew Formation is probably a lateral equivalent of the Carynginia Formation. These three units are not shown in the generalised stratigraphic table but are described in the following section. Only one Permian unit, the Sue Coal Measures, is recognised in the southern Perth Basin.

Nangetty Formation: The Nangetty Formation (Clarke et al., 1951; amended Playford & Willmott in McWhae et al., 1958) crops out in the valleys of the Irwin, Lockier, Greenough, and Murchison Rivers, the type section being around the Nangetty Hills in the Irwin River area. It consists of a poorly sorted, poorly bedded matrix of sandy clay, conglomerate, sandstone, claystone, siltstone, and shale with erratic boulders usually up to 50 cm in diameter but exceptionally up to 6 m. Well-developed facets and striations on many of the erratics indicate a glacial origin, and they are interpreted as ice-rafted

TABLE 1. PERTH BASIN, GENERALISED STRATIGRAPHY.

SYSTEM	SERIES	STAGE	UNIT	COMMENTS	ENVIRONMENT
QUATERNARY	PLEISTOCENE		Coastal Limestone		
TERTIARY	PLIOCENE- L. MIOCENE?		Unnamed carbonate Fm.		
	MAINLY M. MIOCENE		Stark Bay Fm.		
	PALEOCENE- E. EOCENE		Mullaloo Sst. Mbr Kings Park Fm.		
CRETACEOUS	LATE	Campanian	Coolyena Gp Lancelin Beds? Poison Hill Greensand		
		Santonian	Gingin Chalk		
		Coniacian	Molecap Greensand		MARINE
		Turonian			
		Cenomanian			
	EARLY	Albian	Osborne Fm.		
		Aptian	Warnbro Gp Dandaragan Sst. Leederville Fm.	Mainly continental in onshore area	
			South Perth Shale Gage Sst. Mbr	Bunbury Basalt (southern Perth basin)	
		Neocomian	Otorowiri Slt. Mbr Quinns Sh. Mbr Yarragadee Formation	Marginal marine 'Carnac Fm.' developed offshore in Vlaming Sub-basin	CONTINENTAL
JURASSIC	LATE	Tithonian to Callovian			
	MIDDLE	Bathonian			
		Bajocian	Cadda Formation		MARINE
	EARLY	Liassic	Cattamarra C.M.Mbr Cockleshell Gully Fm. Eneabba Mbr		MARGINAL MARINE TO CONTINENTAL
TRIASSIC	LATE	Rhaetian to Carnian	Lesueur Sandstone		
	MIDDLE	Anisian	Woodada Formation	Sabina Sst (Southern Perth Basin)	
	EARLY	Scythian	Kockatea Shale Dongara Sst. Mbr*		MARINE
PERMIAN	LATE	Kazanian	Yardarino Sst.Mbr* Wagina Sst.	Sue Coal Measures (U. Permian-Sakmarian, Southern Perth Basin)	MARGINAL MARINE TO CONTINENTAL (Continental in south)
	EARLY	Kungurian	Carynginia Fm.		
		Artinskian	Irwin River Coal Measures		
		Sakmarian	Holmwood Shale		GLACIAL
			Nangetty Fm.		
ORDOVICIAN -SILURIAN			Tumblagooda Sst.		CONTINENTAL
PRECAMBRIAN			Basement		

* 'Basal Triassic Sandstone'

detritus. Outcrops of the Nangetty Formation are generally poor, often consisting only of erratic boulders in the soil. No more than 130 m has been measured in any one outcrop section but it is estimated to be up to 1200 m thick in the Dandaragan Trough adjacent to the Darling Fault. It thins westward to pinch out on the Northampton Block and the Beagle Ridge. The formation is thought to contain both marine and continental deposits. The shales in the upper part are very similar to the marine shale in the overlying Holmwood Shale and the poorly sorted tillitic sandstone and conglomerate are probably fluvioglacial. The only known fossils are plant microfossils which suggest a Sakmarian age (Balme, *in* McWhae et al., 1958).

Holmwood Shale: The Holmwood Shale (Clarke et al., 1951) is conformable on the Nangetty Formation or unconformable on the Tumblagooda Sandstone except in the west where it rests unconformably on Precambrian rocks. The formation consists of grey-green shale and siltstone with thin beds of limestone and rare glacial erratics. The main area of outcrop is in the Irwin River area and it also crops out in the valleys of the Lockier and Greenough Rivers. It is recognised in the subsurface from Abbawardoo No. 1 southwards to Cadda No. 1, the thickest section being 415 m in Wicherina No. 1. The type section is on the Holmwood property and although there is some doubt about the thickness it is thought to be about 450 m. Several members, of which only two are named, are recognised in various areas. The Beckett Member occurs in the type area and consists of shale with yellow-brown calcareous concretions containing the goniatite *Juresanites jacksoni*. *J. campbelli* and *Uraloceras irwinense* occur in the Woolaga Limestone Member in the Mingenew area (Playford, 1959; Glenister & Furnish, 1961). These fossils date the Holmwood Shale as Sakmarian. Their presence, plus the rare glacial erratics, indicate a marine depositional environment and waning glacial conditions.

Fossil Cliff Formation: The Fossil Cliff Formation (Clarke et al., 1951) is a siltstone unit with richly fossiliferous limestone lenses which conformably overlies and interfingers with the Holmwood Shale. It crops out in the Irwin River area and has been correlated with units in bores as far south as Cadda No. 1. The type section at Fossil Cliff is 31 m thick and the thickest known section 45 m thick. There has been disagreement about its 'unit' status (Johnstone & Willmott, 1966) but it is given formation status in Playford et al. (1975). It is distinguished as one of the most richly fossiliferous formations in the Perth Basin. The fauna includes a variety of bivalves, gastropods, ammonoids, ostracods, foraminifera, bryozoans and corals, plus the crinoid Calceolispongia, the trilobite Ditomopyge, and the ammonoid Juresanites (Dickins, 1963; Dickins & Thomas, 1957). The presence of Juresanites indicates a Sakmarian age (Glenister & Furnish, 1961).

High Cliff Sandstone: The High Cliff Sandstone (Clarke et al., 1951) comprises white, yellow, and dark grey very fine to very coarse-grained quartz sandstone containing thin beds of siltstone and granule and pebble conglomerate. It crops out in the valleys of the Irwin, Lockier, and Greenough Rivers where it is conformable between the Fossil Cliff Formation and the Irwin River Coal Measures. The type section at High Cliff is 24 m thick and the maximum exposed thickness at Woolaga Creek, 31 m. The formation is difficult to distinguish from the Irwin River Coal Measures in the Sub-surface (Johnstone & Willmott, 1966). In the Woolaga Creek area a highly fossiliferous limestone lens occurs at the base of the formation. The fauna which includes the bivalves Parallelodon, Atomodesma, Aviculopecten and Schizodus, the gastropod Bellerophon, and the brachiopods Linoproductus, Avlosteges, and Neopisifer (Dickins, in Playford, 1959; Dickins, 1963) is younger than that of the Fossil Cliff Formation and could be early Artinskian. It is possible that the formation represents in part a beach deposit associated with the marine regression which preceded the deposition of the Irwin River Coal Measures.

Irwin River Coal Measures: The Irwin River Coal Measures (Clarke et al., 1951) is a sequence of rapidly alternating siltstone and fine to medium-grained sandstone with lenses of sub-bituminous poor-quality coal (Johnson et al., 1954) and carbonaceous clay. It is known in outcrop and in wells in the northern Perth Basin. In outcrop it is conformable between the underlying High Cliff Sandstone and the overlying Carynginia Formation. The type section on the Irwin River near High Cliff is 63 m thick and the maximum exposed thickness is 123 m at Woolaga Creek. In the subsurface the High Cliff Sandstone can not be reliably distinguished and the sequence representing the two formations together has a constant thickness of about 300 m, both in the Dandaragan Trough and on the Beagle Ridge, indicating that it was deposited during a period of tectonic stability (Johnston & Willmott, 1966). The formation contains typical representatives of the Glossopteris flora (Rigby, 1966) and a rich microflora (Balme, in McWhae et al., 1958). The formation is dated as Artinskian.

Caryngginia Formation: The Caryngginia Formation (Clarke et al., 1951; amended Playford & Willmott, in McWhae et al., 1958) is a unit of dark micaceous siltstone with minor beds of fine-grained sandstone. The formation crops out in the Irwin Sub-basin and has been penetrated in the subsurface from Wicherina No. 1 in the north as far south as Cadda No. 1. The contact with the underlying Irwin River Coal Measures is conformable but the formation is unconformably overlain by the Wagina Sandstone. The main reference section which is 257 m thick is exposed along the Woolaga Creek (Playford, 1959). The thickest known section is 349 m thick in Cadda No. 1 where however it is incomplete, being truncated by the Triassic unconformity. The formation contains very few megafossils, but a rich microflora including microplankton suggests that the formation is Artinskian, possibly ranging into the Kungurian (B.E. Balme, pers. comm., 1969, in Playford et al., 1975).

Mingenew Formation: The Mingenew Formation (Maitland, 1919; amended Playford & Willmott, in McWhae et al., 1958) consists of ferriginous sandstone and siltstone and crops out over a small area east of Mingenew and has also been identified 5 km west of Arrino (Edgell, 1965). It is considered likely that the formation is probably a lateral equivalent of part of the Caryngginia Formation. Johnstone & Willmott (1966) correlate fossiliferous beds at the top of the Caryngginia Formation in Jurien No. 1 and BMR No. 10A (Beagle Ridge) with the Mingenew Formation, and consider that post-Artinskian erosion is responsible for its absence in other wells in the area. It contains a rich marine fauna of Artinskian age.

Wagina Sandstone: The Wagina Sandstone (Clarke et al., 1951) consists of white, fine to medium-grained sandstone with minor siltstone, conglomerate, and coal. The main reference section proposed by Playford & Willmott (in McWhae et al., 1958) near Woolaga Creek is 251 m thick and the top of the formation is not exposed. The thickest known section in the subsurface is 95 m in Wicherina No. 1. The formation contains spores, pollen, and acritarchs and has been dated as mainly Late Permian, possibly extending down into the Kungurian stage of the Early Permian (Balme, 1964; Segroves, 1971). Where the formation crops out in the Irwin River to Woolaga Creek area the contact with the underlying Caryngginia Formation seems to represent a brief interval of non-deposition, and in the subsurface, drilling in the northern Dandaragana Trough has indicated that the Wagina Sandstone rests with angular unconformity on older Permian units ranging from the Carynginia Formation to the Holmwood Shale, and is unconformably overlain by the Triassic Kockatea Shale (Johnstone & Willmott, 1966).

The Yardarino Sandstone Member of the Wagina Sandstone is a unit of quartz sandstone developed at the top of the Wagina Sandstone in the Yardarino - Dongara area. It was defined by Playford & Low (1972), and was included in the Basal Triassic Sandstone Member of the Kockatea Shale by Hosemann (1971). However palynological work by WAPET (Lowry, 1972) has shown that much of the unit is Late Permian, and McKellar in Playford et al. (in press) proposes that this part should be a member of the Wagina Sandstone. The type section is in Yardarino No. 1 from 2284 m to 2307 m.

Sue Coal Measures: The Sue Coal Measures was the name proposed by Playford & Low, (1972) for the coal measure sequence encountered in Sue No. 1, Wicher Range No. 1, Alexandra Bridge No. 1, and Blackwood No. 1 wells. The type section in Sue No. 1 (WAPET, 1966) is 1917 m thick and was intersected at 1137 m. It overlies Precambrian rocks and is overlain unconformably by Triassic sediments which probably correlate with the Lesueur Sandstone. The base of the formation was not reached in the other wells where it was overlain by Cretaceous, Jurassic, or Triassic sediments. Palynological evidence (Balme, in WAPET, 1966) indicates that the Sue Coal Measures range from Late Permian to the Sakmarian Stage of the Early Permian and they are therefore equivalent to the whole of the Permian sequence in the northern Perth Basin above the upper part of the Nangetty Formation.

Triassic

In the northern part of the Perth Basin three Triassic formations are recognised which are from oldest to youngest, the Kockatea Shale, Woodada Formation, and Lesueur Sandstone. In the southern Perth Basin only one unit, the Sabina Sandstone, lies below the Lesueur Sandstone. Although Triassic rocks are widespread in the sub-surface only the Kockatea Shale and the Lesueur Sandstone have been mapped in outcrop; the Kockatea Shale on the eastern and western sides of the Northampton Block, and the Lesueur Sandstone in a small area around Cockleshell Gully.

Kockatea Shale: The Kockatea Shale (Playford & Willmott, in McWhae et al., 1958) was deposited during the Early Triassic in the Dandaragan Trough where it reaches a thickness of over 1000 m. The first open-sea macrofossils from Australia which could be referred with certainty to the Triassic were described from the Kockatea Shale in BMR No. 10 bore (Beagle Ridge) (Dickins et al., 1961; Dickins & McTavish, 1963; McTavish & Dickins, 1974). The formation consits of light grey to black shale and siltstone, with interbedded sandstone in some sections. In the subsurface the formation is commonly calcareous and outcrops are usually bleached white or yellow. The formation is disconformable or rests with angular unconformity on all the older units of the northern Perth Basin and is overlain conformably by the Woodada Formation or unconformably by Jurassic rocks. The type section is on the Greenough River (28°33'00", 115°10'00"E) where it is 7.3 m thick. R.G. McKellar (pers. comm. 1972, in Playford et al., 1975) believes that the Kockatea Shale contains a basal quartz sandstone unit, the Dongara Sandstone Member, in some parts of the Dongara area (Lowry, 1972a). The macrofauna recovered from the Kockatea Shale mainly from the BMR No. 10 (Beagle Ridge) bore, comprises ceratitic ammonoids (including Ophiceras cf. subkvokticum and Subinvoites Kashmiricus), bivalves (including Claraia perthensis), brachiopods, fish fragments, estheriids, and ostracods. Edgell (1964) and Kummel (in Karajas, 1969) have identified a small ammonoid fauna from the Mount Minchin area in the northernmost part of the Perth Basin west of the Northampton Block which probably includes a species of Owenites, and an amphibian skull found in a core from the BMR well was named Deltasaurus pustulatus (Cosgriff, 1965). A rich microflora including microplankton has also been recorded from the Kockatea Shale (Balme, 1963, 1969). Conodonts recovered from a core from Dongara No. 4 well have been dated as Lower Triassic (Dienerian) by McTavish (1973). McTavish & Dickins (1974) present a reassessment of the age of the Kockatea Shale in BMR No. 10 (Beagle Ridge) bore. The age originally determined for the macrofauna was that of the oldest part of the Early Triassic Scythian Stage. The age has now been reassessed to range from the earliest (Griesbachian) up to the middle (Smithian) Scythian. The age of the Kockatea Shale in the Sugarloaf Hill - Mount Minchin area is middle Scythian (Edgell, 1964; Karajas, 1969). In this area the older part of the formation is absent because of onlap against the Northampton Block. The age of the Kockatea Shale in BMR No. 10 (Beagle Ridge) is based on fauna in the lower 270 m of the formation. The age of the upper 125 m is not known precisely. Balme (1969) places the upper boundary of the Kockatea Shale at the Smithian/Spathian boundary although with reservations, and McTavish & Dickins (1974) consider that in view of the thickness of the undated part of the formation, and the apparent rate of deposition in BMR No. 10, (Beagle Ridge) the age of the formation may range into the Spathian.

Woodada Formation: The Woodada Formation (Willmott & McTavish, in Willmott, 1964), is a stratigraphic unit which is recognised only in the subsurface. The formation consists of fine-grained sandstone and siltstone. It overlies the Kockatea Shale conformably and with a transitional contact. The overlying Lesueur Sandstone is probably disconformable on the Woodada Formation. The type section, which is 276 m thick, is in BMR No. 10 (Beagle Ridge). The Woodada Formation contains a wide variety of spores and pollen grains and minor microplankton which Balme (1969) dates as late Scythian to Middle Triassic on the evidence of the plant microfossils.

The formation is believed to represent the final regressive stage of the phase of marine deposition which was initiated by the Early Scythian transgression and may be a deltaic deposit (Balme, 1969).

Lesueur Sandstone: The Lesueur Sandstone (Willmott et al., in Willmott, 1964) is predominantly a sequence of coarse to very coarse-grained feldspathic sandstone characterised by large-scale cross-bedding, which is believed to be fluviatile. The formation is probably disconformable on the Woodada Formation in the northern part of the basin and apparently conformable on the Sabina Sandstone in the south. The type section is in Woolmulla No. 1 where it is 583 m thick, and the formation is named from Mount Lesueur. The formation thickens southward and reaches a thickness of 2201 m in Pinjarra No. 1 where the base was not reached.

In the northern Perth Basin the Lesueur Sandstone is dated by plant microfossils as Middle to Late Triassic (Balme, 1969). It may interfinger with the lower part of the Cockleshell Gully Formation and range into the Early Jurassic. In Whicher Range No. 1 in the southern Perth Basin, Balme (in Union Oil Development Corporation, 1968) dated part of the Lesueur Sandstone as Early Triassic.

Sabina Sandstone: The type section for the Sabina Sandstone is in Whicher Range No. 1 where it is 249 m thick. The formation is probably unconformable on the Sue Coal Measures and is conformably overlain by a sandstone unit correlated with the Lesueur Sandstone. The Sabina Sandstone is regarded as the correlative of the Kockatea Shale in the northern Perth Basin. Balme (in Union Oil Development Corporation, 1968) dates the formation as Early Triassic (earliest Scythian) on palynological evidence. The environment of deposition was continental, although there are slight indications of a marine environment in one microfloral sample.

Jurassic

Jurassic sediments crop out in the Hill River area, and farther north around Geraldton. The sequence comprises three main stratigraphic units: an Early Jurassic continental sequence; a thin Middle Jurassic marine sequence, and a Middle to Late Jurassic continental sequence which extends into the Cretaceous Neocomian Stage. The northern section represents a condensed sequence onlapping the Northampton Block and reaches a total thickness of only about 180 m. It comprises from oldest to youngest, the Chapman Group, Champion Bay Group, and Yarragadee Formation.

The Hill River sediments, although not as well exposed as at Geraldton, have more affinity with the subsurface sequence and the stratigraphic subdivisions recognised in this area are those applied in the subsurface. The three main stratigraphic units are from the base: the Cockleshell Gully Formation; the Cadda Formation, and the Yarragadee Formation. An aggregate maximum thickness of about 4200 m is estimated for the three units.

Cockleshell Gully Formation: The Cockleshell Gully Formation (Playford et al., in McWhae et al., 1958; amended Willmott, 1964) consists of a sequence of sandstone, siltstone, shale, and coal which is at least 2400 m thick in the Dandaragan Trough, 2000 m in the Bunbury Trough, 900 m in the Abrolhos Sub-basin and possibly 3300 m in the Vlaming Sub-basin. The type section (712 m thick) at Cockleshell Gully is faulted at top and bottom and reference sections have been proposed for the top of the section at 30°15'55"S, 115°17'30"E and in Eneabba No. 1 for the whole sequence, particularly the base (Willmott, 1964). The formation is conformable on the Lesueur Sandstone (may interfinger in some areas) and is conformably overlain by the Cadda Formation. Two members are recognised (Playford and Low, 1972); an upper Cattamarra Coal Measures Member, and a lower Eneabba Member. The upper member is characterised by interbedded shale, sandstone, and coal seams, and the lower member by multicoloured claystone (red, brown, yellow, green, purple, white and grey). The Eneabba Member has been dated palynologically as Early Jurassic (Balme 1964). The Cattamarra Coal Measures Member is also dated as Early Jurassic and both members are believed to be predominantly continental.

Cadda Formation: The Cadda Formation (Playford et al., *in* McWhae et al., 1958) is a unit of sandstone and siltstone grading in places to sandy, shelly limestone, and appears to be conformable between the Cockleshell Gully and Yarragadee Formations. It is recognised at the surface only in the Hill River area where the type section is about 37 m thick. It occurs in the subsurface northwards to the southern end of the Northampton Block. The limestone content increases to the north and the formation grades into the Newmarracarra Limestone of the Champion Bay Group. Southwards it changes from marine to continental facies. In the Abrolhos Sub-basin it is represented by a 240 m thick marine shale. The limestone in the Cadda Formation contains a shelly invertebrate fauna which includes the ammonites *Pseudotoites* emilioirdes and *P. Semiornatus*, indicating that at least part of the formation is of middle Bajocian (Middle Jurassic) age (Arkell & Playford, 1954).

