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Record 1976/66

A REVIEW OF PETROLEUM EXPLORATION AND PROSPECTS IN THE ARAFURA SEA - GULF OF CARPENTARIA REGION

by

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

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SUMMARY

Petroleum exploration carried out in the Arafura Sea - Gulf of Carpentaria region up to 1975 has been reviewed to provide a current assessment of the knowledge of this region and to determine the need for future exploration.

The region extends over the northern Australian continental shelf and marginal areas onshore. This Record is mainly concerned with the Mesozoic-Cainozoic Money Shoal Basin in the western part of the region and the Mesozoic Carpentaria Basin in the eastern part. Apart from the western portion of the Money Shoal Basin, both basins contain only a restricted thickness of mostly undeformed sediments. However, the Money Shoal Basin is underlain by a pre-Mesozoic graben about 300 km in length which contains appreciable thicknesses of sediments presumably of Palaeozoic age.

Although a considerable amount of geophysical work has been done, further geophysical surveys are required, particularly in the east. Only two wells have been drilled in the Money Shoal Basin and no wells have been drilled offshore in the Carpentaria/Karumba Basins. Further wells are required to provide stratigraphic information. Petroleum prospects of the region are not promising, but several structures which may warrant drilling have been mapped in the western part of the Money Shoal Basin.

1. INTRODUCTION

This Report provides a review of the geology, geophysics, and petroleum prospects of the Arafura Sea - Gulf of Carpentaria region using relevant information available up to October 1975, including confidential information supplied to BMR under the Petroleum (Submerged Lands) Act 1967-1974. It is intended that this summary should be useful in the formulation of future exploration programs by BMR and in the evaluation of exploration proposed and carried out by petroleum companies.

The region covered in the summary extends over the Australian part of the northern Australian continental shelf between Australia and Irian Jaya/Papua New Guinea extending approximately from longitude 130°E, eastwards through the Arafura Sea and the Gulf of Carpentaria to longitude 142°E.

Four Phanerozoic sedimentary basins have been recognized in the region: the Mesozoic-Cainozoic Money Shoal Basin and the underlying Arafura Basin in the west, and the Mesozoic Carpentaria Basin and overlying Cainozoic Karumba Basin in the east.

The Money Shoal Basin (Williams et al., 1973) is roughly coextensive with the Arafura Basin as used by Shell Development (Aust.) Pty Ltd (Nicol, 1970; Balke et al., 1973; Shell, 1973). The use of the name 'Arafura Basin' is preferred for a sedimentary basin offshore and onshore in the northeastern part of Arnhem Land (Rix, 1964; Plumb, 1965; Plumb & Derrick, in press; Dunnet, 1965; GSA, 1971), until recently thought to be Proterozoic, but for which a Palaeozoic age is now proposed (Plumb et al., in press).

The onshore parts of the Carpentaria and Karumba Basins, south and east of the Gulf, and the onshore margins of the Money Shoal Basin in the Northern Territory are included in the review.

2. REGIONAL TECTONIC SETTING AND BASIN BOUNDARIES

The region is a tectonically stable area bordered on the north and northwest by the mobile orogenic belt of New Guinea, Timor, and the Banda Arcs (Fig. 1). The Bonaparte Gulf Basin lies to the west, and the region is bordered on the east by the Carboniferous igneous rocks of the Cape York-Oriomo Ridge which also forms the eastern offshore boundary of the Carpentaria Basin.

The Carpentaria Basin developed as an epeirogenic intracratonic downwarp during Jurassic and Cretaceous times contemporaneously with the Eromanga Basin to the south (Pl. 1), to which it is joined across the Euroka Arch - the present structural boundary between the two basins (Doutch et al., 1970; Doutch, 1973 and in press; Smart, in press). It forms part of the Trans-Australian Platform cover as defined on the Tectonic map of Australia and Papua New Guinea (GSA, 1971). On present stratigraphic evidence, the cratonic basement appears to be mainly Precambrian rocks. The Precambrian metamorphic rocks and Precambrian and Palaeozoic intrusives and extrusives of the Georgetown, Yambo, and Coen Inliers, and the Carboniferous igneous rocks of the Cape York-Oriomo Ridge form the eastern margin. On the west, the basin is flanked by the Precambrian rocks of the McArthur and South Nicholson Basins, the Mount Isa Geosyncline, and the ?Palaeozoic sediments of the Arafura Basin. To the north, the Carpentaria Basin joins the Morehead Basin across a broad area of shallow basement (Doutch, 1973, and in press).