Yarragadee Formation: (Fairbridge, 1953; amended Playford et al., *in* McWhae et al., 1958) consists of interbedded sandstone and siltstone, with some shale, claystone, and conglomerate. The bedding is characteristically lenticular and the sandstones are poorly sorted with grainsize varying from very fine to very coarse-grained. The unit is thin and faulted in the type locality near Mingenew, and two reference sections, one in the Hill River area north of Cantabilling homestead and the other in the Bringo railway cutting east of Geraldton, have been designated. The Yarragadee Formation crops out in the northern part of the basin. In the subsurface it is at least 4000 m thick in the Dandaragan Trough, up to 3000 m in the Vlaming Sub-basin (Plates 6, 7, and 8), and 1200 m in the Abrolhos Sub-basin. Palynological evidence (B.E. Balme & B.S. Ingram, pers. comm., 1969 in Playford et al., 1975) indicates that the formation ranges from Middle Jurassic to the Early Cretaceous Neocomian Stage. The formation appears to be a fluviatile deposit, becoming paralic in the Early Cretaceous. It is thought to have been deposited during the main period of Mesozoic movement on the Darling Fault.

The Neocomian part of the Yarragadee Formation will be described in the following section. For details of the Early Jurassic Chapman Group and the Middle Jurassic Champion Group (Arkell & Playford, 1954) which are mainly developed in the Geraldton 1:250 000 Sheet area, the reader is referred to Playford (1959) and Playford et al. (1975).

Cretaceous

The stratigraphic nomenclature of the Cretaceous rocks of the Perth Basin was revised by Cockbain & Playford (1973) as a result of the information provided by regional mapping and petroleum exploration drilling. The revised nomenclature is shown in Table 1. Only the more important units will be detailed herein. The Cretaceous sediments crop out over a large area of the basin but the exposures are generally poor. The major intra-Neocomian unconformity separates the Late Jurassic and Neocomian Yarragadee Formation from the younger Cretaceous sediments which are subdivided into the Warnbro Group and the Coolyena Group. The Warnbro Group was deposited during the Early Cretaceous marine transgression of the Perth Basin and comprises a sequence of mixed marine and continental sediments. The Coolyena Group includes fossiliferous glauconitic marine sediments of mainly Late Cretaceous age which occur in the Dandaragan Trough and Vlaming Sub-basin.

Yarragadee Formation: Fluvial sands and thin shales of Neocomian age form the upper part of the Yarragadee Formation in the Dandaragan Trough and offshore in the Vlaming Sub-basin where they attain their maximum thickness of possibly 4500 m. The 'Carnac Formation' (WAPET informal name) is a shaley sequence of Neocomian age intersected in the Vlaming Sub-basin by Roe No. 1, Gage Roads No. 2 (Appendix 3), Charlotte No. 1, and Warnbro No. 1 (See Appendix 3 for last 3 wells) and originally considered to be the upper part of the Yarragadee Formation.

The Quinn's Shale Member (WAPET, 1969a; Cockbain & Playford, 1973) occurs in offshore wells between Quinn's Rock No. 1 in the north and Sugarloaf No. 1 in the south and is associated with a good seismic reflection. The microflora suggests that the unit was deposited in a lagoonal environment, and that it is earliest Neocomian. The base of the member is taken as the Jurassic/Cretaceous boundary.

The Otorowiri Siltstone Member (Ingram, 1967a) is recognised in water-bores west of Arrino in the northern Dandaragan Trough. It is a richly fossiliferous, predominantly siltstone unit containing plant microfossils, including microplankton of Early Cretaceous age, plus reworked forms of Devonian, Permian, Triassic, and Jurassic age. The maximum known thickness is 37 m and the type section (24 m) is in Arrowsmith River No. 25 water-bore. On the microfloral evidence the Otorowiri Siltstone Member is correlated with a group of shales in the Neocomian Yarragadee Formation offshore (A. Williams, pers. comm. 1972, in Playford et al., 1975).

The Warnbro Group (Cockbain and Playford, 1973) comprises the South Perth Shale, Leederville Formation, and Dandaragan Sandstone. The reference section is in Warnbro No. 1 in the Vlaming Sub-basin.

South Perth Shale : The South Perth Shale (Fairbridge, 1953) is 75 m thick onshore in the type section in the South Perth No. 1 water-bore (31°58'31"S, 115°50'57"E). It thickens to 795 m offshore in Warnbro No. 1 and probably reaches a greater thickness farther west. To the north and south of Perth there is evidence that the South Perth Shale is overlapped by the Leederville Formation. The formation is not known to crop out. Lithologically it consists of a shallow marine to continental sequence of interbedded shale and siltstone with minor sandstone. In some areas calcareous beds grading to limestone occur, and the sandstone is mainly developed at the base of the formation.

The Gage Sandstone Member (Bozanic, 1969) is the name which has been given to the sandstone at the base of the South Perth Shale in the offshore wells. The type section, 213 m thick, is in Gage Roads No. 1. It consists of fine-grained to conglomeratic sandstone with minor siltstone and shale and appears to have been deposited in a near-shore marine environment. The maximum known thickness is 259 m in Warnbro No. 1.

Leederville Formation: The Leederville Formation ('Leederville Sandstone' of Fairbridge, 1973, amended Cockbain & Playford, 1973) is about 250 m thick in the subsurface in the Perth area and thickens offshore to a maximum known thickness of 545 m in Gage Roads No. 1 well. In some areas the formation appears to overlap the South Perth Shale, as in Sugarloaf No. 1 well where it overlies Neocomian Yarragadee Formation. Sandstone, shale, siltstone, claystone, and conglomerate occur in the formation, some beds being glauconitic and pyritic. The type section in the Leederville Valley water-bore (Pudovskis, 1962) is 235 m thick. It is overlain probably unconformably by the Kings Park Shale, and is conformable on the South Perth Shale. In places in the Perth metropolitan area the Osborne Formation overlies it probably unconformably (B.S. Ingram, pers. comm., in Playford et al., 1975). In Sugarloaf No. 1 microplankton indicate a Neocomian to Aptian age. The sediments are usually continental and unfossiliferous onshore.

Dandaragan Sandstone: The Dandaragan Sandstone ('Dandaragan Series', Blatchford, 1912; amended Fairbridge, 1953) is exposed discontinuously betwen Gingin and Badgingarra. It consists of massive to thickly bedded medium to coarse-grained ferruginous and feldspathic sandstone. It rests with angular unconformity on the Yarragadee Formation and is overlain probably disconformably by the Molecap Greensand. The type section (33 m thick) is 6 km west of the Dandaragan and this is the thickest section so far measured. It is unfossiliferous except for the presence of fossil wood and is dated as Early Cretaceous on its 'stratigraphic position'. It may possibly correlate with the top of the Leederville Formation.

The Coolyena Group comprises the Osborne Formation, Molecap Greensand, Gingin Chalk, and Poison Hill Greensand.

Osborne Formation: The Osborne Formation (McWhae et al., 1958) is a unit of interbedded sandstone, siltstone, shale, and claystone, characteristically glauconitic. It contains a rich microflora including microplankton which dates it as Albian and Cenomanian (Cookson & Eisenack, 1958). The type section is in the King Edward Street bore Osborne Park (31°54'00"S, 115°49'00"E) in the Perth area. The formation crops out in the Moore River and is known from bores in the Perth area and offshore wells (Plate 6). It is disconformable on the Leederville Formation and is overlain probably conformably by the Molecap Greensand except in the Perth area where it is overlain disconformably by the Tertiary Kings Park Formation.

Molecap Greensand: The Molecap Greensand (Fairbridge, 1953) consists of greensand and glauconitic quartz sandstone resting probably conformably on the Osborne Formation and conformably overlain by the Gingin Chalk. The type section is in a quarry on Molecap Hill near Gingin where it is 11 m thick. Late Cretaceous microplankton were reported from the Molecap Greensend by Deflandre & Cookson (1955), and the dating was confirmed by B.S. Ingram (pers. comm. 1969 in Playford et al., 1975). The formation also contains ichthyosaur and plesiosaur bones (Teichert & Matheson, 1944), and a few bivalves and belemnites.

Gingin Chalk: The Gingin Chalk (Glauert, 1910) is a unit of white, friable, slightly glauconitic chalk, with thinly interbedded greensand in some area. It rests disconformably on the Dandaragan Sandstone or conformably on the Molecap Greensand and is overlain conformably by the Poison Hill Greensand. The type section, in McIntyres Gully 1.6 km north of Gingin, is 19 m thick and the formation is about 18 m thick in most areas. The Gingin Chalk contains a rich micro and macrofauna; foraminifera (including the Globotruncana lapparenti group, G. marginata, and Rugoglobigerina, spp; Belford, 1960), the pelagic crinoids Marsupites and Uintacrinus, abundant Inoceramus and other bivalves (Feldtmann, 1963), ammonites of the Pachydiscus type, ostracods, echinoids, brachiopods, and abundant coccoliths. The fauna indicates a Santonian (middle Senonian) age and the possibility that the upper part of the formation may extend into the Campanian.

Poison Hill Greensand : The Poison Hill Greensand (Fairbridge, 1953) consists of greensand and glauconitic sandstone which is commonly strongly laterised in outcrop. The type section at Poison Hill near Gingin is 37 m thick but the formation probably reaches a maximum of at least 45 m. Palynological evidence suggests a Late Cretaceous age but the precise age has not been established. It may be a facies equivalent of the Campanian Lancelin Beds (Edgell, 1964) which were intersected in a water-bore near Lancelin.

Tertiary

Tertiary sediments are known with certainty only from the subsurface in the Perth Basin. Those shown in Plate 1 in the northern part of the basin form a thin veneer of uncertain age.

The most recent reviews are by Quilty (1974 a & b) and the reader is referred particularly to Quilty (1974b) for a very detailed treatment of the Cainozoic sequence onshore near Perth and offshore in the Vlaming Subbasin. Two major sedimentary cycles are recognised, late Paleocene to early Eocene, and early to middle Miocene. The first includes the Kings Park Formation and the second the Stark Bay Formation.

In the Perth area, thin discontinuous sediments with characteristic molluscan faunas represent a fairly widespread Pliocene to Quaternary marine incursion.

Kings Park Formation: The Kings Park Formation (Fairbridge, *in* Colman, 1952) consists of dark shale, sandstone, and minor limestone, all glauconitic. It overlies the Yarragadee Formation, the Warnbro Group, or the Osborne Formation with angular unconformity and is disconformably overlain by Quaternary deposits. It occurs in water-bores in the Perth area and in one bore on Rottnest Island, and offshore in wells in the Vlaming Sub-basin (Warnbro No. 1 (Plate 6), Quinns Rock No. 1). The type section in Kings Park No. 2 bore (31°58'30"S, 115°50'30"E) is 276 m thick. The formation was laid down in a restricted embayment which underlies the city of Perth and extends westwards offshore. The foraminiferal fauna indicates that the formation is of late Paleocene age onshore, but that offshore it could range from late Palaeocene to early Eocene. The Mullaloo Sandstone Member of the Kings Park Formation is thought to be a marine sand deposited from the early Swan River and the rest of the formation is believed to be a more southerly estuarine to marine unit.

Stark Bay Formation: The Stark Bay Formation consists mainly of white bryozoal calcarenite with some dolomite and chert deposited on the inner continental shelf. The type section is in Gage Roads No. 2 (Appendix 3). The formation is unconformable either on Cretaceous sediments or on the Kings Park Formation. It contains a rich foraminiferal fauna of early and middle Miocene age.

Quaternary

Sand dunes along the present coastline were calcified and consolidated to form the Coastal Limestone. This formation, which extends the full length of the basin and up to 40 km inland is notorious for the difficulties it causes in seismic data acquisition. Other static dune systems and surficial laterites are also believed to have developed during the Pleistocene.

3. GEOPHYSICS

As far as is known the first geophysical observations in the Perth Basin were done by the Dutch geophysicist Vening Meinesz, who carried out submarine observations of gravity, supplemented by some land observations at widely-spaced points on a single east-west traverse through Perth. This work was done within the period 1923-1939. Vening Meinesz's gravity readings were too few to reveal the nature of the Perth Basin. The first significant geophysical investigations of the basin were done by BMR, beginning with gravity surveys in 1949 and the early 1950s. West Australian Petroleum Pty Ltd (WAPET) commenced geophysical work in the basin in 1955 and since then that company has been responsible for the greater part of the geophysical exploration carried out. However, several other companies and BMR have also contributed to geophysical investigations since 1955.

Most of the geophysical surveys done in the Perth Basin up to 1975 are listed in Appendix 2. A large proportion of the surveys were done by petroleum exploration companies with subsidies from the Australian Government under the Petroleum Search Subsidy Act 1959-1973 (PSSA). Copies of reports on subsidised operations can be purchased through the Australian Government Publishing Service and some private copying firms. The reports and basic data relating to subsidised surveys can be viewed at BMR, Canberra and at the Western Australian Department of Mines. As BMR lacks information on some onshore geophysical operations which were not subsidised, the list of onshore surveys in Appendix 2 may not be complete. Basic data from some operations on Petroleum Titles or portions of Petroleum Titles relinquished by the original titleholders have been made available to the public by the Designated Authority for Western Australia.

Appendix 2, in addition to listing the year of each operation, the operator, the contractor, the mileage or number of observations and other survey information, shows the PSSA file number or other reference for the survey. References to surveys mentioned are generally not given in the text, as the reader may refer to Appendix 2. In this review the authors have relied heavily on the geophysical interpretations given in the operator's reports and maps for the various surveys. We gratefully acknowledge those sources for the information presented here.

Magnetic surveys

Plate 2 shows interpreted depths to magnetic basement in the Perth Basin and also serves to give an indication of the extent of magnetic coverage over the area. The Perth Basin Aeromagnetic Survey carried out by BMR in 1957 was an extensive survey which covered all of the onshore portion of the basin between Geraldton in the north and Cape Leeuwin in the south, and also a considerable part of the offshore portion of the basin. Survey lines were east-west, with a close line spacing of about 1.5 km.

Between 1956 and 1961 BMR carried out aeromagnetic and radiometric surveys over the southern portion of the Carnarvon Basin and the Coolcalalaya Sub-basin of the Perth Basin (Spence, 1962).

BMR aeromagnetic data offshore were supplemented by two surveys flown for WAPET in 1969. The offshore West Beagle survey covered an area offshore extending from about 120 km north of Perth northwards to the Geelvink Channel northwest of Geraldton. The Offshore Leeuwin aeromagnetic survey covered the continental shelf (water depths less than about 200 m) extending from Cape Naturaliste south to Cape Leeuwin and southeast to Pt D'Entrecasteaux. This included the southernmost portion of the Perth Basin. The BMR surveys and the two WAPET surveys have provided fairly complete aeromagnetic coverage of the Perth Basin.

The BMR Continental Margin survey of 1970-1973, some oceanographic surveys (Riesz & Moss, 1971) and some of the more recent marine geophysical surveys by WAPET included magnetometer recordings in the offshore Perth Basin. The line spacings for these marine magnetic surveys were relatively large compared with aeromagnetic surveys and the value of the marine magnetic data lies more in direct comparison with seismic results obtained concurrently than in mapping magnetic basement for the basin as a whole.

The magnetic method has been quite effective in delineating the gross structure of the basin. The most obvious feature of the magnetic intensity map is a sharp change in the character and intensity of magnetic anomalies across the Darling Fault and other faults at or near the boundaries of the basin from intense, short-wavelength anomalies on the upthrown blocks to broad, low-intensity anomalies within the basin. The magnetic data clearly define the Darling Fault as a single, south-trending fault with very large throw forming the eastern limit of most of the Perth Basin. In the northern part of the basin east of Dongara and Geraldton, a series of high-intensity anomalies parallel to and some 25 km to the west of the Darling Fault defines the Urella Fault, which like the Darling Fault is strongly downthrown to the west. At the southern end of the basin the offshore extension of the Darling Fault is oriented south-southwest.

The western boundary of the Perth Basin is much less defined by the available magnetics except to the south of about 33°S. Onshore between Cape Naturaliste and Cape Leeuwin an area of intense magnetic anomalies defines the Precambrian Leeuwin Block which is limited on its eastern side by the south-trending Dunsborough Fault. This fault is marked by a very abrupt change in the character of magnetic anomalies between the Precambrian rocks to the west and the sedimentary sequence within the basin to the east. North of Cape Naturaliste the aeromagnetic data indicate that the Dunsborough Fault changes its orientation offshore from south to southeast, so that north of Cape Naturaliste and Busselton the Perth Basin broadens to the west.

The aeromagnetic results over the basin indicate a deep, elongate trough of sediments overlying a basement complex of Precambrian rocks. The deepest part of the basin, the Dandaragan Trough, lies onshore to the north of Perth. In the deepest part of this trough aeromagnetic results indicate a maximum thickness of sediments in excess of 7000 m. Farther north, to the southeast of Dongara, a narrow trough was indicated which probably contains up to a maximum of 6000 m of sediments. Offshore, to the southwest of Geraldton and Dongara, the Offshore West Beagle aeromagnetic survey indicated the presence of another sedimentary trough trending roughly parallel with the coast and containing up to 6000 m of sediments (Abrolhos Sub-basin).

Aeromagnetic data indicate the extent of sediments forming the Coolcalalaya Sub-basin in the extreme north of the region, the character of magnetic profiles over the sediments being markedly different from that over the Precambrian Yilgarn Block to the east and the Northampton Block and the

Ajana - Wandagee basement ridge to the west. The latter features separate the Coolcalalaya Sub-basin from the southern Carnarvon Basin farther west.

In the central area of the Perth Basin the aeromagnetic data indicate offshore a large region with a thick sedimentary sequence extending to the edge of the continental shelf. To the west of Perth, basement could be at a depth in excess of 6000 m. The magnetic data indicate that the basin also extends southwards from the area between the Leeuwin Block and the Darling Fault to the edge of the continental shelf south of Cape Leeuwin.

Outcrops of basalt, which produce magnetic anomalies, occur on the coast near Bunbury and in other places in the southern part of the Basin. A line of distinctive magnetic anomalies which extends offshore to the west of Bunbury and southwards from Bunbury across an area of moderately thick sediments to the south coast, has been interpreted as tracing the pattern of an old stream system filled with basalt (Quilty, 1963).

Gravity surveys

The gravity method has played an important role in the history of exploration in the Perth Basin. Apart from a few widely spaced observations, the first gravity readings across the Perth Basin were made by BMR in 1949, when an east-west gravity traverse was surveyed westward from Precambrian outcrops near Watheroo, about 190 km north of Perth, to assess sediment thickness before the drilling of a water-bore (Thyer & Everingham, 1956). It was found that the Bouguer gravity anomaly decreased westward by about 75 milligals over a distance of only 13 km, an exceptionally large gravity gradient. The traverse was extended westward to the coast. An interpretation of the intense gravity gradient, based on the assumption that the gravity deficiency was due to the presence of light sediments in proximity to denser Precambrian rocks, suggested a major fault (Darling Fault) and that the thickness of sediments on the down-thrown side of the fault might be of the order of 9000 m, a much greater thickness than had previously been suspected. Similar gravity results were obtained on an east-west traverse near Bullsbrook, about 30 km north of Perth. These interesting results prompted a reconnaissance gravity survey by BMR in 1951 and 1952 covering the whole of the onshore coastal region between Geraldton in the north and Cape Leeuwin in the south. In general, this survey consisted of a series of east-west traverses 30 to 50 km apart, with stations at 8 to 16 km intervals.

Between 1962 and 1967 WAPET carried out a number of land gravity surveys in the Perth Basin which greatly increased the station density. The largest of these was the Augusta-Moora gravity survey in 1963, which covered much of the onshore basin between Watheroo in the north and Cape Leeuwin in the south. The survey consisted of more than 6000 stations read at approximately 0.8 km intervals on 6 x 10 km loops. The WAPET surveys were subsidised under the Petroleum Search Subsidy Act (PSSA) and reports are available at BMR (see Appendix 2 for PSSA file numbers).

In 1969 BMR extended the reconnaissance gravity coverage of Australia by conducting two helicopter gravity surveys in the southern part of Western Australia (Fraser, 1973, 1974). These surveys, with a grid spacing of about 11 km, extended almost from the South Australian border in the east to the west coast south of about 24°S. They included part of the onshore Carnarvon Basin and the northern onshore portion of the Perth Basin, but because of the previous surveys by BMR and WAPET they did not include the central and southern portions of the Perth Basin.

In 1971 and 1972 Oceania Petroleum Pty Ltd carried out the Murchison-Gascoyne D-1 gravity survey onshore in the southern part of the Carnarvon Basin and the northwestern part of the Coolcalalaya Sub-basin. Stations were located at intervals of 0.8 km along traverses spaced approximately 12 km apart. In 1973 Sunningdale Oils Pty Ltd did the Coolcalalaya gravity survey over the central portion of the Coolcalalaya Sub-basin to the northeast of Geraldton, with readings at intervals of about 0.8 km on traverses 8 to 16 km apart. Those surveys were subsidised and PSSA reports on the surveys are available.