The Karumba Basin defined by Doutch (in prep. b) is a Cainozoic epicratonic basin in Queensland and southern New Guinea, superimposed on the Mesozoic Carpentaria Basin. At the present time, the basin covers an area which coincides with the Gulf of Carpentaria and the river systems draining into it. The Cainozoic sequence was previously regarded as part of the Carpentaria Basin. Plate 1 shows the Cainozoic Karumba Basin sequence onshore in the areas where it exceeds 50 m.

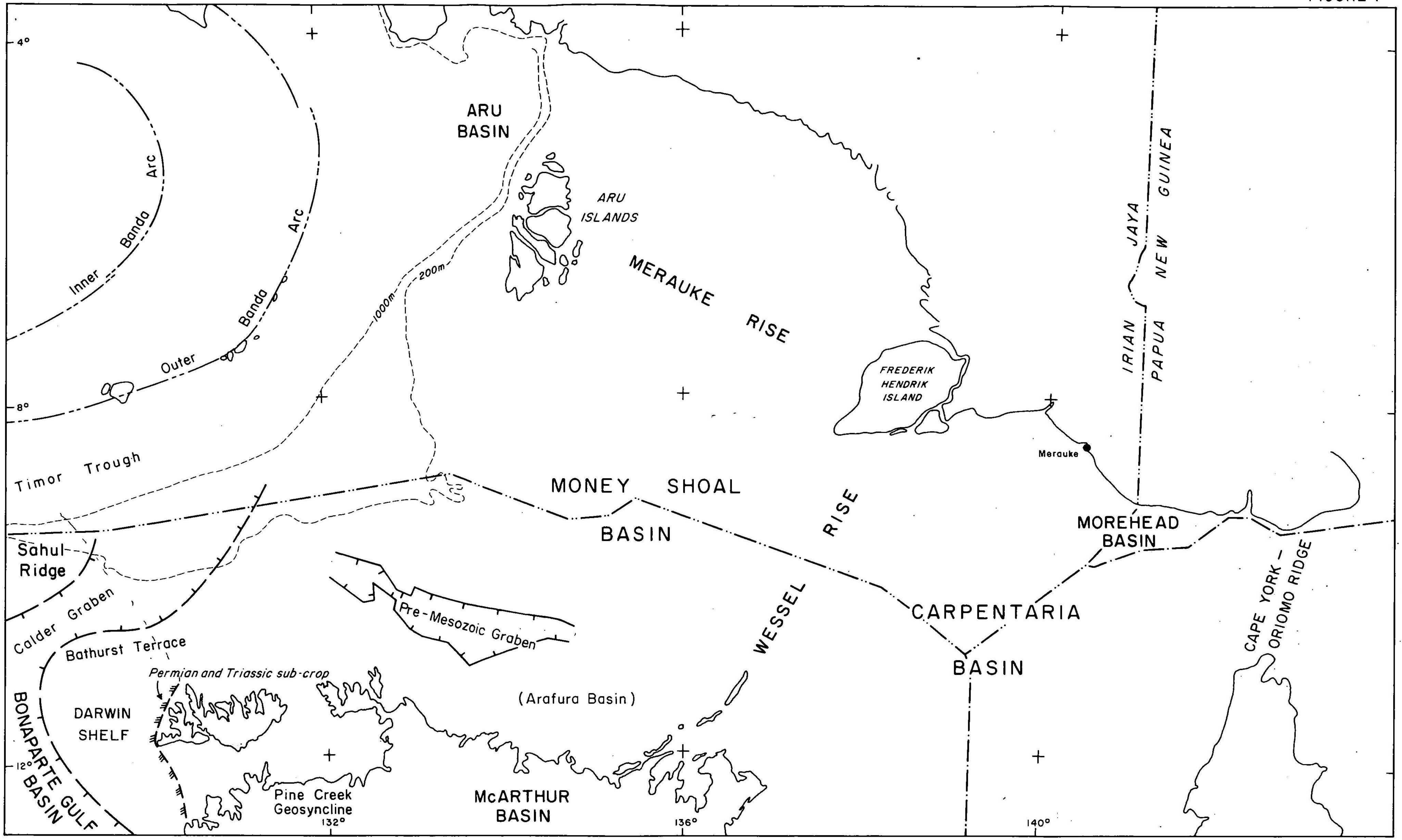
The boundary between the Carpentaria and Money Shoal Basins is taken as a poorly defined positive feature, the 'Wessel Rise' (Nicol, 1970), extending northeast from the Wessel Islands towards Frederik Hendrik Island in Irian Jaya. Doutch (1973 and in press) recognizes the possible existence of a small Mesozoic basin ('Merauke Basin') between the Carpentaria Basin and Merauke in New Guinea.