Gravity data in the offshore part of the Perth Basin are sparse. The BMR Continental Margin survey of 1970-1973 included both north-south and east-west lines with spacings varying from about 25 to 100 km over portion of the western Perth Basin and the Naturaliste Plateau. Few of the BMR traverses extended closer than about 30 km to the coast. A number of oceanographic survey cruises have extended to Fremantle and some of these have included gravity readings (Riesz & Moss, 1971). Some offshore seismic surveys in recent years have included gravity recordings made in conjunction with the seismic surveying. The gravity data have proved useful in delineating faults in areas of poor seismic reflection quality, such as on the Beagle and Turtle Dove Ridges.

The Bouguer anomaly map in Plate 3 was prepared by BMR but includes gravity data from all available sources. It should be noted that the gravity contours offshore are poorly controlled. The water layer has not been replaced by rock density material in calculating, offshore anomalies, so that these could be termed 'free air anomalies'.

With the exception of the offshore part of the basin, particularly near the coast, the Perth Basin is adequately covered by gravity readings on a regional scale. There is a considerable quantity of seismic and aeromagnetic data available in the offshore area where gravity data are lacking so that systematic completion of the gravity coverage does not have high priority from the point of view of petroleum exploration. However, gravity coverage with greater station density may be useful in defining the deeper regional structure in the offshore part of the basin and in delineating fault blocks.

Gravity surveys in the Perth Basin have made a useful contribution to the understanding of basin structure. As with aeromagnetic data, the outstanding features of the gravity anomaly pattern are the intense, linear gradients marking the Darling and Dunsborough Faults. The gravity observations led to the first realisation of the magnitude of these faults and provided the first indications of other faults such as the Urella Fault in the north and the Bussellton Fault in the south, which diverges to the northeast from the Dunsborough Fault near Busselton (Pl. 1). The steep gravity gradient defining the eastern margin of the Dandaragan Trough in the north follows the Urella Fault, some 25 km west of the Darling Fault, rather than the Darling Fault itself, indicating that the vertical throw of the Urella Fault exceeds that of the Darling Fault in the area southeast of Geraldton (Fraser, 1973). At the same time the gravity results have shown that some faults which had previously been mapped from surface geology were of little significance from a regional structural point of view.

The gravity data onshore south of the Northampton Block outlined the basin as a deep, relatively narrow trough of sediments within which there are two depressions named, following gravity evidence of their existence, the Dandaragan and Bunbury Troughs. Gravity interpretation suggests that the deepest part of the Dandaragan Trough to the north of Perth contains some 9000 m of sediments. Thicknesses of sediments in the Bunbury Trough to the south are believed to be about 5000 m and even on the gravity saddle between the Dandaragan and Bunbury Troughs near Harvey a sedimentary thickness of the order of 3000 m is expected.

An elongated gravity minimum (labelled 'Coolcalalaya Gravity Trough' in Plate 3) extends north of the Dandaragan Trough gravity minimum for some hundreds of kilometres to about 26°30'S latitude. The southern end of this northern gravity minimum terminates in 'en echelon' fashion just to the east of the northern end of the Dandaragan Trough gravity minimum, which tends slightly west of north in this area east of Geraldton and Dongara. The Coolcalalaya Gravity Trough, which corresponds approximately in extent with the Coolcalalaya Sub-basin, is similar in trend and profile shape to the Dandaragan Trough gravity minimum. This similarity in gravity anomalies suggests a structural similarity between the two areas and supports the idea that the Coolcalalaya Basin should be regarded as part of the Perth Basin rather than the Carnarvon Basin (Fraser, 1973).

The gravity profile across the Coolcalalaya Basin suggests that the basin floor dips gently east into the Darling Fault, which has significant vertical throw in that area. Gravity and seismic data indicate that the deepest part of the Coolcalalaya Basin, adjacent to the fault, contains some 4000 m of sediments. On the western side of the Coolcalalaya Sub-basin a south-trending gravity maximum, the Ajana-Wandagee Gravity Ridge, has been interpreted (Murchison-Gascoyne D-1 gravity survey, PSSA file 71/555) as the gravity expression of a basement ridge between the South Gascoyne and Coolcalalaya Sub-basin.

As already indicated, the Bouguer map of the Perth Basin is dominated by steep gradients related to major structural features. However, WAPET and others have attempted to separate regional structural effects from the more local gravity features. A number of residual gravity anomalies which might indicate structures of interest for petroleum exploration have been noted (see Augusta-Moora gravity survey, PSSA file 62/1935). Some of these have been further investigated by other means. For example, seismic surveys in the Lake Preston area northeast of Harvey and in the Sue area east of the Dunsborough Fault have confirmed gravity indications of structurally high areas and test wells have subsequently been drilled. In the Bunbury Trough residual gravity studies have helped to define the extent of near-surface basalts.

Seismic surveys

Seismic survey and line locations for most seismic surveys in the Perth Basin are shown in Plate 4, which serves to illustrate the density of seismic coverage in various areas. This plate also shows the location of seismic surveys listed in Appendix 2. The numbers shown in Column 1 of Appendix 2 provide the key to the map in Plate 4. Regional seismic contours are presented in Plate 5. Contours have been drawn on different seismic horizons in different areas, as there is no horizon which is persistent throughout the basin. Only the most important faults and regional structural features are shown.

Onshore The first seismic survey in the Perth Basin was the Gingin seismic survey by BMR in 1955. An east-west traverse was surveyed near Gingin, about 65 km north of Perth, to cross the centre of the major gravity depression of the Perth Basin (Dandaragan Trough). The results indicated the presence of sediments at least 5000 m thick and the deepseated, south-trending Gingin Anticline was discovered.

BMR carried out three other small seismic surveys in 1956 using explosives as energy source and simple reflection and refraction techniques. The Rockingham/Mundijong and Cookernup seismic surveys south of Perth confirmed the presence of large thicknesses of sediments west of the Darling Fault and raised the possibility that the sedimentary sequence at the eastern margin of the basin may continue east of the Darling Scarp at depth. This possibility is at variance with gravity indications that the Darling Fault is a normal fault. The Busselton seismic survey indicated a thickening of sedimentary section eastwards from the Dunsborough Fault towards the Darling Fault, near which at least 2500 m of folded and faulted sediments are present. In 1964 BMR conducted the Bullsbrook seismic survey across the basin about 50 km north of Perth in an attempt to derive a suitable recording technique for use on the Coastal Limestone formation, which had presented difficulties in obtaining useful seismic reflections in the past, and also to investigate geological structure in the basin. The survey used explosives and single-fold cover with a moderately heavy shot and geophone technique, but was largely unsuccessful in obtaining useful reflections on the coastal limestone. However, an anticline was located near the gravity minimum axis beneath about 2000 m of sediments.

WAPET also commenced seismic work in the Perth Basin in 1955. They did seismic reflection surveys in the Hill River and Arrowsmith-Dongara areas about 250 km north of Perth in 1955 and 1956. Survey results were reported to be generally poor. Apart from the early work by BMR, most seismic surveys in the Perth Basin have been undertaken by WAPET and their farmout partners French Petroleum Company Pty Ltd (later known as Total Exploration Australia Pty Ltd) and Union Oil Development Corporation (Union). Between 1955 and 1975, 48 land seismic surveys which were subsidised under the Petroleum Search Subsidy Act and which are listed in Appendix 2, and a number of unsubsidised land surveys were carried out by these companies. Most of the unsubsidised surveys, for which little or no data are available, were near the gas fields near Dongara. The subsidised surveys, and some of the unsubsidised surveys, are listed in Appendix 2.

Seismic surveys in the basin are too numerous to describe in detail, but the nature of the seismic work done can be illustrated by reference to some of the more significant surveys and groups of surveys. For convenience the onshore part of the basin will be considered from north to south.

(a) Coolcalalaya Sub-basin Very little seismic work has been done in the Coolcalalaya Sub-basin north of Geraldton. The Hyde Soak seismic survey was done for Continental Oil Company of Australia in 1964 and consisted of a single east-west reflection and refraction traverse across the Coolcalalaya Sub-basin at about latitude 28°S. Results were very poor despite the use of 12-fold multiple coverage. However a sedimentary thickness of more than 4000 m was indicated west of the Darling Fault near the eastern margin of the basin.

(b) Northern Dandaragan Trough In the northern part of the Dandaragan Trough, one of the larger reflection and refraction surveys carried out by WAPET was the Wicherina Survey. Conducted between 1962 and 1964, it covers nearly 1200 km of traverse in two areas. The larger area lies approximately 60 km east of Geraldton and the smaller one about 190 km south-east of Geraldton. An explosive energy source and single-fold coverage resulted in fair-quality reflections.

The objective of the survey was to investigate several gravity anomalies in the area. The northern survey area consists of a number of fault-bound blocks between which little or no seismic correlation is possible. The greatest thickness (about 3000 m) of sediments was indicated immediately west of the Urella Fault, about 25 km west of the Darling Fault. Follow-up surveys delineated the fault-bound, northwest-trending Yardarino Anticline about 55 km southeast of Geraldton, the northwest-trending Eneabba Fault about 95 km southeast of Geraldton, and several other faults and fault-controlled anticlines.

As already mentioned, many of the seismic surveys done for WAPET in the Dongara area, southeast of Geraldton, were unsubsidised and the results are not available. However, several of the earlier surveys up to 1964, before the discovery of hydrocarbons in the area, were subsidised. The Irwin seismic survey was done in 1964 to investigate further the Yardarino Anticline indicated by earlier surveys about 14 km east-northeast of Dongara. Explosives were used as energy source in conjunction with single-fold reflection coverage. Reflection results were generally poor. Some refraction shooting was also done.

More recently the Warradong 2 seismic survey and the Erregulla 3 seismic survey were done in the area to the southeast of Dongara in 1973 and 1974 respectively to map structure in more detail. Reports on these surveys are available through PSSA. The Warradong 2 seismic survey used explosives as energy source and six-fold multiple coverage. Data quality was fair to good on the Donkey Creek Coal (within Early Jurassic Cattamarra Coal Measures Member) horizon mapped, but much poorer on the Base Kockatea Shale (Lower Triassic) horizon. The results of the survey were integrated with data from 240 km of previous seismic work in the area and provided improved detail on the Warradong structure and other anticlines in the area. The Erregulla 3 seismic survey was a Vibroseis survey of 104 km of 24-fold reflection seismic coverage. Data quality ranged from poor to good. The resolution at the Base Kockatea Shale level showed an improvement over earlier surveys. However, deep mapping was done on an horizon associated with the Eneabba Member of the Lower Jurassic Cockleshell Gully Formation, which is generally conformable with the Base Kockatea Shale. The survey provided improved structural definition of the extensively faulted Erregulla structure.

French Petroleum Company held a farmout from WAPET between about 29°30'S and 30°30'S, south of the Dongara area, for some years and carried out three seismic surveys between 1964 and 1966. Of these Woodada seismic and gravity was the first, covering approximately 560 km of reflection and refraction traverse with single-fold coverage and using explosive energy source. Despite poor-quality data a number of faults and anticlines were evident. The site for Arrowsmith No. 1 well was established. The second survey, the Podooloo reflection survey, covered some 70 km of traverse and used a weight-drop energy source to achieve a slight improvement in data quality. The objective of testing the southern extension of the anticline that Arrowsmith No. 1 well was drilled on was not fully achieved, as the results were inconclusive.

The Athamo seismic and gravity survey covered over 400 km of traverse. The survey employed the weight-drop method and 4 to 6-fold multiple coverage to good effect. A horizon associated with the Middle Jurassic Coal Measure member was mapped with fair reliability over the whole area. Trends were roughly north-south and sediment thicknesses between 3000 and 4000 m. The northwest-trending Eneabba Fault, running approximately mid-way between the Darling Fault and the coastline, with several fault-bound anticlines of either side, was clearly defined. The Beagle Fault, approximately 6 km inland from and parallel to the coastline was delineated on the Beagle Ridge, the south-trending western limit of the northern portion of the Dandaragan Trough. It was deduced that the major gravity anomalies had their causes in basement rather than shallow structures.

(c) Central Dandaragan Trough The Barragoon reflection seismic survey conducted by WAPET in 1971 covered the remainder of the Perth Basin to the north of Perth. The survey involved 558 km of traverse using 6-fold multiple coverage and a dynamite energy source. Data quality ranged from poor to good. Objectives were to provide regional information on the Dandaragan Trough and detailed coverage on the Walyering fold trend, an anticlinal axis trending south on the western side of the Dandaragan Trough. Particular emphasis was placed on tracing a prospective reservoir in the Upper Jurassic Yarragadee Formation. It was possible to map five horizons between the Upper Triassic and the Lower Cretaceous.

Between the surface and the Lower Jurassic Donkey Creek horizon two approximately south-trending anticlinal axes were mapped. These were the Gingin trend on the eastern side of the basin and the Walyering trend on the western side. Several interesting culminations were mapped on both trends. Data were too poor to indicate whether the structures exist below the Donkey Creek horizon.

Since 1971 a number of other seismic surveys have been carried out in the Dardaragan Trough north of Perth to provide more information on the complex structure of the area. Three of the largest surveys were the Dandanagan East Flank (324 km), the Gingin-Bullsbrook D-1 (211 km) and the Mullering (196 km) seismic surveys. Explosive energy source and six-fold multiple coverage shooting were used on all three surveys, but Vibroseis and some 24-fold coverage were also used on the Mullering survey, on which the presence of Coastal Limestone at the surface in the west of the area adversely affected results, as on all previous surveys.

(d) Southern Dandanagan Trough and Harvey Ridge Immediately south of Perth, the Rockingham seismic survey conducted by WAPET in 1972/1973 covers an area as far ssuth as 33^{o} latitude. Approximately 156 km of seismic reflection work was done using a Vibroseis energy source and with 12 and 24-fold multiple coverage. Eighty-eight km of previously recorded data was reprocessed to give improved results and allowed a tie to be made to Pinjarra No. 1 and Cockburn No. 1 wells. The Vibroseis method gave poor but sometimes usable results over Coastal Limestone outcrops where previous dynamite surveys had produced very poor results. Data quality elsewhere was poor to fair but also mostly usable. Rather long (1700-1900 m) geophone spreads were used to enhance data at deeper levels. Survey objectives were to explore the southern part of the Dandaragan Trough and the southern extension of the Gingin trend. Of the four horizons mapped the two deepest, in the Upper Triassic and Lower Jurassic, show complex faulting with a predominant north-south trend. In the Pinjarra area an anticlinal axis was mapped on these horizons at depths of between 1900 m and 4600 m. There is some suggestion that this anticline may be continuous with the Gingin trend to the north.

The Lake Preston seismic reflection and refraction survey, conducted by WAPET in 1964, overlapped the southern part of the Rockingham Survey and extended coverage farther south to Bunbury. This survey had the objective of investigating the possible relationship between structure and gravity anomalies at Pinjarra and Lake Preston. Approximately 224 km of traverse was shot using explosives and single-fold coverage. Although data quality was poor in the Lake Preston area, north, south, and east dips indicated a seismic 'high' corresponding to a positive gravity anomaly.

WAPET have since done a number of seismic surveys in the Lake Preston area, including the Preston Detail seismic survey in 1970 and the Preston D1 seismic survey in 1971. These surveys were designed to detail structures on the northwest-trending Harvey Ridge near Lake Preston. The surveys employed explosives and 6-fold multiple coverage and data quality ranged from poor to good. Three reflecting horizons were mapped, which were identified as near top of Lower Jurassic Eneabba Member, near top of Upper Triassic Lesueur Sandstone and near top of Permian. A closed anticline, the Myalup structure, was defined.

The Harvey D-1 seismic survey, conducted by WAPET in 1969/1970, improved knowledge of structural detail in the Bunbury area. Survey objectives were to obtain detailed seismic control over the Harvey Ridge and to tie seismic results to Pinjarra No. 1 well. Very poor to good data were obtained using explosives and six-fold multiple coverage along 135 km of traverse. The three horizons mapped revealed several anticlines and fault-bound 'highs'. The deepest horizon, near top of Permian, ranged in depth from 3000 to 6000 m, deepening to the northeast and in the extreme south. The Harvey Ridge was confirmed as a northwest-trending anticline, approximately 15 km northeast of Bunbury. Both the northeastern and southwestern margins of the ridge are faulted.

(e) <u>Bunbury Trough</u> Following earlier geophysical surveys by BMR and WAPET, Union carried out several surveys from 1967 to 1969 in the area between Bunbury in the north and Flinders Bay in the south. The Margaret River seismic survey, conducted from near Busselton almost south to Flinders Bay in 1967/1968, consisted of approximately 356 km of traverse shot using explosives and six-fold multiple coverage. Reflection quality varied between poor and good. The objectives of the survey were to examine anomalous features suggested by previous geophysical surveys. Five horizons were mapped, although geological identification only became possible by virtue of wells drilled after the survey. The survey area covered the western half of the Bunbury Trough. Sediments were found to exhibit a general east dip and reached a maximum thickness of 3500 m. The survey indicated that a number of south-trending normal faults, and intersecting east-west faults break the area up into fault blocks superimposed onto a general north-south fold trend. Several structural closures were discovered on this fold trend. On the western side the fault blocks constitute a series of steps rising to the west.

In 1969 Union conducted the Wonnerup-Flinders seismic survey of 131 km in two areas, the Wonnerup area northwest of Busselton and an area north of Flinders Bay, to extend detailed seismic control and to evaluate anomalous features suggested by the 1967 survey. Using explosives and six-fold multiple coverage, fair to good-quality data were obtained in the northern area, but data in the Flinders area were poor. Five seismic horizons were mapped, the deepest within the Permian Irwin River Coal Measures. A number of faulted anticlines were detailed, including a closed structure in the Flinders area which was tested by the drilling of Blackwood No. 1 well.

Offshore. More than 30 marine seismic surveys have been done in the offshore Perth Basin. Marine seismic coverage is illustrated in Plate 4.

The first offshore seismic survey was a large survey done for BP Petroleum Development Australia Pty Ltd in 1965, the Abrolhos marine seismic survey. This survey was west and northwest of Geraldton and covered the boundary region between the Perth and Carnarvon Basins. Explosives were used as energy source and most recording was single-fold. Results were generally poor, but experiments with three-fold and six-fold multiple coverage gave improved data quality. The survey showed the region between the Perth and Carnarvon basins to be characterised by northeast-trending step faults rising to the southeast of the Carnarvon Basin and suggested a large basin deepening to the south of Geraldton (Abrolhos Sub-basin)., with sedimentary thicknesses of up to 500 m in the south of the survey area. Detailing by later seismic surveys in this southern area has revealed a number of small fault-bounded anticlines.

Most offshore seismic surveys in the Perth Basin south of Geraldton have been carried out for WAPET. That company commenced offshore seismic exploration in 1965 with the Perth marine seismic survey, followed in 1966 by the Rottnest marine seismic survey. These surveys involved some 784 km of reconnaissance lines using explosives and three-fold multiple coverage. The results were adversely affected by water reverberations, but a regional structural picture of the central offshore portion of the Perth Basin was established. Since 1965 WAPET carried out marine surveys annually to 1974, and BP Petroleum Development did several seismic surveys in the extreme north of the basin. In the following paragraphs only some of the more significant offshore seismic surveys are mentioned. The regional structural picture which has evolved for the basin is illustrated in Plate 5, which shows seismically derived contours for various horizons in different areas.

In 1968 WAPET conducted the Direction Bank marine seismic survey consisting of 1610 km of traverse in the central part of the Perth Basin. Explosive and air gun energy sources were used with 3, 6, and 24-fold multiple coverage. Data quality varied from poor in the northern part of the survey area to fair elsewhere. In the north of the area the south-trending Beagle Ridge was indicated on a possibly Palaeozoic horizon at a depth of about 1200 m, with sediments deepening rapidly to the southwest into the Vlaming Sub-basin. Farther south the deeper horizons mapped were tentatively identified as Early Jurassic and Triassic. At the Lower Jurassic level a large graben was mapped in the centre of the survey area and some structural leads of interest for petroleum search were indicated. About 40 km west of Perth the Early Jurassic was shown to reach depths in excess of 5000 m.

The Koombana marine seismic survey was done by WAPET in the southern part of the Perth Basin in 1969. About 1316 km of seismic traverse was surveyed using mainly airguns as energy source and sum-2 12-fold multiple coverage. Data quality varied from poor to good. The survey covered the western portion of the continental shelf southwards from Perth to Cape Naturaliste and the shelf from Cape Naturaliste south to Cape Leeuwin and east to Pt D'Entrecasteaux. The Koombana seismic interpretation report available through PSSA incorporates a considerable amount of previous seismic work in the survey area. In the northern part of the survey area large thicknesses of sediments were confirmed. Several north-trending fault-bound anticlines were indicated in the pre-Cretaceous sediments, but no significant closures were indicated in the overlying sediments. The Precambrian Leeuwin Block was shown to extend offshore to the northwest, west, and south and to be covered by only a thin sequence of sediments in those areas. Southeast of the Leeuwin Block the Perth Basin was confirmed to extend offshore between the Dunsborough and Darling Faults. Basement was indicated to deepen from about 1000 m immediately east of the Dunsborough Fault to about 6000 m west of the offshore extension of the Darling Fault.

The Perth Waters seismic survey was a large (900 km) survey done by WAPET in 1970 to provide more detailed mapping of structural leads revealed by earlier surveys. The survey lines were widely scattered over the offshore area from near Dongara in the north to Bunbury in the south. An airgun energy source was used with 24-fold multiple coverage, but results were only poor to fair and were sometimes inadequate to define structural prospects for drilling. In the north of the area the survey provided additional seismic control on the Turtle Dove Ridge and its junction with the Beagle Ridge near the coast. These two structural features form a bifurcating subsurface ridge system to the west of and more or less parallel to the Dandaragan Trough. Two anticlines considered to be possible drilling targets were indicated, but because of the poor quality of the seismic data they were not well-defined. In the southern portion of the basin no significant new structures were discovered but seismic control was extended. New data from the Perth Waters survey were combined with about 2150 km of previous seismic lines for interpretation.

After the Abrolhos marine seismic survey already mentioned, BP Petroleum Australia and its partners carried out several marine seismic surveys between 1966 and 1972 in the permits which they held near the northern margin of the Perth Basin. The largest of these, the Geelvink Channel marine seismic survey in 1970, involved 1435 km of traversing with airguns and 24-fold multiple coverage, but not all of this survey was within the Perth Basin. Data quality was generally poor below a Lower Cretaceous unconformity, largely because of the prevalence of faulting. A number of structural leads were indicated but none was well defined. The Geelvink Channel D-1 seismic survey and the Zeewyk seismic survey in 1971 and 1972 respectively were done to map drilling prospects in more detail. In 1971 Aquapulse (propane-oxygen gas mixture in rubber cylinder) and in 1972 Maxipulse (small, deep explosive charge) energy sources were used and results were slightly improved compared with pre-1971 surveys. Of several structures mapped, a horst trending parallel to the coast about 30 km west-southwest of Geraldton and known as the Zeewyk structure was the most attractive prospect mapped by BP and partners, but closure on this was of small extent. Farther south, near the centre of the Abrolhos Sub-basin, the Geelvink structure mapped by WAPET seems a better prospect.

Since 1970 the offshore geophysical surveys done by WAPET in the Perth Basin have not been subsidised. The results of these are not generally available to the public.

4. PETROLEUM PROSPECTS

Discoveries of petroleum

Gas has been discovered in five fields located onshore in the Dandaragan Trough in the northern and central part of the basin: Yardarino (discovered 1964); Gingin (1965); Dongara (1966); Mondarra (1968), and Walyering (1971). Although the five fields were connected by pipeline to Perth, Kwinana, and Pinjarra, only the Dongara field and the small Mondarra field are in commercial production. Non-commercial oil was also discovered in the Yardarino and Dongara fields.

The Dongara field came into production in October 1971, and the Mondarra field in April 1972. The Gingin field produced from Gingin No. 1 for production testing purposes during 1972 and the well was then shut in. Walyering No. 1 was brought into production in March 1972 but pressure decline led to the shutting off of the well in July 1972. The connection with the pipeline has been severed, and the well plugged and abandoned. The Yardarino field has not so far been developed to the production stage.

Table 2 gives estimates of hydrocarbon reserves and production figures for the Dongara, Mondarra, Yardarino, and Gingin fields.

Non-commercial gas flows were produced in Whicher Range No. 1 in the Bunbury Trough, and in Arrowsmith No. 1 in the Dandaragan Trough.

In addition to the non-commercial oil in the Yardarino and Dongara fields, minor oil occurred in Mt Horner No. 1, North Erregulla No. 1, and Erregulla No. 1, also located in the Dandaragan Trough. Non-commercial oil was produced in the offshore wells Gage Roads Nos. 1 and 2 drilled in the Vlaming Sub-basin.

Appendix 3 includes the stratigraphic sequences and lithologies penetrated by selected wells which have produced either commercially significant hydrocarbons or significant shows.

TABLE 2

ESTIMATES OF THE RECOVERABLE, PROVED PLUS PROBABLE, PETROLEUM RESERVES IN THE PERTH BASIN AS AT 31.3.77

FIELDS	INITIAL RESERVES				CUMULATIVE PRODUCTION				CURRENT (REMAINING) RESERVES			
	Hydrocarbon liquids ($x10^6 m^3$)				Hydrocarbon liquids ($x10^6 m^3$)				Hydrocarbon liquids ($x10^6 m^3$)			
	Crude Oil	Natural Gas Liquids (NGL): Well Condensate & Plant Products	Natural Gas Liquids (NGL): Liquified Petroleum Gas (LPG)	Natural (Sales) Gas ($x10^9 m^3$)	Crude Oil	Natural gas liquids (NGL): Condensate	Natural gas liquids (NGL): Liquified Petroleum Gas (LPG)	Natural (Sales) Gas ($x10^9 m^3$)	Crude Oil	Natural Gas liquids (NGL): Condensate	Natural Gas liquids (NGL): Liquified Petroleum Gas (LPG)	Natural (Sales) Gas ($x10^9 m^3$)
Dongara, Mondarra, Yardarino, Gingin	0.24	0.07	-	12.74	0.02	0.02	-	4.18	0.22	0.05	-	8.56

Definitions

Proved reserves: Those reserves established by drilling in a reservoir of known lateral extent, and included within an arbitrary radius of one mile from a well bore.

Probable reserves: Those reserves established in a reservoir beyond the radius of one mile from a well and reasonably assumed to be contained within the limits of the reservoir as indicated by seismic and geological control.

Sales gas: Raw gas obtained from the well after processing to remove condensate and LPG, and CO_2 in excess of 3%.

Note

The table indicates the Company estimate of the initial and current reserves of those fields which have been declared commercial and combines both the Proved and Probable reserves.

Prepared from THE PETROLEUM NEWSLETTER No. 69, Petroleum Technology Section, BMR

Source, reservoir, and cap rocks

Northern Dandaragan Trough: In the Dongara area the reservoirs are sandstones in the Early Permian Carynginia Formation and Irwin River Coal Measures, the Late Permian Yardarino Sandstone Member of the Wagina Sandstone, and the Early Triassic Dongara Sandstone Member of the Kockatea Shale. The depositional history of these units has been studied by Bird et al. (1971) by interpreting the four-arm dip meter analysis log from Dongara No. 17 in conjunction with electric log and geological data. The stratigraphy of the 'Basal Triassic Sandstone' (includes Yardarino and Dongara Sandstone Members, see Stratigraphy Section) is discussed by Hosemann (1971).

The depositional environment of the Irwin River Coal Measures is interpreted as probably near-shore marine with a possible northwesterly source area. The Yardarino and Dongara Sandstone Members are interpreted as a composite of shore-line and offshore bar accumulations. High, essentially random dip scatter reflects the high energy of the environment. Gas is produced from these reservoirs in the Dongara and Mondarra fields and occurs in commercially significant quantity in the Yardarino field (Table 3). The Yardarino Sandstone Member also contains oil in the Dongara and Yardarino fields.

Other reservoirs in the northern Dandaragan Trough are sandstone lenses within the Early Triassic Kockatea Shale in Mt Horner No. 1 and North Erregulla No. 1, and the Early Jurassic Cockleshell Gully Formation (Eneabba Member) in Erregulla No. 1 which produced non-commercial oil shows, and the Lower Permian Carynginia Formation which produced non-commercial gas flows in Arrowsmith No. 1.

The sandstone reservoirs in the Irwin River Coal Measures are capped by the interbedded shale and coal in which the gas originated. The Kockatea Shale caps the underlying Yardarino and Dongara Sandstone Members.

Geochemical analysis of oils and condensates from the Dongara, Mondarra, and Yardarino fields, and the Erregulla and Mt Horner wells (Powell & McKirdy, 1973) has shown that although they occur in reservoirs ranging in age from Permian to Triassic, their composition is very similar, suggesting a common source. They are highly paraffinic, with low pristane to phytane ratios, and API gravities in the range 34.6^{o} to 37.6^{o}. The oils are very waxy, being solid at room temperature. The most likely source for the liquid hydrocarbons is the Kockatea Shale in which the oil found is considered to be more or less in situ. Distillation data show an absence if light fractions in oils from the Dongara, Mondarra, and Yardarino fields, indicating that the oils are not in equilibrium with the overlying gas, and implying that the accumulation of the oil and gas were separate events. A separate source for the gas is suggested, which seems more likely than two separate periods of generation and migration from the same source. A possible origin for the gas is considered to be the Permian Coal Measures downdip of the present hydrocarbon accumulations, and it is suggested that the gas has mobilised the light boiling fractions from the oils. The geochemical characteristics of the oils: waxy nature; lack of naphthenic components; low yield of light fractions (Mt Horner and Erregulla wells); and low pristane to phytane ratios, indicate that the source is terrestrial organic matter which has undergone little thermal alteration. Pristane to phytane ratios are usually high in oils from a non-marine source but Brooks et al. (1969) have shown that low pristane to phytane ratios are characteristic of low-rank coals which have not undergone a high degree of thermal alteration.

Central Dandaragan Trough: Sandstones within the Early Jurassic Cockleshell Gully Formation have produced gas and condensate in the central Dandaragan Trough. The hydrocarbons occur at a number of separate levels within the Cattamarra Coal Measures Member. Geochemical analysis of condensate from different levels within the Gingin and Walyering fields (Powell & McKirdy, 1973), which are about 55 km apart, has shown that samples from equivalent stratigraphic horizons in the two fields are similar in composition but that samples from upper and lower levels in the same field are markedly different. The condensates are paraffinic to naphthenic and those from the deeper levels have a high wax content. All show intermediate pristane to phytane ratios. They are interpreted to have been derived from a mixed marine and non-marine source probably within the Cockleshell Gully Formation itself which was deposited in a marginal marine to continental environment. Bird et al. (1971) in a detailed analysis of the depositional environment of this unit in the Dongara area, find evidence of frequent shallow marine transgressions and regressions over a mature land surface with a gentle south-southeast palaeoslope, the thin coal seams resulting from the growth of vegetation at the end of a regression (e.g. as in mangrove swamps), and the clean sands from the reworking of sediments on a coastal plain of low relief.

Bunbury Trough: Gas shows were recorded below 4000 m in the Late Permian Sue Coal Measures in Whicher Range No. 1 and in Wonnerup No. 1 (Appendix 3 and Plate 8) associated with sandstone interbeds. Drill-stem testing failed in the Wonnerup well, but in Whicher Range No. 1 up to 1.93 MMcfD of gas was produced through a ½" choke in one drill-stem test, and several barrels of condensate from another at a deeper level. The gas zones were in medium to coarse-grained sandstones with relatively poor porosity and permeability, and were clearly associated with the occurrence of coal seams.

Abrolhos Sub-basin: Only well, Gun Island No. 1, has been drilled in this sub-basin. South Turtle Dove No. 1 was located on the Turtle Dove Ridge which forms its western flank. Although there were no significant indications of hydrocarbons in Gun Island No. 1, the well confirmed the extension of the Jurassic Yarragadee, Cadda, and Cockleshell Gully Formations offshore to at least the outer edge of the continental shelf in the Abrolhos area. Good potential sandstone reservoirs occur throughout the Yarragadee Formation and in the upper two-thirds of the Cockleshell Gully Formation. Very minor shows of methane associated with carbonaceous shales and rare coal beds were recorded in the Cockleshell Gully Formation. Thin potential cap rocks occur throughout the Jurassic sequence, but the most significant is the Cadda Formation which is predominantly a thick succession of marine shales overlying the Cockleshell Gully Formation.

No hydrocarbons were reported from South Turtle Dove No. 1B.

Vlaming Sub-basin: Wells have now been drilled on structural traps in the Rottnest Trench (Charlotte No. 1, Quinns Rock No. 1) and on its western flank (Roe No. 1 and Cage Roads Nos. 1 and 2), in the central part of the sub-basin, (Warnbro No. 1, Challenger No. 1, Bouvard No. 1), and near the southern margin (Sugarloaf No. 1), but the only significant indications of hydrocarbons were in Gage Roads Nos 1. and 2 from sandstone in the Upper Jurassic - Neocomian Yarragadee Formation, and the basal sand (Gage Sandstone Member) of the Neocomian South Perth Shale. The sequences penetrated by representative wells in the sub-basin are given in Appendix 3 and a stratigraphic cross-section is shown in Plate 6. The South Perth Shale, the 'Carnac Formation' and the Quinns Shale Member provide capping for the reservoir sands. Hydrocarbons are believed to have been generated in the South Perth Shale deposited in the Rottnest Trench during the Neocomian marine incursion. Although hydrocarbons have been encountered only in the Gage Roads wells, the reservoir characteristics of the Gage Sandstone Member and, to a lesser extent, sandstone beds in the Yarragadee Formation, where intersected in other wells, are generally favourable.

In Gage Roads No. 1 the shows were from the intervals 1743.5 - 1794 m in the Neocomian Yarragadee Formation and 2618.2 - 2645.7 m in the Late Jurassic Yarragadee Formation. Analysis of a core from the upper zone gave porosities generally greater than 25% and permeabilities ranging up to 1132 md and averaging around 350 md. Water saturation was estimated from wireline log analysis to be greater than 70%, and the salinity from water recovered during drill-stem testing was 38200 ppm NaCl. Drill-stem testing of two zones was carried out. The first test (swab and flow) covering the intervals 1760.2 - 1783.2 m and 1764.8 - 1769.1 m recovered 40 barrels of 37° A.P.I. oil and 82 barrels of water over a 30 hour period. The second test covering the intervals 1779.4 - 1782.2 m recovered a total of 58.5 barrels of 41.2° A.P.I. oil and 25 barrels of water. Recovery rates of about 350 barrels per day were attained. The oils from both intervals were similar in composition, having a high paraffin content. Core analysis of the lower zone indicated poor reservoir characteristics with porosities generally less than 15% and mainly zero permeability. In Gage Roads No. 2 a core cut over the interval 1357.3 - 1358.8 m (Gage Sandstone Member) bled oil and gas, but the reservoir characteristics were poor owing to calcite cementation and thin limestone beds. Wireline log evaluation indicates only 1.5 m of non-commercial oil sand.

Table 3 gives porosity and permeability values for known reservoirs in the Perth Basin.

Hydrocarbon traps

The hydrocarbon traps in the Perth Basin are mainly structural. Surface mapping and seismic surveys have shown that the general structure of the basin is characterised by tilted fault blocks with associated marginal folds. All the hydrocarbons discovered have been in fault-controlled anticlines. However, in the case of the Late Permain-Early Triassic reservoir sands, stratigraphic pinchout may occur beneath the Kockatea Shale.

Table 3.

POROSITIES AND PERMEABILITIES, PERTH BASIN RESERVOIRS

FIELD OR WELL	LOCATION	RESERVOIR	POROSITY (intergranular) %	PERMEABILITY milidarcies
Dongara*	Northern Dandaragan Trough	Yardarino Sst Mbr	average 22	average 127
Mondarra*	"	Irwin River C.M. Yardarino Sst Mbr ('Basal Triassic Sst')	average 5.4-9 9-16	average 1.0 3-164
Yardarino*	"	"	7-17 (average 14)	7-5537 (average 780 ±)
Gingin*	Central Dandaragan Trough	Cockleshell Gully Fm.	5-14 (average 10)	0.1-5.4
Walyering*	"	Cattamarra C.M. Mbr of Cockleshell Gully Fm. 11050' Sand	4.4-14.8 (average 9.5)	up to 93 (average effective 5.
Whicher Range No.1**	Bunbury Trough	Sue Coal Measures (4008-4058 m)	7.1-35.4 (average 15.0)	0.1-3.7 (average about 2.59)
Wonnerup No. 1**	"	Sue Coal Measures (4454-4459 m)	4.6-15.8 (average 11.0)	0.1-63.0 (average about 16.7)

* After Beddoes (1973)
** From well completion reports

The Dongara field lies on the southern nose of the Northampton Block in an anticlinal flexure which covers an area of about 26 km^2 and is bounded on the east by a fault with a down-to-the-east displacement of about 600 m. The distribution of oil and gas in the field is probably controlled by a combination of small-scale faulting and stratigraphic complications. Production is obtained from depths of about 1670 m (Playford, 1971; Beddoes, 1973).

The Yardarino and Mondarra fields are located in similar but very much smaller structures 10-20 km to the east of the Dongara field.

The Gingin field is in a very large south-trending anticline first located by a BMR seismic survey (Vale, 1956). The structure, which is about 48 km long, developed during the Late Jurassic and is mapped in sediments below 1500 m (subsea). The reservoir sandstone occurs between 3795 m and total depth in Gingin No. 1. Restricted permeability in the field is a limiting factor to production (Playford, 1971; Beddoes, 1973; Jones, 1976).

The Walyering field lies about 80 km northwest of Gingin in a large faulted anticline which developed during the Middle and Late Jurassic with further growth and faulting at the end of the Jurassic and in the Early Cretaceous (WAPET, 1971a). The reservoir sands occur at 3270 m and 3368 m. As in the Gingin field, permeability is restricted, particularly in the lower reservoir.

Petroleum exploration in the Perth Basin has been hampered by the generally poor quality of the seismic data obtained over a large area of the basin owing to the presence of outcropping Coastal Limestone, deep weathering, and the structural complexity of the Palaeozoic and Mesozoic sequence (Taylor, 1969). Many wells have been drilled on poorly defined structures, but they have provided much needed stratigraphic control and velocity data.

Seismic surveys and surface mapping carried out to date have indicated the existence of numerous fault blocks and faulted anticlines, both onshore and offshore, which could form suitable traps for hydrocarbons. Many of these structures require further detailed seismic mapping before locations for test drilling can be selected.

Prospectivity of the basin

The most prospective areas are believed to be offshore, particularly in the Abrolhos Sub-basin where the only well drilled so far established the offshore extension of the Jurassic sequence which has yielded gas in significant quantity onshore. WAPET (1968; 1969 b and c) has detailed a prospect, the Geelvink structure, in the central Abrolhos Sub-basin which is a complex structure associated with a major down-to-the-east fault, mapped on the Jurassic Cattamarra Coal Measures Member. Another less attractive prospect the Zeewyk structure (Chapter 3) was mapped by BP Petroleum and partners north of the Geelvink structure and about 30 km west-southwest of Geraldton. Closure on this structure is about 25 km^2.

In the Vlaming Sub-basin the only encouragement after the drilling of nine wells has been the discovery of oil in non-commercial quantity in Gage Roads Nos. 1 and 2. As source, reservoir, and cap rocks have been shown to occur in the sub-basin in structures suitable for hydrocarbon accumulation, exploration so far can be said to have downgraded its prospectivity.

Onshore, all the exploration wells drilled since the discovery of the commercial gas fields in the Dandaragan Trough have generally downgraded the prospectivity of the basin. Although poor seismic control must be regarded as a contributing factor to the lack of success, the lenticular nature of the reservoir sands, evidence of restricted permeability, flushing of potential reservoirs, and in the southern part of the basin the depth of the prospective horizons all detract from the petroleum prospects. In the Dandaragan Trough there has been no further appraisal of the Dongara and Mondarra fields since 1969, and of the Yardarino field since 1964. However a recent press statement ('Australian Financial Review' 10-11-76) indicated that WAPET is considering drilling a well close to the Dongara gas field but on an independent structure. The siting of the well has resulted from a reassessment of the seismic data using modern techniques. Even a small discovery would be valuable in this area in view of the declining reserves in the Dongara field. The proven reserves are expected to be exhausted by about 1985, and from 1981 only 66 MMcfD will be available in comparison with the present daily consumption of about 82 MMcf (Press statement, op.cit.).

The most recent petroleum exploration drilling in the Dandaragan Trough was not encouraging. Heaton No. 1 and Narlingue No. 1 were drilled in 1972 about 20 to 30 km to the northeast of the Dongara, Yardarino, and Mondarra fields. There were no indications of hydrocarbons but sandstones with excellent reservoir qualities were encountered in the 'Basal Triassic Sandstone' and the Wagina Sandstone in both wells, and also in the Irwin River Coal Measures in Narlingue No. 1. In the well completion reports the lack of hydrocarbons was attributed to possible migration before the completion of structural growth in the Cretaceous. In 1974 Coomallo No. 1 was drilled on the west flank of the central Dandaragan Trough to test a small closure detailed by the Coomallo 2 seismic survey (Appendix 2). Again there were no significant indications of hydrocarbons. The objective horizon, the Cattamarra Coal Measures Member, was encountered about 900 m below the depth predicted from the poor-quality seismic data. The well completion report suggests several possible reasons for the lack of hydrocarbons: lack of closure of the objective horizon; inhibition of up-dip migration by structural or stratigraphic discontinuities; palaeotemperatures too low for hydrocarbon generation. The present-day geothermal gradient is low in the area. A gradient of about $2^{o}C/100$ m ($1.1^{o}F/100$ ft) was estimated in Coomallo No. 1.