In this record and in BMR (1975) the southern margin of the Money Shoal Basin is taken as the contact between basin sediments and the Precambrian rocks of the Pine Creek Geosyncline and McArthur Basin in the northwestern Northern Territory. Hughes & Senior (1973) and Hughes (in press) have taken the northern boundary of the Bathurst Terrace as the southern margin.

boundary Bonap/ Mog

There appears to have been no depositional barrier between the Bonaparte Gulf Basin and the Money Shoal Basin since the Late Jurassic. Hughes & Senior (1973) and Hughes (in press) have shown that the Upper Jurassic/Cretaceous and Cainozoic sediments on the Bathurst Terrace thicken northwards into the Money Shoal Basin, and westwards over a geophysically determined basement feature, the Van Diemen Rise, into the Bonaparte Gulf Basin. Permian and Triassic sediments deposited in the Bonaparte Gulf Basin. Permian and Triassic sediments deposited in the Bonaparte Gulf Basin wedge out against the Van Diemen Rise. This

FIGURE 1



MONEY SHOAL AND CARPENTARIA BASINS

TECTONIC SETTING

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sub-crop as far as it can be determined at present has been taken (Williams et al., 1973; BMR, 1975) as the margin between the two basins.

The southern margin of the Arafura Basin is the unconformable contact between the basin sediments and Precambrian rocks of the McArthur Basin along the north coast of Arnhem Land, Northern Territory. The offshore extent of the basin has not been determined.

The area covered by the Money Shoal Basin includes about 390 000 km^2 offshore in the Arafura Sea in adjacent areas of the Northern Territory of Australia and Indonesia, and 1000 km^2 onshore north of the Pine Creek Geosyncline and the McArthur Basin. About 230 000 km^2 of the offshore area are under Australian jurisdiction. The Carpentaria Basin covers an area of about 125 000 km^2 onshore mainly in Queensland, and about 375 000 km^2 offshore in the adjacent areas of Queensland, Northern Territory, Irian Jaya, and Papua New Guinea; 345 000 km^2 offshore is in Australian waters.

These areas are from BMR (1975). For measuring purposes the western margin of the Money Shoal Basin was taken as the Permian-Triassic sub-crop as far north as Bathurst Island, and then as an arbitrary line extending in a northwesterly direction to the edge of the continental shelf. Doutch (1973 and in press) gives the area for the Carpentaria Basin as about 560 000 km^2 of which at least 300 000 km^2 underlies the Gulf. The 'Merauke Basin' was not included in Doutch's estimates.

3. GEOPHYSICS

Geophysical exploration of the region commenced in some of the onshore marginal areas in the late 1950s and early 1960s but it was not until the mid-1960s that significant offshore exploration was carried out. Aeromagnetic surveys and/or marine magnetic surveys in varying degree of detail had been done over much of the region by 1969. To date there has been little gravity coverage offshore, except west of 132°E, but there is regional gravity coverage of all of the Australian mainland adjacent to the region considered. The first offshore seismic surveys were done in 1964. Since that time marine seismic exploration has been continued each year up to 1973 in the western part of the Arafura Sea, west of about 134°E, with the result that that area is well covered by reconnaissance and in some areas more detailed seismic traverses tied to several wells. However the large offshore area east of 134°E is only sparsely covered with seismic surveys and there are no offshore wells to which the geophysical data can be tied.

A list of geophysical surveys done in the region is presented as Appendix 1. This list includes the survey name and type, year, operator, geophysical contractor, number of kilometres surveyed, and the Petroleum Search Subsidy Act (PSSA) or Petroleum (Submerged Lands) Act (P(SL)A) reference number or other reference for the survey. Altogether some 40 geophysical surveys have been done in the region. Pinchin (1973) produced a geophysical review of the Carpentaria, Laura, and Olive River Basins, which has been useful in the preparation of the current review, especially the Plates. Pinchin's contribution is gratefully acknowledged.

Magnetic surveys

Plate 2 shows the aeromagnetic flight lines and marine magnetic traverses carried out in the region. Much of the region has some magnetic coverage. Areas with little or no coverage include an area northeast of the Wessel Islands and the southeastern part of the Gulf of Carpentaria. Apart from the areas in the northeast of the Gulf covered by the North-East Carpentaria aeromagnetic survey for Marathon Petroleum Australia, the aeromagnetic coverage of the Gulf of Carpentaria is very sparse. In Plate 3 interpreted depth to magnetic basement contours are shown. These contours are closely based on those presented in the PSSA final reports.