The least prospective areas seem to be the Coolcalalaya Sub-basin in the north, which is poorly known but which is thought to contain mainly unprospective Lower Palaeozoic sediments, and the Yallingup Shelf in the south, which generally has only a thin sedimentary sequence overlying Precambrian basement.

In summary, the Perth Basin contains large thicknesses of sediment which include suitable source, reservoir, and cap rocks. Commercial hydrocarbons have been proved to exist in modest quantities onshore and these have been minor indications of hydrocarbons, including oil, offshore. Although in general terms the stratigraphy and structure of the basin is now fairly well known, stratigraphic control is still sparse in many areas, particularly offshore and the basin cannot be said to have been exhaustively explored for petroleum. This is particularly the case offshore, where only 11 wells have been drilled in a large area.

The prospectivity of the basin as a whole must therefore be regarded as fair.

5. FUTURE EXPLORATION REQUIRED

Geophysical

Magnetic coverage of the Perth Basin is adequate. Regional gravity coverage of the onshore areas of the basin is also complete, but detailed gravity surveys may be useful in the future as an aid to mapping structure, particularly faults, in certain areas where seismic record quality is poor. Regional gravity coverage offshore is incomplete. As exploration is now at the stage where there is a reasonable reconnaissance grid of seismic lines offshore, a systematic survey to complete regional gravity coverage does not rate high priority from the point of view of petroleum search. However, the value of the gravity method in defining faults has already been demonstrated in the basin both onshore and offshore and it is therefore recommended that gravity should be recorded in conjunction with marine seismic surveys wherever practicable in the future.

Plate 4 indicates that there is seismic reconnaissance coverage of most of the basin, with semi-detailed and detailed coverage in a number of areas. However, it should be noted that some of the existing coverage is inadequate because of poor data quality. Seismic coverage of the Coolcalalaya Sub-basin is very sparse. Apart from filling existing gaps, the future need is particularly for more detailed mapping of the numerous structural leads which have been indicated to date in order to select drill sites.

Seismic data quality in the Perth Basin has generally been poor, largely because of the complexly faulted nature of much of the basin and also because of the screening effect of the near-surface Coastal Limestone both onshore and offshore. Future seismic surveys will generally need to employ the most up-to-date, high-effort technology in order to produce results of adequate reliability for detailed mapping of prospective drill targets. Modern surface input methods have made some slight improvements to onshore data quality on the Coastal Limestone in recent times, but a major improvement in seismic technique is required to produce satisfactory records on this formation. If a major breakthrough in technique is made, there will be a need for a considerable amount of reshooting.

As offshore drilling and production technology improves to the point where exploration in water more than 2000 m deep becomes attractive, it will be desirable to carry out further seismic profiling over those areas of the Naturaliste Plateau where a considerable thickness of sediments has been indicated, in order to locate drilling targets.

Drilling

The Geelvink structure in the central part of the Abrolhos Sub-basin is sufficiently detailed for a well site to be selected. The drilling of such a well would establish the stratigraphic succession in the Abrolhos Sub-basin, which is at present extrapolated from Gun Island No. 1, in addition to testing the hydrocarbon potential of the predicted Permian, Triassic, and Jurassic rocks which have yielded gas onshore in the Dongara, Mondarra, Yardarino, Gingin, and Walyering fields.

Drilling is required to establish the stratigraphic succession in the offshore Bunbury Trough. Similarly, when the required deep-water technology becomes available, a well or wells to provide stratigraphic information on the Naturaliste Plateau would be desirable.

A prerequisite for further drilling onshore is better definition of structures by seismic work than has generally been possible in the past.

6. CONCLUSIONS

The Perth Basin is a medium-sized basin containing large thicknesses of sediments known to include suitable source, reservoir, and cap rocks. It has been explored for petroleum more or less continuously since 1949 and there is a large body of geological and geophysical information available both onshore and offshore. Gas has been discovered in modest but commercial quantities onshore in the northern part of the basin, but elsewhere exploration efforts have been disappointing.

The prospectivity of the basin as a whole is regarded as fair. The most prospective areas are believed to be offshore, particularly in the Abrolhos Sub-basin in the north, where only one well has so far been drilled. Only eleven wells have been drilled in the whole of the extensive offshore area of the basin to date, so that some areas are still poorly known. Several attractive, undrilled structures are known offshore and it is likely that many other prospects exist. Onshore, improvement in seismic techniques, providing better definition of structures, would greatly increase the chances of success.

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APPENDIX 1.

PETROLEUM EXPLORATION AND STRATIGRAPHIC WELLS, PERTH BASIN

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
ABROLHOS OIL N.L.						
Heaton No. 1 BMR file 72/979	29 07 18 115 12 45	H/50-5	GL 185.6 RT 190.5	3 5 72 24 6 72	2438.4	PA
Narlingue No. 1 BMR file 72/790	29 04 14 115 06 10	H/50-5	GL 192.9 RT 196.6	27 3 72 24 4 72	2130.3	PA
Bureau of Mineral Resources						
BMR No. 10 (Beagle Ridge)	29 49 38 114 58 30	H/50-5	GL 10 KB 21	1 8 59 6 9 59	1192.4	PA
BMR No.10A (Beagle Ridge)	29 49 36 114 58 30	H/50-5	GL 15 KB 26	2 5 60 24 6 60	1482.7	PA
B.P. PETROLEUM DEVELOPMENT AUSTRALIA PTY LTD						
Gun Island No.1 BMR file 68/2015	28 53 30 113 51 27	H/49-4	GL 3.0 KB 7.3	26 6 68 6 11 68	3724.6	PA
FRENCH PETROLEUM COMPANY (AUSTRALIA) PTY LTD (now Total Exploration Australia Pty Ltd)						
Cadda No. 1 BMR file 65/4164	30 20 15 115 12 48	H/50-9	GL 77.7 KB 82.2	13 7 65 16 9 65	2794.7	DPA
Donkey Creek No. 1 File 66/4223	29 37 35 115 17 25	H/50-5	GL 106.6 KB 111.2	30 8 66 14 10 66	3852.6	PA
Arrowsmith No. 1	29 36 35 115 06 55	H/50-5	GL 51.2 KB 55.7	4 4 65 10 6 65	3446	Potential gas well
Beharra No. 1	29 19 10 115 00 45	H/50-5	GL 21.9 KB 26.5	28 11 66 16 12 66	2055.5	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/Rt	Date spudded T.D. reached	T.D. (m)	Status
Beharra No. 2	29 30 55 115 01 15	H/50-5	GL 27.7 KB 31	11 1 67 28 1 67	1925.1	PA
UNION DEVELOPMENT CORPORATION						
Blackwood No. 1 BMR file 69/2017	34 08 55 115 21 20	I/50-9	GL 65.2 KB 70.4	18 8 69 3 10 69	3332.9	PA
Whicher Range No. 1 BMR file 68/2005	33 50 15 115 22 11	I/50-5	GL 147.8 KB 153	19 3 68 23 7 68	4653	PA
Wonnerup No. 1 BMR file 71/929	33 37 55 115 28 16	I/50-5	GL 15.8 KB 24.4	18 4 72 1 8 72	4727.5	PA Gas show
WEST AUSTRALIAN PETROLEUM PTY LTD						
Abbarwardoo No. 1 BMR file 62/222	28 35 10 115 09 35	H/50-1	GL 219.4 KB 220.9	12 12 62 20 12 62	600.4	Dry and abandon
Barragoon No. 1 BMR file 74/210	31 21 40 115 35 09	H/50-14	GL 36 RT 40	31 3 74 20 4 74	3526	PA
Bullsbrook No. 1 BMR file 72/3026	31 28 42 115 50 28	H/50-14	GL 86.3 RT 90.8	1 10 72 28 11 72	4256.8	PA
Charlotte No. 1 BMR file 70/761	31 48 36 115 26 56	H/50-13	WD 42 RT 30.3	19 12 70 7 1 71	2435.4	PA
Cockburn No. 1 BMR file 67/4251	32 08 02 115 44 05	I/50-2	GL 2.4 RT 7.3	17 5 67 1 7 67	3054	PA
Coomallo No. 1 BMR file 73/285	30 14 55 115 24 57	H/50-9	GL 253 KB 258	17 1 74 25 2 74	3526	PA
Eneabba No. 1 BMR file 62/1076	29 34 14 115 19 56	H/50-5	GL 123.1 DF 126.7	12 6 61 25 11 61	4179.4	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longtitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
Eganu No. 1 BMR file 62/1221	29 59 05 115 49 35	H/50-6	GL 236.8 KB 238.3	31 12 62 15 1 63	600.4	Dry and abandoned
Gage Roads No. 1 BMR file 68/2039	31 57 12 115 22 33	H/50-14	WD 58.2 RT 21.3	27 11 68 24 1 69	3660.3	PA
Gage Roads No. 2 BMR file 71/21	31 57 05 115 21 45	H/50-14	WD 73.2 RT 30.2	14 1 71 8 2 71	2971.8	PA
Gingin No. 1 BMR file 64/4121	31 08 32 115 49 35	H/50-14	GL 75.9 KB 80.8	16 11 64 31 3 65	4543.9	Potential gas well
Hill River No. 1 BMR file 62/1402	30 16 00 115 18 00	H/50-9	GL 110.6 KB 112.1	2 4 62 25 4 62	579.1	Dry and abandoned
Hill River No.2 BMR file 62/1402	30 11 00 115 14 00	H/50-9	GL 188.9 KB 190.5	6 5 62 24 5 62	493.7	Dry and abandoned
Hill River No. 2A BMR file 62/1402	30 11 12 115 14 00	H/50-9	GL 183.7 KB 185.3	24 5 62 25 5 62	115.8	Dry and abandoned
Hill River No. 3 BMR file 62/1402	30 00 30 115 11 15	H/50-9	GL 124.3 KB 125.8	12 8 62 26 8 62	263.6	Dry and abandoned
Hill River No. 4 BMR file 62/1402	30 23 24 115 13 49	H/50-9	GL 92.9 KB 94.1	19 6 62 30 6 62	307.8	Dry and abandoned
Hill River No. 4/1 BMR file 62/1402	30 21 39 115 12 03	H/50-9	GL 66.7 KB 68.2	7 7 62 9 7 62	152.4	Dry and abandoned
Hill River No. 4/2 BMR file 62/1402	30 21 35 115 12 34	H/50-9	GL 70.7 KB 72.2	21 6 62 29 6 62	155.4	Dry and abandoned
Hill River No. 4/3 BMR file 62/1402	30 22 37 115 13 03	H/50-9	GL 72.8 KB 74.3	3 7 62 7 7 62	155.4	Dry and abandoned

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded	T.D. (m)	Status
Hill River No. 4/4 BMR file 62/1402	30 22 32 115 13 34	H/50-9	GL 85.6 KB 87.1	2 7 62 6 7 62	155.4	Dry and abandoned
Jurien No. 1 BMR file 62/1110	30 08 40 115 02 54	H/50-9	GL 9.1 DF 11.8	9 7 62 21 8 62	1025.9	PA
Lake Preston No. 1 BMR file 72/3302	32 55 13 115 39 39	I/50-2	GL 10.2 RT 14.7	20 12 72 6 3 73	4565.0	PA
Mungarra No. 1 BMR file 64/4105	28 51 02 115 06 55	H/50-1	GL 190.5 KB 192.0	3 10 64 4 11 64	609.2	Dry and abandoned
Pinjarra No. 1 BMR file 65/4176	32 40 32 115 46 16	I/50-2	GL 5.4 KB 10.3	5 10 65 28 12 65	4572.3	PA
Preston No. 1 BMR file 66/4219	32 56 53 115 42 33	I/50-2	GL 6.0 RT 7.6	26 8 66 18 9 66	765.3	PA
Quinns Rock No. 1 BMR file 68/2046	31 48 09 115 30 50	H/50-14	WD 40.5 RT 24	10 10 68 10 11 68	2209.1	PA
Roe No. 1 BMR file 70/912	31 56 26 115 19 07	H/50-14	WD 104.5 RT to seabed 134.7	23 11 70 13 12 70	2133.9	PA
Sue No. 1 BMR file 66/4186	34 03 57 115 19 04	I/50-9	GL 81.9 KB 86.8	31 1 66 5 3 66	3077.5	PA
Sugarloaf No. 1 BMR file 70/1020	32 54 55 115 03 09	I/50-1	WD 46.0 RT 30.2	14 2 71 6 4 71	3657.6	PA
Walyering No. 1 BMR file 71/48	30 42 57 115 27 55	H/50-9	GL 94.5 RT 99.1	31 1 71 10 4 71	3643.3	Gas producer
Warnbro No. 1 BMR file 70/825	32 14 20 115 20 45	I/50-1	WD 47.2 RT 25.0	26 11 70 1 1 71	3660.3	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
Wicherina No. 1 BMR file 63/1056	28 49 53 115 14 19	H/50-1	GL 262.7 DF 266.3	14 2 64 3 3 64	1685.5	PA
Woolmulla No. 1 BMR file 62/1127	30 01 24 115 11 28	H/50-9	GL 116.4 DF 120	3 11 62 8 3 63	2811.4	PA
Yardarino No. 1 BMR file 64/4035	29 13 13 115 03 10	H/50-5	GL 43.2 DF 46.9	7 4 64 4 6 64	2377.4	Potential oil well
Alexander Bridge No. 1	34 09 35 115 15 35	I/50-9	GL 37.1 DF 39.0	27 5 65 10 8 65	765.9	Dry and abandoned
Allanooka No. 1	29 08 31 115 00 40	H/50-5	GL 47.2 RT 51.2	8 1 65 29 1 65	1186.5	PA
Allanooka No. 2	29 06 00 114 59 36	H/50-5	GL 66.4 RT 70.4	3 2 65 13 2 65	1005.8	PA
Badaminna No. 1	31 20 31 115 40 02	H/50-14	GL 36.5 RT 41.4	31 1 67 27 2 67	2438.4	PA
Bookara No. 1	28 59 28 114 45 50	H/50-1	GL 19.8 DF 21.3	23 4 65 29 4 65	282.2	Dry and abandoned
Bookara No. 2	29 09 59 114 54 30	H/50-5	GL 9.4 RT 10.9	24 8 67 9 9 67	762	PA
Bookara No. 3	29 06 27 114 53 14	H/50-5	GL 31 RT 32.6	15 9 67 24 9 67	537.6	PA
Bouvard No. 1	32 31 26 115 15 10.53	I/50-2	WD 51.0 RT 58.0	3 1 75 27 1 75	1980	PA
Challenger No. 1	32 25 20.784 115 00 46.288	I/50-2	WD 212 RT 12	13 2 75 19 3 75	2250	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o ″ ′	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
Dongara No. 1	29 15 00 114 59 07	H/50-5	GL 45.1 DF 49	30 3 66 28 6 66	2161.3	Potential gas well
Dongara No. 2	29 14 46 114 58 26	H/50-5	GL 22.5 KB 26.5	31 7 66 10 8 66	1744.9	Potential gas well
Dongara No. 3	29 15 18 115 00 04	H/50-5	GL 27.7 KB 31.6	2 9 66 18 9 66	1774.5	Potential gas well
Dongara No. 4	29 13 46 114 58 49	H/50-5	GL 61.2 KB 65.2	27 2 67 15 3 67	1817.5	Potential gas well
Dongara No. 5	29 11 14 114 58 54	H/50-5	GL 27.7 RT 32	9 10 67 3 11 67	1808.3	PA
Dongara No. 6	29 14 44 114 56 16	H/50-5	GL 24.6 RT 28.6	12 12 67 31 12 67	1559	PA
Dongara No. 7	29 18 36 115 01 38	H/50-5	GL 42.9 RT 46.9	24 7 68 20 8 68	2164.0	PA
Dongara No. 8	29 15 08 115 01 13	H/50-5	GL 49.3 RT 53.6	13 5 69 27 5 69	1830	Oil well
Dongara No. 9	29 13 23 115 00 00	H/50-5	GL 83.2 RT 86.5	15 4 69 7 6 69	1909.8	Gas well
Dongara No. 10	29 14 17 115 00 07	H/50-5	GL 69.1 RT 71.9	14 6 69 1 7 69	2042.1	Gas well
Dongara No. 11	29 17 00 115 00 24	H/50-5	GL 63.3 RT 66.7	9 7 69 24 7 69	1828.8	Gas well
Dongara No. 12	29 14 18 115 01 10	H/50-5	GL 25.6 RT 28.9	30 7 69 18 8 69	2012.5	Gas well
Dongara No. 13	29 12 46 114 59 40	H/50-5	GL 83.5 RT 88	21 8 69 13 9 69	2038.8	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
Dongara No. 14	29 13 26 115 00 59	H/50-5	FF 73.4 RT 77.1	21 9 69 9 10 69	1918.1	Oil well
Dongara No. 15	29 16 28 115 00 55	H/50-5	GL 62.4 RT 65.8	16 10 69 1 11 69	1939.4	Gas well
Dongara No. 16	29 16 13 114 59 28	H/50-5	GL 25.2 RT 29.2	8 11 69 26 11 69	1923.8	Gas well
Dongara No. 17	29 17 06 115 01 29	H/50-5	GL 77.7 RT 81.9	5 12 69 24 12 69	1948.5	Oil well
Erregulla No. 1	29 22 28 115 23 45	H/50-5	GL 232.5 DF 237.4	8 9 66 16 11 66	4244.3	Suspended
Eurangoa No. 1	29 07 34 115 08 10	H/50-5	GL 249.6 KB 253.5	14 6 65 6 7 65	2276.8	PA
Gingin No. 2	31 10 08 115 50 35	H/50-14	GL 260.9 DF 265.7	25 7 65 13 12 65	4481.7	Gas well
Mondarra No. 1	29 18 51 115 06 55	H/50-5	GL 77.4 DF 83.2	9 10 68 25 11 68	3062.9	Potential gas well
Mondarra No. 2	29 21 07 115 06 05	H/50-5	GL 26.5 KB 30.7	19 12 68 22 1 69	2853.8	Gas well
Mondarra No. 3	29 17 32 115 06 44	H/50-5	GL 98.7 KB 102.7	5 4 69 10 5 69	2987	PA
Mondarra No. 4	29 19 09 115 05 59	H/50-5	GL 45.1 RT 49.3	19 7 69 22 8 69	2895.2	PA
Mt Adams No. 1	29 24 25 115 10 00	H/50-5	GL 85.9 KB 89.3	26 3 66 25 5 66	3791.1	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
Mt Hill No. 1	29 04 05 114 58 53	H/50-5	GL 115.2 KB 116.7	8 11 64 21 11 64	565.4	Dry and abandoned
Mt Horner No. 1	29 07 42 115 05 00	H/50-5	GL 195.6 RT 199.6	26 2 65 22 3 65	2252.4	Potential oil well
Mt Horner No. 2	29 08 41 115 04 34	H/50-5	GL 151.1 KB 154.8	24 4 65 27 5 65	2056.1	PA
Mungarra No. 2	28 54 30 115 04 54	H/50-1	GL 232.2 RT 233.7	25 1 65 10 2 65	612.6	Dry and abandoned
Mungarra No. 3	28 57 52 115 04 53	H/50-1	GL 246.2 RT 247.8	9 3 65 24 3 65	630.9	Dry and abondoned
Mungarra No. 4	28 54 15 115 15 50	H/50-1	GL 262.4 RT 263.9	16 6 65 29 6 65	643.1	Dry and abandoned
Mungarra No. 5	28 54 40 115 08 03	H/50-1	GL 233.1 RT 234.6	30 6 65 10 7 65	621.7	Dry and abandoned
North Erregulla No. 1	29 14 44 115 19 34	H/50-5	GL 162.4 RT 166.7	4 10 67 25 11 67	3444.2	PA
South Turtle Dove No. 1	30 07 43 114 38 10	H/50-9	WD 63	16 4 75	350	PA
South Turtle Dove No. 1A	lats and longs approx. to No.1	H/50-9		25 4 75	330	Abandoned becaus of mechanical difficulties
South Turtle Dove No. 1B	30 07 47 114 38 11	H/50-9	WD 63	4 5 75 18 6 75	1830	PA
Strawberry Hill No. 1	29 15 17 115 07 13	H/50-5	GL 58.5 RT 61.2	28 5 69 9 7 69	2869.9	PA

COMPANY Well Name BMR file No. if subsidised	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD/FF DF/KB/RT	Date spudded T.D. reached	T.D. (m)	Status
West White Point No. 1	29 20 42 115 02 23	H/50-5	GL 76.2 RT 80.2	1 2 71 25 2 71	2248.2	PA
West White Point No. 2	29 22 44 115 02 24	H/50-5	GL 32.2 RT 36.3	27 11 71 28 12 71	2350.0	PA
Yardarino No. 2	29 12 22 115 03 38	H/50-5	GL 88.3 DF 92.0	8 7 64 20 9 64	3075.4	PA
Yardarino No. 3	29 13 27 115 03 10	H/50-5	GL 41.4 DF 45.1	8 10 64 17 11 64	2699.6	Potential oil/gas wel
Yardarino No. 4	29 13 03 115 02 39	H/50-5	GL 39.9 DF 43.8	4 12 64 29 12 64	2489.6	PA

KEY

GL - ground level
WD - water depth
FF - first flange
DF - **derrick floor**
KB - kelly bushing
RT - rotary table
PA - plugged and abandoned

APPENDIX 2.

GEOPHYSICAL SURVEYS

Onshore seismic surveys (results available)

Map key number (plate 4)	Survey Name	Operator	Seismic Energy Source	CDP Coverage (fold)	Contractor	Year	No. of km	Reference or file Number
1	Gingin seismic	BMR	Explosives	1	-	1955	43	Rec. 1956/26 & 1966/149
2	Cookernup seismic*	"	"	"	-	1956	70	Rec. 1962/109
3	Busselton seismic	"	"	"	-	1956	64	Rec. 1962/108
4	Rockingham-Mundijong seismic*	"	"	"	-	1956	33	Rec. 1962/107
5	Beagle & Cockleshell seismic*	WAPET	"	"	GSI	1961	275	PSSA. 62/1534
6	Eneabba seismic*	"	"	"	"	1960	260	" 62/1541
7	Warradong seismic	"	"	"	"	1962	55	" 62/1590
8	Hill River seismic	"	"	"	"	1962	238	" 62/1602
9	Woolmulla South seismic	"	"	"	"	"	938	" 62/1627
10	Wicherina & Eganu seismic*	"	"	"	"	1962/3	1190	" 62/1651
11	Dongara seismic	"	Vibroseis	"	Seismograph Service Ltd	1963	63	" 63/1507
12	Gingin seismic*	"	Explosives	"	United Geophysical	1963/4	319	" 63/1541
13	Bullsbrook seismic survey, Perth Basin	BMR	"	"	-	1964	37	Rec. 1966/203
14	Lake Preston seismic*	WAPET	"	"	GSI	1964	222	PSSA 64/4501
15	Darradup seismic*	"	"	"	United Geophysical	"	318	" 64/4502
16	Irwin seismic*	"	"	"	GSI	"	43	" 64/4511
17	Hyde Soak seismic*	Continental Oil.	"	1 & 12	Western Geophysical	"	109	" 64/4538

* Included refraction seismic ≠ Geophysical Service International

Map key number (plate 4)	Survey Name	Operator	Seismic Energy Source	CDP Coverage (fold)	Contractor	Year	No. of km	Reference or file Number
18	Wooramel seismic*	Continental Oil	Weight drop	6 & 12	Western Geophysical	1964-5	257	PSSA 64/4545
19	Woodada seismic & gravity*	French Petroleum Co.	Explosives	1	GSI	1964-5	566	" 64/4547
20	Pinjarra seismic	WAPET	"	6 & 12	"	1965	161	" 65/4578
21	Blackwood seismic	"	"	6	United Geophysical and GSI	"	133	" 65/4591
22	Poodooloo seismic	French Petroleum Co.	Weight drop	1	Ray Geophysics	"	75	" 65/11010
23	Yalbalgo-Yaringa seismic*	Continental Oil	"	6 & 12	Western Geophysical	"	440	" 65/11021
24	Bullsbrook seismic	WAPET	Explosives	6	GSI	1965-6	177	" 65/11048
25	Ballythanna Hill seismic*	Continental Oil	Weight drop	6 & 12	Western Geophysical	1965-6	154	" 65/11049
26	Yanchep seismic	WAPET	Weight drop	4 & 6	Ray Geophysics	1965-6	95	" 65/11050
27	Athamo seismic & gravity	French Petroleum Co.	"	4 & 6	"	1966	408	" 65/11060
28	Dandaragan seismic	WAPET	"	6	GSI	"	287	" 66/11065
29	Karnup seismic	"	Explosives	"	"	"	88	" 66/11069
30	Charla seismic	"	"	"	"	"	37	" 66/11071
31	Wedge seismic	"	Weight drop	"	Ray Geophysics	"	203	" 66/11082
32	Smokebush seismic	"	Vibroseis	"	"	"	23	" 66/11114

* Included refraction seismic ∤ Geophysical Service International

Map key number (plate 4)	Survey Name	Operator	Seismic Energy Source	CDP Coverage (fold)	Contractor	Year	No. of km	Reference or file Number
33	Coogee seismic	WAPET	Explosives	6 & 12	GSI	1966	30	PSSA 66/11125
34	Walyering seismic	"	"	6	United Geophysical	1967	134	" 67/11143
35	Geraldton seismic	"	Weight drop	5	Ray Geophysics	"	48	" 67/11146
36	Sabina seismic	Union Oil	Explosives	6	United Geophysical	"	79	" 67/11154
37	Lancelin seismic	WAPET	Weight drop	6	Ray Geophysics	"	24	" 67/11182
38	Margaret River seismic	Union Oil	Explosives	"	GSI	1967-8	356	" 67/11191
39	Wonnerup-Flinders seismic	"	"	"	"	1969	131	" 68/3060
40	Harvey seismic	WAPET	"	"	"	1969	65	" 69/3022
41	Namban seismic	"	"	6 & 12	"	"	50	" 69/3025
42	Harvey D-1 seismic	"	"	"	"	1969-70	135	" 69/3074
43	Dandaragan West seismic	"	"	"	"	1970	43	" 70/104
44	**Moore River-Lancelin seismic**	"	"	12 & 24	Digicon	"	29	" 70/194
45	Walyering Detail seismic	"	"	6	Austral United	"	35	" 70/717
46	Preston Detail seismic	"	"	"	"	"	88	" 70/858
47	Barragoon seismic	"	"	"	Austral United and GSI	1971	558	" 70/999
48	Moore River seismic	"	"	"	GSI	"	34	" 70/1001
49	West Walyering seismic	"	"	"	"	"	130	" 71/565
50	Preston D-1 seismic	"	"	"	"	"	29	" 71/678
51	Dandaragan East Flank seismic	"	"	"	Digicon	1971-2	323	" 71/850
52	Gingin-Bullsbrook D-1 seismic	"	"	"	GSI	1972	211	" 71/855
53	Coomallo seismic	"	"	"	Digicon	1972	146	" 71/928
54	Rockinghan seismic	"	Vibroseis	12 & 24	GSI	1972-3	156	" 72/3179

Map key number (plate 4)	Survey Name	Operator	Seismic Energy Source	CDP Coverage (fold)	Contractor	Year	No. of km	Reference or file Number
55	Barberton seismic	WAPET	Explosives	6	GSI	1972	59	PSSA 72/3277
56	Coomallo II seismic	"	Vibroseis	12 & 24	"	1973	35	" 73/206
57	Mullering seismic	"	Vibro./Expl.	6 & 24	"	"	196	" 73/208
58	Warradong II seismic	"	Explosives	6	"	"	47	" 73/211
59	Erregulla 3 seismic	"	Vibroseis	24	Petty Ray Geophysical	1974	105	" 74/219

Unsubsidised onshore seismic surveys by WAPET

Map key number (plate 4)	Area Name	Seismic Energy Source	CDP coverage (fold)	Contractor	Year	WAPET Project Number
200	Ejarno	Explosives	1	United Geophysical	1964	145
201	Bookara-Ejarno	"	4,6, & 12	"	1964-5	145
202	Hunt Gully	"	1	"	1964	145
203	Mt Adams, Warradong, Depot, & Mungaterra	"	1 & 6	"	1965	145
204	Bonnefield	Weight drop	-	Unknown	1966	320
205	Erregulla & Depot Hill	Explosives	6	United Geophysical	1967	145
206	Dongara, White Point, & North Erregulla	Weight drop	-	Ray Geophysics	1967	327
207	Mondarra & Heaton	Explosives	6	United Geophysical	1968	372
208	White Point	Weight drop	-	Ray Geophysics	1968	319
209	Southwest Dongara	Explosives	-	Digicon	1970	321-1
210	Grange	"	6	"	1970	321-1
211	Erregulla	"	6	Austral United	1971	171
212	East White Point	"	12	Digicon	1972	324

Offshore seismic survey

Map key number (plate 4)	Survey name	Operator	Seismic Energy Source	CDP Coverage (fold)	Contractor	Year	No. of km	Reference or File Number
100	Vena 16 Cruise	Lamont Geological Observatory of Columbia University	Explosives	-	-	1960	-	Hawkins et al 1965
101	Abrolhos seismic	BP Petroleum	"	1		1965	1226	PSSA 65/4592
102	Perth-Rottnest seismic	WAPET	"	3	GSI	1965-6	784	" 65/11039
103	Snag Island seismic	French Petroleum Co.	"	1 & 3	"	1965	45	" 65/11043
104	Cockburn seismic	WAPET	Sparker	1	United Geophysical	1966	655	" 65/11110
105	Zeewyk Channel	BP Petroleum	"	1	"	1966	100	" 66/11112
106	Coventry seismic	WAPET	Explosives	3 & 6	GSI	1966	253	" 66/11116
107	Abrolhols D-1 seismic	BP Petroleum	"	1 & 3	"	1966	248	" 66/11127
108	Dongara seismic	WAPET	"	3	"	1967	467	" 67/11150
109	Charlotte seismic	"	"	6	"	1967	523	" 67/11160
110	Bunbury seismic	"	"	4	"	1967	67	" 67/11180
111	Turtle Dove seismic	"	Airgun/Expl.	3,6,24	"	1968	368	" 68/3000
112	Direction Bank seismic	"	"	"	"	"	1628	" 68/3003
113	Koombana seismic	"	"	6 & 24	"	1969	1316	" 69/3008
114	Pelsart seismic	"	"	"	"	"	506	" 69/3014
115	Koombana Wedge seismic	"	Explosives	6 & 12	CGG*	"	379	" 69/3060
116	Perth Waters seismic	"	Airgun	24	GSI	1970	900	" 69/3090
117	Geelvink Channel seismic	BP Petroleum	"	"	GSI & Digitech	"	1435	" 70/241
124	Southern Australia Scientific, gravity, magnetic and seismic	Shell Development (Aust.)	"	"	Seismograph Service Ltd		3500	" 72/30
127	BMR Continental Margin, gravity, magnetic and seismic	BMR	Sparker	1	CGG	1972	1500	Rec. 74/15

* Compagnie Generale de Geophysique

Onshore gravity surveys

Survey Name	Year	Operator	Contractor	Traverse Spacing (km)	Station Spacing (km)	Number Of Stations	Reference or File Number	
Bullsbrook gravity	1951	BMR	-	-	2	11	Record 1951/45	
Perth Basin gravity	1951/2	BMR	-	-	4	650	Bulletin 33	
Dongara-Mullewa gravity	1962	WAPET	United Geophysical	8	0.8	2394	PSSA	62/1925
Eganu gravity	1962	WAPET	United Geophysical	6	0.8	203	"	62/1933
Augusta-Moora gravity	1962	WAPET	United Geophysical	8	0.8	6032	"	62/1935
Geraldton gravity	1967	WAPET	Wongela Geophysical	0.8	0.8	546	"	67/4827
Murchison-Gascoyne helicopter gravity	1970	Barewa Oil & Mining	"	6	6	956	"	70/326
Murchison-Gascoyne D-1 gravity	1971-2	Oceania Petroleum	Austral United	12	0.8	6000	"	71/555
Coolcalalaya gravity	1973	Sunning-dale Oils	Wongela Geophysical	12	0.8	2535	"	72/3303
Reconnaissance helicopter gravity W.A.	1971-2	BMR	"	11	11	8300	Record 1973/130	
Reconnaissance helicopter gravity of the south-west of W.A.	1969	BMR	"	11	11	3961	"	1974/26

Offshore surveys which included gravity readings are indicated in the list of offshore seismic surveys.

Magnetic surveys

Survey Name	Year	Operator	Contractor	Survey Altitude (m)	Traverse Spacing (km)	Total Traverse Length (km)	Reference or File Number
Scott River magnetic	1962	BMR	-	Ground level	0.6	88	Record 1962/163
Perth Basin aeromagnetic	1957	"	-	457	1.6	15,000	" 1963/74
Offshore West Beagle aeromagnetic	1969	WAPET	Hunting Geology & Geophysics	304	3	4 467	PSSA 69/3050
Offshore Leeuwin aero-magnetic	1969	"	"	304	3	3 700	" 69/3053
Coolcalalaya gravity and magnetic	1973	Sunningdale Oils	Wongela Geophysical	Ground level	12 x 0.8	2 535	" 72/3303

Offshore surveys which included magnetic readings are indicated in the list of offshore seismic surveys.

APPENDIX 3

Stratigraphic tables, Perth Basin wells

APPENDIX 3

STRATIGRAPHIC TABLES, PERTH BASIN WELLS

ABROLHOS SUB-BASIN

AGE	UNIT	GUN ISLAND NO. 1 Depth(m) K.B.	Thickness (m)	LITHOLOGY
QUATERNARY PLEISTOCENE	Coastal Limestone	4.3	125.9	Mainly white, shelly and detrital, porous limestones with subordinate generally tight dolomites and porous dolomitised calcarenites
		UNCONFORMITY		
L. TERTIARY (L. MIOCENE AND YOUNGER)	Unnamed formation	130.1	74.7	Thin unit of red and yellow ferruginous calcarenitic dolomite overlying 12.5 m of soft yellow limestones, which in turn overlie a sequence of fossiliferous and chalky limestones with minor siliceous limestones
		DISCONFORMITY		
L. TERTIARY (L. MIOCENE)	Trealla Limestone Equivalent	204.8	41.5	Massive galuconitic, fossiliferous limestones with minor interbedded siliceous limestone and chert nodules. Unit resembles Trealla Limestone of the Carnarvon Basin
		DISCONFORMITY		
E. TERTIARY (PALAEOCENE?)	Unnamed dolomites	246.3	41.5	Porous secondary calcarenitic dolomites with minor finer grained and tighter dolomite-intercalations. No fossils have been found but since the unit is probably genetically related to the underlying calcarenites it has been given a tentative Palaeocene age.
(PALAEOCENE)	U. Cardabia Gp Equivalent	287.7	103.6	Massive fossiliferous calcarenites with thin basal interval of argillaceous limestones. Unit resembles U.Cardabia Gp of Carnarvon Basin
		DISCONFORMITY		
L. CRETACEOUS (Maastrichtian to Campanian)	Miria Marl Equivalent	391.4	26.8	Yellow, ferruginous silty limestones grading down to hard tight, white limestones with abundant _Inoceramus_ fragments, overlying claystones at 405.4 m. Unit is correlated with Miria Marl of Carnarvon Basin
		DISCONFORMITY		
E. CRETACEOUS? (Aptian ? to Turonian?)	Winning Gp Equivalent	418.2	489.5	Massive sequence of unconsolidated, poorly sorted fine to coarse-grained quartz, in part feldspathic sands with minor siltstones and red mudstones. Sequence is unfossiliferous, but lithologically similar to the Birdrong Sst (Winning Gp) in the Dirk Hartog and Yaringa wells, Carnarvon Basin
		MAJOR ANGULAR UNCONFORMITY		
L. JURASSIC TO LATE M. JURASSIC	Yarragadee Fm.	907.7	1279.2	Mainly poorly consolidated, poorly sorted, fine to medium and coarse-grained quartzose sandstones, with interbedded conglomeratic sandstones, and siltstones with minor coal seams
EARLY M. JURASSIC (Bajocian)	Cadda Fm.	2186.9	242	Marine shales with subordinate interbedded siltstone and fine-grained sandstone. Scattered dolomitic siderite nodules
E. JURASSIC	Cockleshell Gully Fm	2428.9	1295.7	
	Cattamarra C.M. Mbr	2428.9		Interbedded quartzose sandstone, siltstone and silty shale with minor thin coal seams and coal fragments
	Eneabba Mbr	2918.8		Distinguished from overlying member by the appearance of claystones and mudstones which increase in colour variation with depth
		TD 3724.7		

NOTES

1) Rare acritarchs in Yarragadee Fm. below 1707.8 m
2) Appearance of Permian remante fossils at 1707.8 m
3) Well velocity data established seismic horizon I (Abrolhos D-1 marine seismic survey) at about 658.4m and III is predicted at 3855.7 m sub-sea.

   Horizon II is interpreted as the top of the Cadda Formation

After B.P. Petroleum Development Australia Pty Ltd (1969)

NORTHERN DANDARAGAN TROUGH

AGE	UNIT	YARDARINO NO. 1 Depth(m) D.F.	Thickness (m)	LITHOLOGY
QUATERNARY	Alluvium	3.7	8.5	Claystone-river flat alluvium
		UNCONFORMITY		
E. CRETACEOUS TO L. JURASSIC	Yarragadee Fm.	12.2	1063.4	Mainly coarse, very coarse and pebbly sandstones, with interbedded fine and medium-grained sandstones, siltstones, and thin black coal seams
M. JURASSIC	Cadda Fm.	1075.6	80.2	Carbonaceous siltstone and coarse-grained to conglomeratic sandstone, with minor interbedded carbonaceous shale and claystone
E. JURASSIC TO L. TRIASSIC	Cockleshell Gully Formation	1155.8	783.9	
E. JURASSIC	Cattamarra Coal Measures Member	1155.8		Fine and coarse-grained sandstone with interbedded siltstone, shale, claystone, and in parts coal
L. TRIASSIC	Eneabba Mbr	1554.5		Interbedded coarse-grained sandstone and claystone, with minor fine-grained sandstone and shale
		UNCONFORMITY		
LOWER M. TRIASSIC	Woodada Fm.	1939.7	69.8	Fine and very fine-grained sandstone with minor interbedded claystone, siltstone, and shale
E. TRIASSIC	Kockatea Shale	2009.5	275.2	Thinly interbedded fine-grained sandstone, siltstone, and shale, and minor limestone
		UNCONFORMITY		
L. PERMIAN	Wagina Sst	2284.8	74.7	
	*Yardarino Sst. Mbr (2284-2307 m)	2284.8	22.6	Sandstone, medium coarse and very coarse-grained, clay matrix, moderate porosity and permeability and occasional steeply dipping silicified and pyritised fractures
		2307		Mainly fine and medium-grained sandstone with abundant kaolinised feldspar and kaolinitic matrix, and some coaly grains
E. PERMIAN	Carynginia Fm	2359.5	17.9	Lithology uncertain because of extensive caving. Core between 2366.2m and 2373.5m consists of carbonaceous siltstone with lenses of very fine-grained sandstone. Siltstone contains worm tubes and a few well preserved brachiopod-shells
		T.D. 2377.4		

Notes

1) *Type section (McKellar *in* Playford et al., in press)

   2288 - 2301 m gas-saturated

   2301 - 2307 m gas and oil-saturated

2) Gas shows in Kockatea Shale particularly below 2194.6 m

AFTER WAPET (1963)

CENTRAL DANDARAGAN TROUGH

AGE	UNIT	WALYERING NO. 1 Depth(m) K.B.	Thickness (m)	LITHOLOGY
E. CRETACEOUS TO L. JURASSIC	Yarragadee Fm.	4.6	26.8	Upper part of formation is mainly medium to coarse-grained sandstone which is interbedded with fine-grained sandstone in lower part. Siliceous and calcareous cement and clay are present throughout, and interbedded shale and siltstone
M. JURASSIC (Bajocian)	Cadda Fm.	2685.3	201.2	Fine-grained sandstone with common clay matrix and calcareous cement, interbedded with carbonaceous siltstone and claystone. Common traces of lignite
E. JURASSIC	Cockleshell Gully Fm. Cattamarra Coal Measures Member	2886.5	756.8+	Shale, carbonaceous, grading to siltstone with interbedded sandstone decreasing with depth. Three gas-bearing sands are recognised: 10 700' Sand (3261.4 m) comprises 37.8 m of massive sands and 6.7 m in three separate sands. From cuttings, the massive unit is fine-grained with interstisial clay and silt reducing porosity. 11 050' Sand (3368 m) comprises 44.2 m of sands, mainly in thin beds. Sandstone is predominantly medium to coarse-grained with siliceous and calcareous cement and interstisial clay. 11 550' (3520 m) comprises 25 m of sandstone similar to above
		T.D. 3643.3		

Notes

1) The Cockleshell Gully Formation was encountered more than 300 m lower than predicted
2) Pressure information from production testing on 11 050' Sand is characteristic of a low-permeability reservoir which may be faulted, fractured, or very heterogeneous such as channel-type sands. There appears to be restricted communication with a high-pressure gas source.