In the western part of the region the Melville Island aeromagnetic survey in 1963 and the Van Diemen Gulf aeromagnetic survey in 1969 indicated magnetic basement generally shallower than 1000 m. No interpreted depths to magnetic basement are available for the 1965 and 1967 BMR marine magnetic traverses or the 1972 Gulf regional geophysical reconnaissance traverse indicated in Plate 2, but the magnetic profiles are available.

The Arafura Sea aeromagnetic survey by Shell Development Australia in 1965 provided coverage of the whole of the Australian part of the Arafura Sea from Melville Island to the Wessel Islands with north-south flight lines about 20 km apart. Interpretation of the results of this survey (Pl. 3) indicated that magnetic basement depth increases northwards from about 1500 m near the coast to more then 9000 m in the northeastern and northwestern parts of the survey area. However, it seems likely that some of the non-magnetic rocks indicated to be present offshore consist of relatively unmetamorphosed Upper Proterozoic sediments such as are known onshore to the south.

In the Gulf of Carpentaria interpreted depths to magnetic basement are significantly less than in the Arafura Sea. Interpretation of the results of the Gulf of Carpentaria aeromagnetic survey flown in 1962 suggested that magnetic basement depth varies from 750 m in the southeast of the Gulf to 3000 m in several areas in the northern half of the Gulf. The North-East Carpentaria aeromagnetic survey in 1964, which overlapped part of the former survey and which involved a much closer flight-line pattern, indicated significantly shallower magnetic basement depths than the Gulf of Carpentaria aeromagnetic survey. However, it was pointed out in the report on the latter survey (BMR file, 64/4607) that there was evidence of two magnetic horizons and that the shallower horizon, although probably basement, could also represent volcanic rocks within a sedimentary sequence. Because of uncertainties in the interpretations of the magnetic data, in particular doubts about the nature of the magnetic horizons mapped, depth contours in Plate 3 can only be regarded as giving a broad outline of maximum sediment thicknesses in the Gulf of Carpentaria.

Several aeromagnetic surveys have been done over the eastern and southern margins of the Carpentaria Basin onshore. The Wenlock River aeromagnetic survey was done in 1964 over the northern part of Cape York Peninsula north of 14°S (Pls. 2 & 3). Interpreted depths to magnetic basement were shallow over the whole of the survey area. They were generally less than 600 m, although two small areas with possibly 1200 m of sediments were indicated.

In 1973 and 1974 BMR carried out aeromagnetic surveys over Cape York Peninsula between latitudes 14°S and 16°S. Flight lines were east-west with 3 km spacing over land and 6 km offshore for Holroyd, Rutland Plains, and Hann River 1:250 000 Sheet areas. Flight line spacing over the Ebagoola Sheet area was 1.5 km. BMR has also flown the onshore portion of the Westmoreland Sheet area on the southwest margin of the Carpentaria Basin with north-south flight lines at 3 km spacing. Interpretation for these areas was not available at the time of writing. Lawn Hill Sheet area was flown as part of the Georgina Basin aeromagnetic survey by BMR (Wells et al., 1966). Interpreted depths to magnetic basement are shown in Plate 3, but as non-magnetic Proterozoic rocks crop out in the southern part of the area contoured, it is clear that magnetic basement in this area does not correspond with the base of the Carpentaria Basin sediments.

In 1962 the Karumba aeromagnetic survey was flown in the southeastern portion of the Carpentaria Basin east and south-east of Karumba and Burketown (Pl. 2). Interpreted magnetic basement depths (Pl. 3) were generally shallow except in a postulated trough trending approximately north-south to the east of Karumba. In this area magnetic basement depths of up to 3000 m were suggested. However, the results of bore-holes and seismic surveys indicate that the Carpentaria Basin sediments are less than 600 m thick in this vicinity, so that if a magnetic basement trough exists it must contain older non-magnetic rocks.

Gravity surveys

Bouguer anomalies for the region are shown in Plate 4. On land, reconnaissance gravity coverage on an 11-km grid has been obtained by BMR between 1964 and 1970 using helicopters, as part of its gravity map of Australia project. Similarly, BMR carried out gravity measurements on a series of east-west traverses about 20 km apart in the Arafura Sea west of 132°E and also immediately north of Cobourg Peninsula in 1967 as part of its combined geophysical survey of the Timor Sea area (Jones, 1969). Bouguer anomaly maps at 1:250 000 are available for these areas surveyed by BMR.