After WAPET (1971)

BUNBURY TROUGH

AGE	UNIT*	WONNERUP NO. 1 Depth(m) K.B.	Thickness (m)	LITHOLOGY
QUATERNARY				No samples above 852.7 m
E. CRETACEOUS TO L. JURASSIC	Yarragadee Fm.	36.6	818.4	
E. JURASSIC	Cockleshell Gully Fm.	855	1271	Medium to very coarse-grained sandstone with interbeds of shale up to 30.5 m thick. Microfloral assemblages of E. Jurassic age
L. TO M. TRIASSIC	Lesueur Sst.	2126	1460	Lithologically similar to above. Palynological studies indicate L. to M. Triassic age 3247.6 - 3256.8 m Dolerite?, dark grey, fine to very finely crystalline. Consists mainly of whitish grey feldspar, magnetite, trace obsidian, trace talcose serpentine, occasional quartz up to 10%
E. TRIASSIC	Kockatea Shale? (now 'Sabina Sst' in southern Perth Basin)	3586	517.9	Fine to very fine-grained sandstone with some interbedded shale and minor siltstone. Abundant clay matrix in sandstone. Palynological studies indicate an E. Triassic age
L. PERMIAN	Irwin River Coal Measures (now Sue Coal Measures in southern Perth Basin)	4103.8	623.6	Coal measure sequence composed of sandstones, shales, coals and minor siltstones. Sandstone is mainly fine-grained with abundant clay matrix. Shale is highly carbonaceous, and coal black brittle and lustrous. Dolerite sill between 4612.8 m and 4626.3 m sequence contains L. Permian microfloral assemblages
		T.D. 4727.4		

Notes

1) *Possible equivalent formations in northern Perth Basin
2) Gas shows recorded in L. Permian coal measures
3) Basement predicted at about 6000 m
4) Microfloral assemblages from 4058.7 m and 4075 m are transitional between Permian and Triassic assemblages previously described from Western Australia

After Union Development Corporation (1973)

CENTRAL DANDARAGAN TROUGH

AGE	UNIT	GINGIN NO. 1 Depth (m) D.F.	Thickness (m)	LITHOLOGY
QUATERNARY		4.9	34.7	Sandstone and laterite
		UNCONFORMITY		
LATE CRETACEOUS	Osborne Fm. ('Mogumber Fm.')	39.6	54.9	Above 67.1 m - Siltstone medium to dark grey, very glauconitic. Below 67.1m, glauconite decreases towards base. Unit is sandy throughout, increasingly so towards base
		DISCONFORMITY		
EARLY CRETACEOUS	Warnbro Gp. Leederville Fm. ('Moochamullah Sst.')	94.5	94.5	Sandstone, medium to very coarse-grained with minor siltstone close to base. Sandstone is feldspathic, and slightly carbonaceous
EARLY CRETACEOUS/ LATE JURASSIC	Yarragadee Fm.			
EARLY CRETACEPIS	Unit A	189	922.6	Interbedded sandstone and siltstone. Sandstone is fine to coarse-grained, grading in parts to conglomeratic, and massive to poorly bedded in parts weakly cross-bedded. Siltstone is slightly carbonaceous, sandy, and grades to shale
LATE JURASSIC	Unit B	1111.6	1627	Sandstone, fine to very coarse-grained loose clear quartz grains, interbedded mainly with shale below 1615.4 m and rare thin beds of siltstone and coal above 1614.4 m
	Unit C	2738.6	575.8	Interbedded sandstone and shale becoming mainly sandstone below 2943 m. Sandstone comprises fine to medium-grained quartz grains in part surrounded by white clay, a little glauconite, feldspar and carbonaceous streaks. Shale is finely micaceous and carbonaceous
		DISCONFORMITY?		
EARLY JURASSIC	Cockleshell Gully Fm.	3314.4	1229.6	Sandstone, fine to medium-grained interbedded with siltstone, shale and minor coal
	Cattamarra C.M. Mbr equiv.	3713.1	34.4	Sandstone, mainly fine to medium-grained with traces of black sub-resinous material, interbedded with and grading to carbonaceous shale, and slightly carbonaceous siltstone
	T.D. 4544			

NOTES

1) Sixteen gas shows, some with minor fluorescence, recorded between 3795 m and total depth.
2) In the Yarragadee Fm. the salinity of the formation waters changes sharply at about 2745 m from 5200 ppm to 33000 ppm.

After WAPET (1965)

VLAMING SUB-BASIN

AGE	UNIT	GAGE ROADS NO. 1 Depth(K.B.) (m)	Thickness (m)	LITHOLOGY
PLEISTOCENE	Coastal Limestone	79.6	?	34.4
?	unnamed fm.	101?		Calcarenite
EOCENE TO MIOCENE	Stark Bay Fm.	384	234.7	Mainly dolomite with chert and sandstone
E. CRETACEOUS	Warnbro Gp*			
	Leederville Fm.	618.7	661.3	Fine-grained to conglomeratic, feldspathic sandstone, with carbonaceous material and locally abundant pyrite, interbedded with siltstone and claystone. Several sandstone units show S.P. and Resistivity curves typical of regressive sands
	South Perth Shale	1280	307.3	Claystone and shale, variably silty to sandy. Some interbedded siltstone. Inoceramus fragments
	Gage Sst. Mbr	1587.4	156.1	Fine-grained to conglomeratic, feldspathic sandstone, locally pyritic, variable amounts of clay matrix and some carbonaceous material. Sandstone in two beds separated by a sequence of sandstone and shale
E. CRETACEOUS TO L. JURASSIC	Yarragadee Fm	1743.5	819.9	Mainly conglomeratic, feldspathic to arkosic sandstones with thin interbeds of shale and siltstone
	Quinns Shale Mbr	2563.4	54.9	
	T.D.	3660.4		

NOTES

1) Non-commercial oil in Neocomian Yarragadee Fm. - the first indication of hydrocarbons in the Cretaceous sequence of the Perth Basin
2) Well penetrated previously unknown dolomite unit of lower Miocene age
3) Palynological evidence indicates mainly non-marine environment of deposition for Yarragadee Fm.
4) *Company nomenclature for Early Cretaceous replaced by revised nomenclature of Cockbain & Playford (1973)

After WAPET, (1969) and revision 1970

AGE	UNIT	GAGE ROADS NO. 2 Depth (m) K.B.	Thickness	LITHOLOGY
PLEISTOCENE	Coastal Lst.	103	±46	
?	Unnamed Fm.	149?	213	Calcarenite?
TERTIARY	Stark Bay Fm.	362	216	Calcarenite, dolomite
		UNCONFORMITY		
EARLY CRETACEOUS	Warnbro Gp			
	Leederville Fm.	578	570	Sandstone, siltstone, coal
	South Perth Shale	1148	202	Shale, carbonaceous, pyritic, rare glauconite, common forams, rare bivalve fragments
	Gage Sst Mbr	1350	25	Sandstone, coarse to very coarse-grained Bottom 15 m, shale
		ANGULAR UNCONFORMITY		
	'Carnac Fm.'	1375	419	Top 250 m Interbedded loose medium to coarse-grained sandstone and pyritic shale. Shale is the dominant lithology in the remaining section
	Yarragadee Fm.	1794	1054	Interbedded fine to medium-grained calcareous white sandstone and siltstone. Sandstone becomes coarser grained in lower part
	Quinns Sh. Mbr	2848	84	Micaceous pyritic shale
LATE JURASSIC	Yarragadee Fm.			Sandstone, white, loose, fine to medium-grained with occasional thin shale beds
	T.D.	2972		

NOTES

1) Wireline log evaluation indicates 2 m net oil pay in the interval 1350-1352 m
2) Marked change in microfloras between 1280 m and 1410 m

After WAPET (1971) and revision 1973

VLAMING SUB-BASIN

AGE	UNIT	SUGARLOAF NO. 1 Depth(K.B.) (m)	Thickness (m)	LITHOLOGY
QUATERNARY TO TERTIARY	Unnamed carbonates	76.2	176.8	No samples to 346.9
L. CRETACEOUS	Osborne Fm. (?)	253(?)	280.4	Mainly fine-grained glauconitic sandstone
E. CRETACEOUS	Warnbro Gp * Leederville Fm.	533.4(?)	176.8	Medium to coarse-grained, commonly highly glauconitic sandstone with minor interbedded shale
E. CRETACEOUS (Neocomian)	Yarragadee Fm.	710.2(?)	1387.4	Two main lithologies:-1) fine to coarse-grained sandstone, unconsolidated, with common lignite and coal traces. 2) Very fine to fine-grained sandstone, feldspathic, carbonaceous, moderately cemented, glauconitic and pyritic
	Quinns Shale Mbr	2097.6	27.4	Poor cuttings recovery. Unit seems to consist of brown shales, slightly to moderately calcareous
L. JURASSIC	Yarragadee Fm.	2125.1	1532.5	Sequences of interbedded fine to coarse-grained sandstone and shale
	T.D.	3657.6		

NOTES

1) Strong seismic reflector between 851.9 m and 877.8 m proved to be a hard fine-grained, limonitic silicified sandstone and not the Quinns Shale Mbr as predicted

2) Well penetrated good reservoir sands in Late Jurassic sequence, but lacked units with source-rock potential

3) *Company nomenclature replaced by that of Cockbain & Playford (1973)

After WAPET (1971)

VLAMING SUB-BASIN

AGE	UNIT	CHARLOTTE NO. 1 Depth(m) K.B.	Thickness (m)	LITHOLOGY
QUATERNARY -TERTIARY	Coastal Limestone	73	20	Calcarenite
	Unknown	93	16	No samples
	Stark Bay Fm.	209	102	Calcarenite
		UNCONFORMITY		
EARLY CRETACEOUS	Warnbro Gp	411		
	Leederville Fm.	411	458	Upper Unit (62.5 m), medium to coarse-grained, minor feldspar, coal fragments, thin beds of siltstone and shale; middle unit (39.6 m) as above but fine-grained and glauconitic; lower unit (317 m), coarse-grained sandstone, abundant feldspar and coal, rare pyrite
	Unnamed unit	869	361	Shale, dark grey, micaceous with interbedded siltstone and minor, fine-grained sandstone
	South Perth Shale	1230	257	Shale, dark grey, micaceous with traces of pyrite and rare limestone nodules
	Gage Sst. Mbr	1487	106	Sandstone, very fine to coarse-grained, with interbedded dark grey shale. Sandstone commonly silty or shale
		ANGULAR UNCONFORMITY		
NEOCOMIAN	Carnac Fm.	1593	842	Unit A (1592.6 2164.1 m), very fine to coarse-grained sandstone, with rare pebbles and coal stringers; carbonaceous siltstone
		T.D. 2435		Unit B (2164.1m - T.D.) mainly shale and siltstone with minor interbedded sandstone

Notes

1) South Perth Shale encountered 365.8 m lower than predicted owing to the greater development of the Leederville Sandstone, and the presence of the unnamed shale unit.

2) Gage Sandstone Member was 268.2 m lower than predicted and thinner. The unit had a higher siltstone content than in adjacent wells. Porosities estimated from sonic log range from 15 to 30%.

After WAPET (1971), and revision 1973

VLAMING SUB-BASIN

AGE	UNIT	WARNBRO NO. 1 Depth (m) K.B.	Thickness (m)	LITHOLOGY
	Unnamed carbonates	72		
TERTIARY	Kings Park Fm.	336		Sandstone and limestone
		UNCONFORMITY		
LATE	Coolyena Gp	552		Medium to coarse-grained glauconitic sandstone
CRETACEOUS	Osborne Fm.	792		Glauconitic sandstone
		UNCONFORMITY		
EARLY CRETACEOUS	Warnbro Gp Leederville Fm.	1003		Mainly medium to coarse-grained sandstone
Aptian-Neocomian	South Perth Shale	1408		Glauconitic claystone and shale
	Gage Sst. Mbr	1945		Mainly sandstone of two types: 1) fine to very fine grained, argillaceous matrix, silica cement; 2) loose, coarse to very coarse-grained
Neocomian	'Carnac Fm.'	2163		Shale, siltstone, fine-grained sandstone
		FAULT		
Neocomian	Yarragadee Fm.	2204		Fine to coarse-grained sandstone
	Quinns Shale Mbr	2932		Dark brown shale with sandstone laminae
LATE JURASSIC	Yarragadee Fm.	2962		Fine to medium-grained sandstone with interbedded shale and minor coal. Cementation argillaceous and/or siliceous increases with depth
		T.D. 3660		

Notes

1) No significant indications of hydrocarbons.
2) The objective horizons, Gage Sst. Mbr and Yarragadee Fm. below Neocomian unconformity, had good reservoir parameters: Core porosities in the Gage Sst. Mbr ranged from 9.5 to 21.8% with an average permeability of 631 md; A 10 m sandstone core from the Neocomian Yarragadee Fm. had porosities ranging from 15 to 21% and permeabilities from 374 to 2031 md.
3) Well intersected Cretaceous sediments younger than the Osborne Fm. for the first time in the offshore Perth Basin.

After WAPET (1971) and revision 1974.

BEAGLE RIDGE

AGE	UNIT	BEAGLE RIDGE NO. 10A Depth(R.T.) (m)	Thickness (m)	LITHOLOGY
PLEISTOCENE	Coastal Limestone	3.4	29	Calcaranite, cavernous and massive, fossiliferous (foraminifera, pelecypods, gastropods, echinoids etc.) in upper part. Basal 7.6 m of massive, vuggy re-cemented limestone
E. JURASSIC	Cockleshell Gully Formation	32.3	310	Friable, fine to very coarse-grained, poorly sorted sandstone with thin beds of pelitic sediments. Kaolinitic matrix in upper part. Sandstone becomes increasingly feldspathic with depth
TRIASSIC	Unit 'A' (Lesueur Sandstone)	342.3	110.6	Fine-grained sandstone with thin beds of interlaminated siltstone and sandstone. Boundary with unit 'B' is transitional
	Unit 'B' (Woodada Fm)	452.9	157.6	Interbedded fine-grained sandstone and interlaminated siltstone/sandstone
TRIASSIC (Scythian)*	Kockatea Shale	610.5	375.2	Interbedded siltstone, micaceous, carbonaceous, sandy; and sandstone, poorly sorted, fine-grained, slumped, crossbedded, kaolinitic, micaceous (about 8 m), underlain by shale, dark green-grey, massive or well-bedded, thin-bedded and fissile; and minor thin beds of sandstone and siltstone. Unit is calcareous near the base. Rich marine macrofauna and microplankton
PERMIAN	Unit 'A' (Mingenew Fm.)	985.7	114.9	Black, carbonaceous, siltstone, pyritic in parts, and poorly bedded, with thin lenticles of fine-grained sandstone. Slumping common
	Carynginia Fm.	1100.6	116.7	Kaolinitic sandstone, moderately sorted very fine to medium-grained, and quartz greywacke, interbedded with carbonaceous shale and fissile sandstone. Rare beds of coarse to very coarse-grained sandstone occur near the base. Bedding largely obscured by slump structures, contorted laminae, and worm burrows
	Irwin River C.N.	1217.4	204.5	Rapidly alternating sandstone, siltstone, shale and thin coal beds. Sandstone is poorly to moderately well sorted, fine to very coarse-grained, commonly cross-bedded
	Unit 'D' (High Cliff Sandstone)	1421.9	39.3	Interbedded dark-coloured siltstone, sandstone, some claystone and rare thin limestone beds
PRECAMBRIAN	Basement	1461.2	20.7	
	T.D.	1481.9		

Notes

*McTavish & Dickins (1974) regard the Kockatea Shale in BMR No. 10 as ranging from Otoceratan probably to Owenitan, (in the sense of Spath, 1934) based on the ammonoid fauna. Skwarko & Kummel (1974) consider that the specimens from Beagle Ridge could be correlative with specimens from the Kockatea Shale in Dongara No. 4 which they date as Gyronitan to Flemingitan

After McTavish (1960 a & b); Balme (1969); Lowry, (1972); Johnstone & Wilmott (1966)

PLATE I


PERTH BASIN
SIMPLIFIED GEOLOGY
0 20 40 60 80 100 km
Quaternary
Tertiary
Cretaceous basalt flows
Jurassic
Triassic
Permian
Ordovician–Silurian
Precambrian
Proterozoic
Well – dry, abandoned
Well with show of gas – drilling suspended
Well with show of oil – abandoned
Gas well
Gas well – abandoned
Well with show of gas – abandoned
Well with show of oil and gas – abandoned
Stratigraphic hole
Geraldton
Dongara
Mingenew
Arrino
Yarra Yarra Lakes
Lancelin
PERTH
Rottnest Island
Garden Island
Medina
Rockingham
Mandurah
Harvey
Bunbury
Collie
Busselton
Cape Naturaliste
Cape Leeuwin
Point D'Entrecasteaux
Manjimup
Narrogin
Katanning
Albany
Northam
York
Lake Monger
Lake Moore
Lake Grady
Lake Mollerin
Murchison River
Greenough River
Lockier River
Moore River
Swan River
Helena River
Avon River
Serpentine River
Murray River
Hotham River
Williams River
Arthur River
Blackwood River
Frankland River
Kent River
DARLING FAULT
URELLA FAULT
BEAGLE FAULT
DUNSBOROUGH FAULT
BUSSELTON FAULT
HARDABUT FAULT
Gun Island 1
Beagle Ridge 10, 10A
South Turtle Dove 1, 1A, 1B
Walyering 1
Gingin 1
Bullsbrook 1
Egonu 1
Charlotte 1
Quinns Rock 1
Roe 1
Gage Roads 2
Cockburn 1
Warnbro 1
Challenger 1
Bouvard 1
Pinjarra 1
Lake Preston 1
Preston 1
Sugarloaf 1
Wonnerup 1
Whicher Range 1
Sue 1
Blackwood 1
Alexander Bridge 1
200m
1000m
(BASED ON XAUS-7-12)
Record No 1977/63, 1978/66
XAUS-7-13


PLATE 2
PERTH BASIN
MAGNETIC BASEMENT DEPTH CONTOURS
(AFTER BMR AND WAPET)
0 20 40 60 80 100 km
(Contours in metres)
WAPET OFFSHORE
WEST BEAGLE
AEROMAGNETIC SURVEY
BMR PERTH BASIN
AEROMAGNETIC SURVEY
WAPET
OFFSHORE LEEUWIN
AEROMAGNETIC SURVEY
BMR
URELLA FAULT
DARLING FAULT
DUNSBOROUGH FAULT
Geraldton
Dongara
Murchison River
Greenough River
Irwin River
Lockier River
Yarra Yarra Lakes
Lake Monger
Lake Moore
Lake Grady
Lake Mollerin
Moore River
Swan River
Northam
York
Helena River
PERTH
Rottnest Island
Garden Island
Medina
Rockingham
Avon River
Serpentine River
Mandurah
Murray River
Hotham River
Williams River
Narrogin
Harvey
Bunbury
Collie
Arthur River
Cape Naturaliste
Busselton
Katanning
Blackwood River
Manjimup
Cape Leeuwin
Frankland River
Kent River
Pt D'Entrecasteaux
Albany
200m
1000m
(BASED ON XAUS-7-12)
Record No.1977/63,1978/66
XAUS-7-23

PLATE 3

Record No.1977/63, 1978/66

—— -20 —— Bouguer anomaly contour

• Gravity station

Note: The Bouguer anomaly contours shown are subject to change, particularly offshore where control is sparse. In the offshore area no correction has been made for the water layer.

PERTH BASIN
GRAVITY ANOMALIES

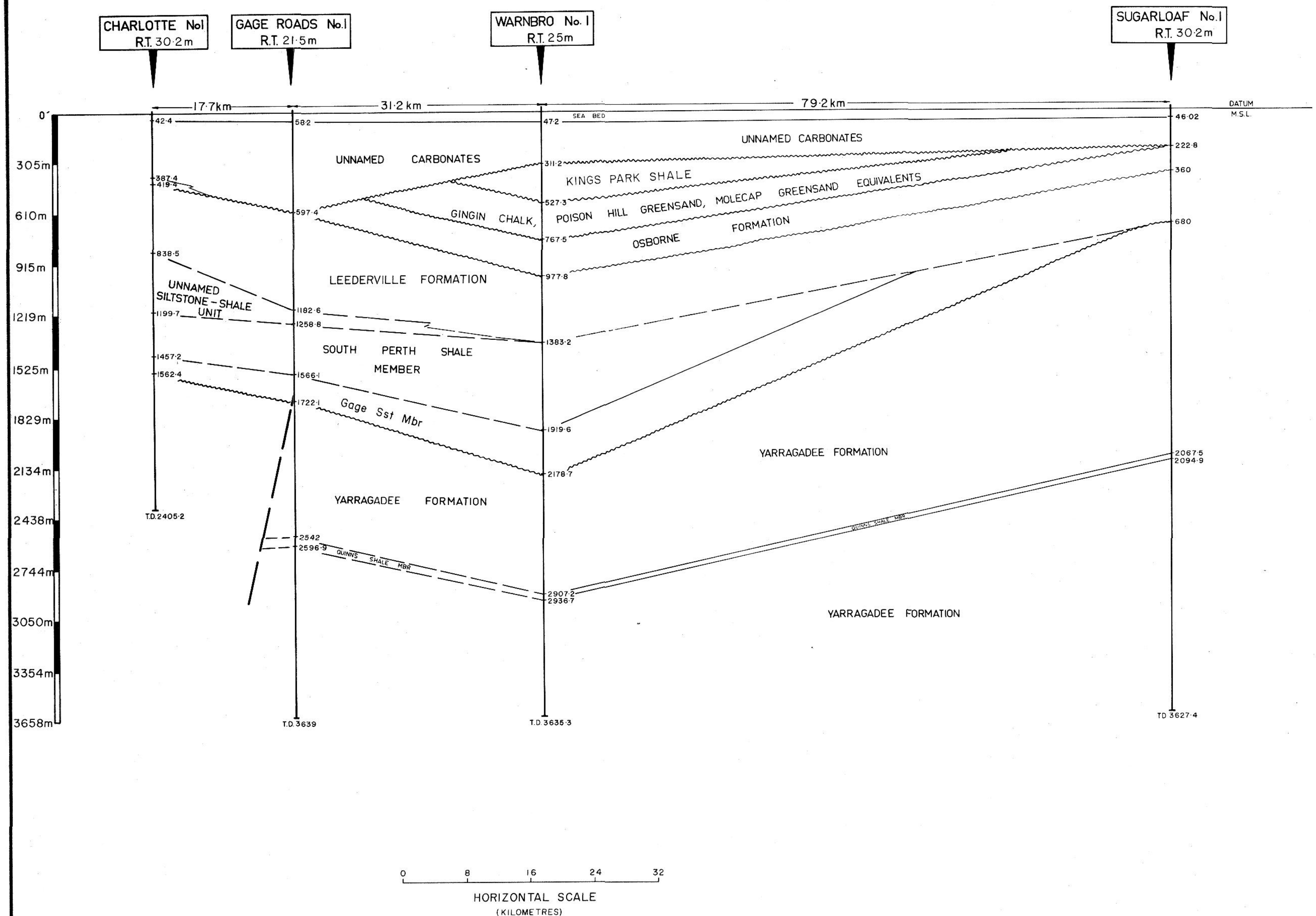
0 20 40 60 80 100 km

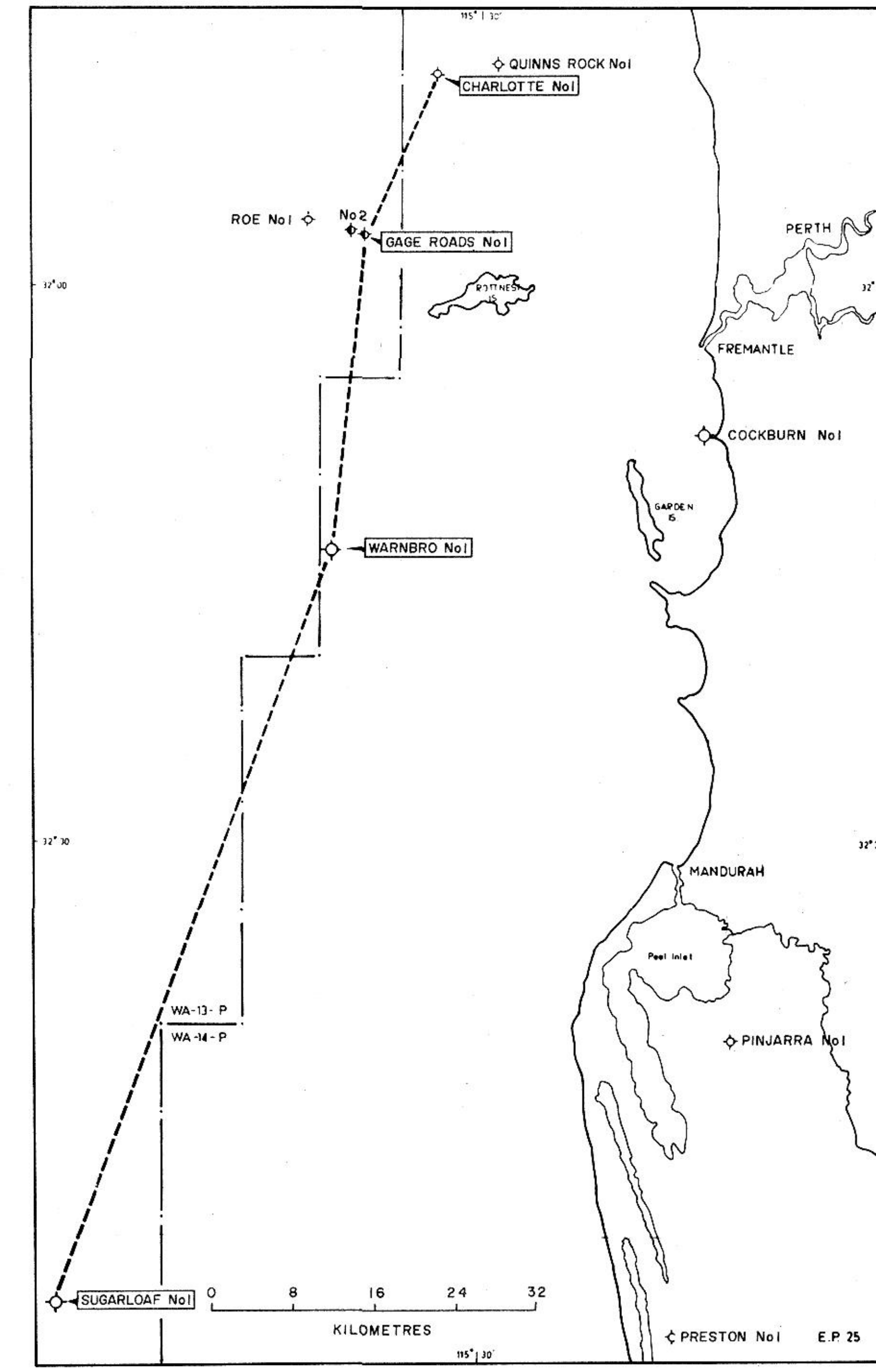
XAUS-7-22

PLATE 4
PERTH BASIN
SEISMIC SURVEY AND LINE LOCATIONS
0 20 40 60 80 100km
Survey names: For key to numbers see Appendix 2
Shark Bay
BYRO SUB-BASIN
COOLCALALAYA SUB-BASIN
Scale 1:2 500 000
0 50 100km
Murchison River
Greenough River
Geraldton
Dongara
Irwin River
Lockier River
Yarra Yarra Lakes
Lake Monger
Lake Moore
Lake Grady
Lake Mollerin
Moore River
Swan River
Northam
York
Helena River
Avon River
PERTH
Rottnest Island
Garden Island
Medina
Rockingham
Serpentine River
Mandurah
Murray River
Hotham River
Williams River
Narrogin
Harvey
Collie
Bunbury
Arthur River
Busselton
Katanning
Blackwood River
Manjimup
Flinders Bay
Frankland River
Kent River
Albany
200m
1000m
(BASED ON XAUS-7-12)
Record No 1978/66
XAUS-7-19


PLATE 5
PERTH BASIN
REGIONAL SEISMIC DEPTH CONTOURS
0 20 40 60 80 100 km
Fault
Seismic horizon change
2000 Depth below sea level (metres)
Murchison River
Insufficient data for contouring
Greenough River
HARDABUT FAULT ?
Geraldton
Basement
ABROLHOS SUB-BASIN
Irwin River
Lockier River
Dongara
ENEABBA FAULT
URELLA FAULT
Pre-Jurassic
Arrowsmith 1
Yarra Yarra Lakes
Lake Monger
Lake Moore
BEAGLE FAULT
Lower Jurassic
DARLING FAULT
Hill River
Hill River 4
TURTLE DOVE RIDGE
BEAGLE RIDGE
Within Permian
Lake Grady
Lake Mollerin
Walyering 1
EDWARDS ISLAND BLOCK
Moore River
Jurassic
Gingin 1
Swan River
Northam
York
Helena River
PERTH
Rottnest Island
Garden Island
Cockburn 1
Medina
Rockingham
Avon River
VLAMING SUB-BASIN
Serpentine River
Mandurah
Pinjarra 1
Murray River
Hotham River
Williams River
Lake Preston
near Top Permian
Narrogin
Harvey
Collie
Bunbury
Cape Naturaliste
VASSE SHELF
Wonnerup 1
Permian
Busselton
Arthur River
Katanning
Within Permian
DUNSBOROUGH FAULT
Blackwood River
Manjimup
Cape Leeuwin
Flinders Bay
Frankland River
Kent River
Pt D'Entrecasteaux
Albany
200m
1000m
(BASED ON XAUS-7-12)
Record No 1977/63, 1978/66
XAUS-7-21

PLATE 6





STRATIGRAPHIC CROSS SECTION

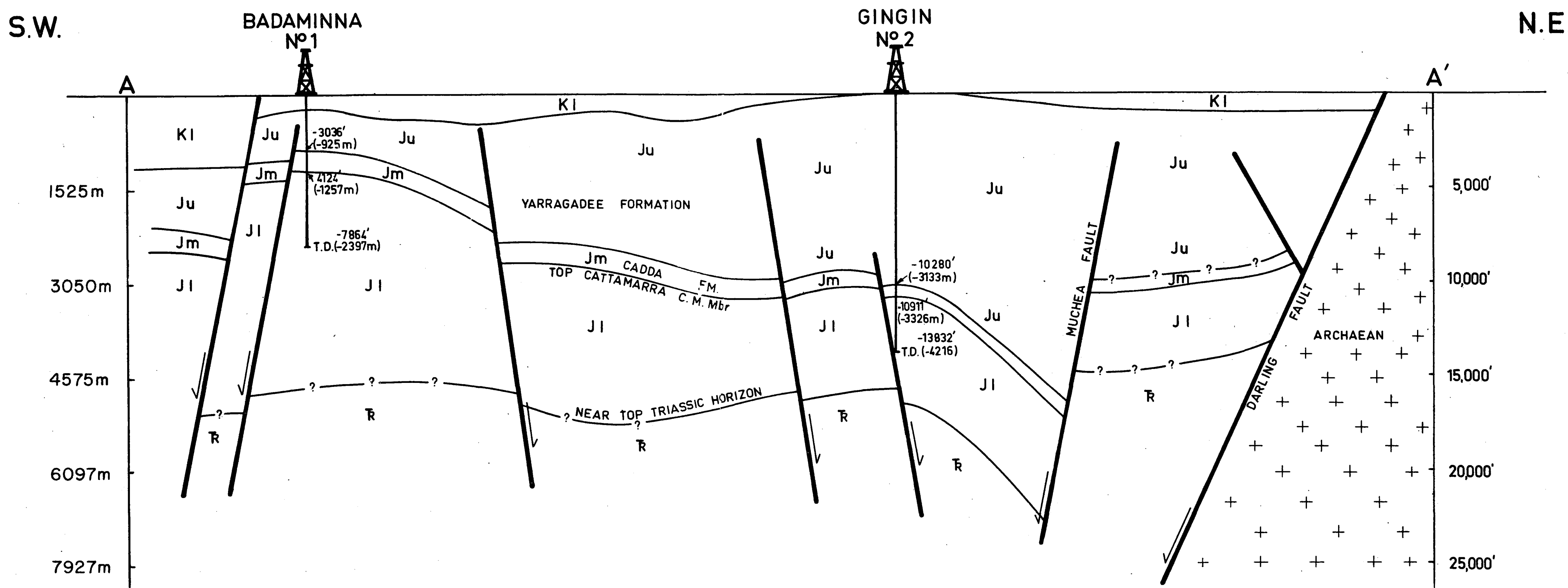
VLAMING SUB-BASIN

DATUM: MEAN SEA LEVEL

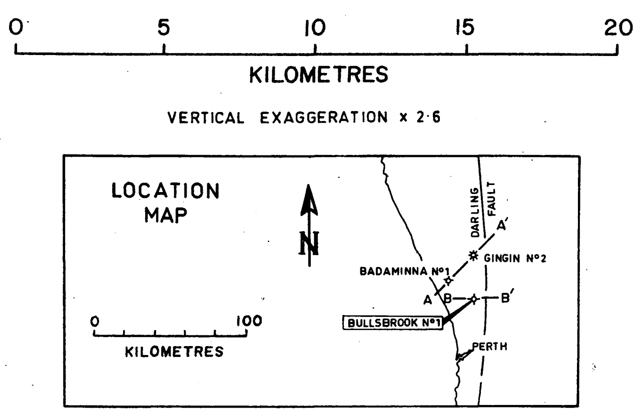
Note – See Appendix 3 For Revisions

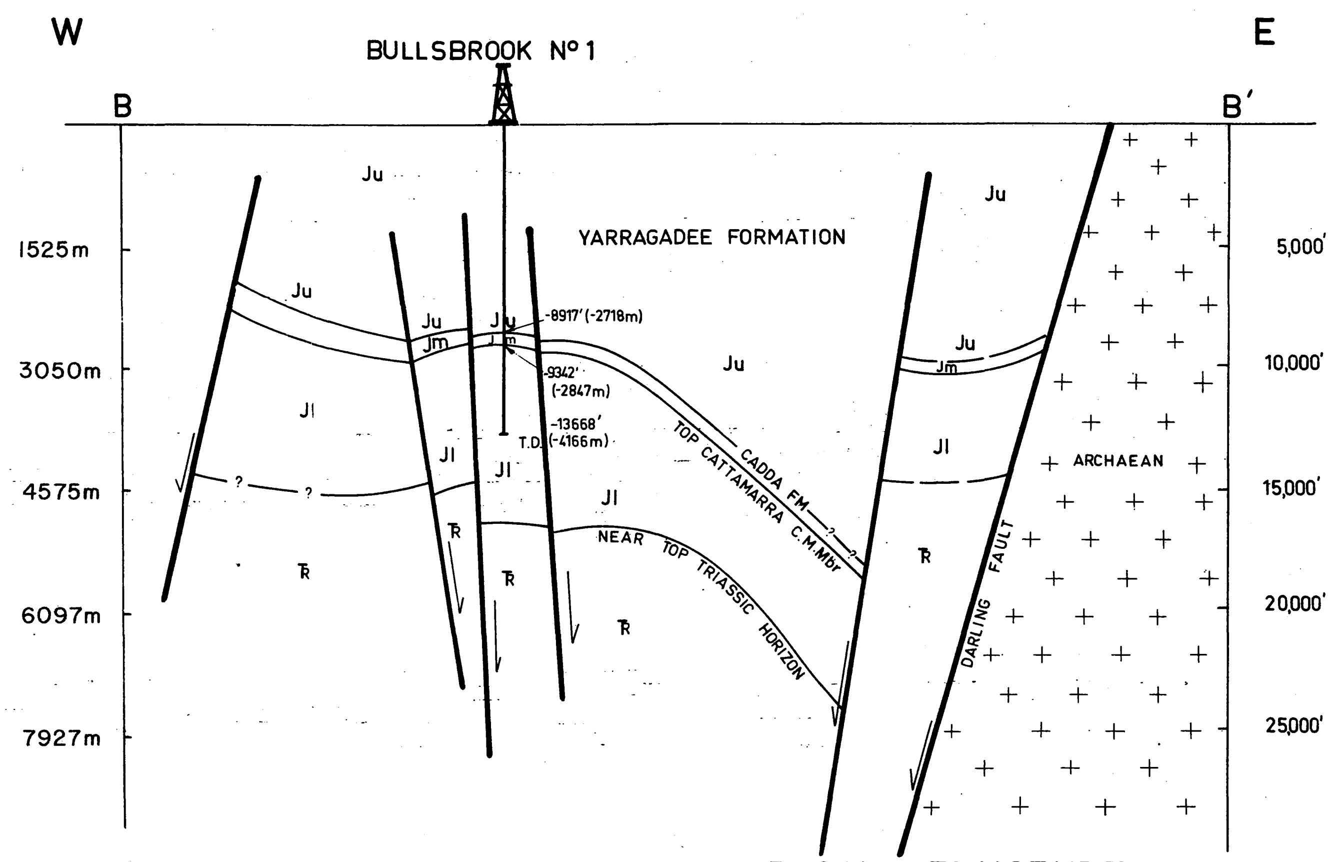
Record No 1978/66

After Wapet, 1971c



SECTION A-A' BADAMINNA Nº1 TO DARLING FAULT





SECTIONS ACROSS THE GINGIN — BULLSBROOK TREND CENTRAL DANDARAGAN TROUGH

SECTION B-B' THROUGH BULLSBROOK STRUCTURE

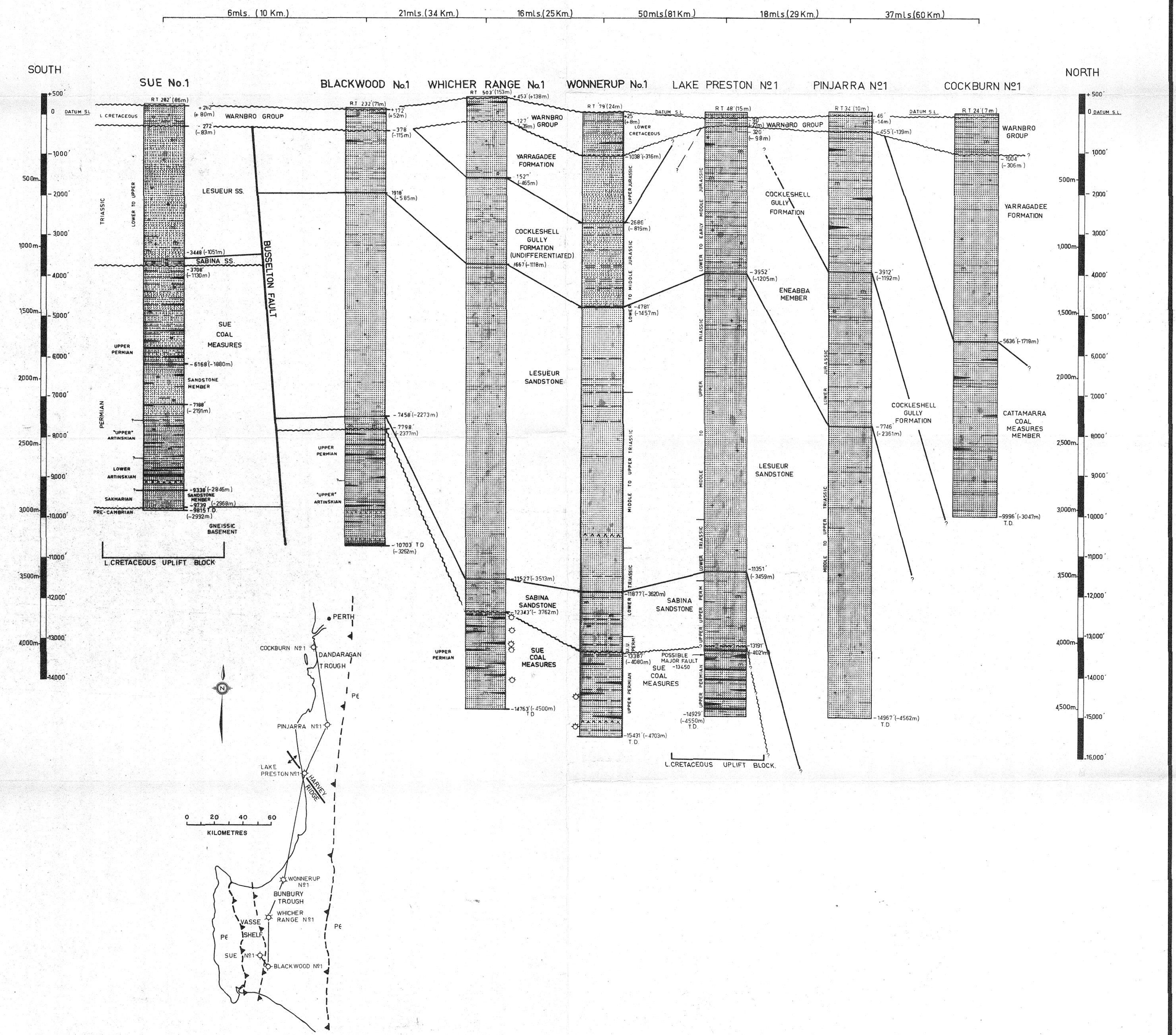
Report No 1978/66

After Wapet, 1972 b

XAUS-7-50

SOUTHERN PERTH BASIN

WELL CORRELATION CHART



Record No 1977/63, 1978/66

After Wapet, 1972 a