In the remainder of the offshore areas of the region gravity coverage is very sparse or non-existent. In 1967 the U.S. Naval Oceanographic Office surveyed a number of gravity traverses forming an irregular pattern over the Gulf of Carpentaria (Pl. 4). Earlier, in 1958, BMR carried out underwater gravity surveys around the perimeter of the Gulf of Carpentaria (Williams & Waterlander, 1958) and near the coast from Cape Arnhem to Darwin (Williams & Waterlander, 1959). Because of their proximity to the coast these BMR underwater surveys add little to the regional anomaly pattern in Plate 4. The regional geophysical reconnaissance traverse surveyed by Australian Gulf Oil Company across the Arafura Sea and northwestern part of the Gulf of Carpentaria in 1972 included gravity readings as indicated in Plate 4. No intense Bouguer gravity gradients were detected.

The area of the Arafura Sea west of 132°E which was covered by the BMR marine gravity traverses does not show any marked Bouguer anomaly trends. Jones (1969) defined a gravity province on the continental shelf north of Melville Island and Cobourg Peninsula which he called the 'West Arafura Regional Gravity Platform'. The east-trending southern margin of this province is marked by a steep gravity gradient, increasing northwards. Over the rest of the province the Bouguer anomaly pattern is relatively smooth, with no intense anomalies and no clear directional trends. The northerly gravity gradient in the south is accompanied by a thickening of the Mesozoic-Tertiary sediments to the north. However, gravity anomalies within the province show no obvious correlation with seismic results and it is probable that the gravity anomalies have their origin below the known sedimentary sequence. The northerly gradient in the south may be due to an intra-basement density contrast or it may represent the boundary between a normal continental region to the south and a shelf area of thinner continental crust to the north.

The sparse gravity data available in the Gulf of Carpentaria from the U.S. Naval Oceanographic Office survey indicate a uniform pattern of low Bouguer anomalies over much of the Gulf. If these data are reliable (and they do tie reasonably well with more detailed work onshore) then they suggest that most of the Gulf is underlain by a uniform continental-type basement and a sedimentary layer of uniform thickness. Certainly the gravity data offshore are consistent with the extension of the Carpentaria Basin, as observed onshore around the southeast corner of the Gulf, northwards over the Gulf. However, a greater variation in Bouguer anomalies on the western side of the Gulf may indicate shallow basement in that area.

Between the BMR marine gravity work in the west of the region and the Gulf of Carpentaria gravity data offshore are insufficient to allow contouring. The Gulf regional geophysical reconnaissance traverse is mostly too far to the north to allow correlation with onshore trends. It is notable that the Gulf traverse shows no indication of a positive gravity anomaly north-east of the Wessel Islands which might correspond with the 'Wessel Rise'. The most significant gravity anomaly observed onshore, which would appear to extend offshore, is a large, positive Bouguer anomaly observed near Elcho Island (Pl. 4). It has been suggested (Pinchin, 1973) that the anomaly may be due to a large intrusive body or that it may be associated with a block of high-grade metamorphic Lower Proterozoic rocks.

<u>Seismic surveys</u>

<u>Arafura Sea and neighbouring areas</u>. The earliest seismic survey in the area was a refraction survey on Bathurst Island in 1962, which established that basement dips to the northwest and that the maximum thickness of sediments is about 1000 m. This confirms estimates from aeromagnetic results. The first marine work was a short reflection program carried out in 1965 by Anacapa Corporation, the Dundas Strait survey. This survey, off the northeast coast of Melville Island, indicated a regional north dip. The locations of seismic lines are shown in Plates 5 and 5A and seismic depth contours in Plate 6.

Much of the exploration done in the Arafura Sea has been done by Shell Development (Australia) Pty Ltd, who held extensive petroleum permits offshore between about 130°E and 133°30'E for a number of years. Shell's first seismic survey, in 1965-66, was a reconnaissance survey extending over a wider area. This survey extended from north of Bathurst Island in the west to the area north of Elcho Island in the east. Later surveys by Shell were confined to the western half of the Arafura Sea. The results of seismic surveys are mainly discussed in the Geology chapter.

The earliest Shell surveys used explosives as energy source and were shot with mostly 3-fold multiple coverage. The Money Shoal seismic survey in 1967 was a sparker seismic survey, which provided fair-quality data except in the northwest where the sediments were thickest and noise and multiple events interfered with deep reflections. From 1968 onwards airgun arrays were used as energy source and by 1969 24-fold multiple-coverage shooting was employed. Surveys were carried out each year up to 1973 and refinements in technique produced steadily improving data quality. Because the base of the Mesozoic is at relatively shallow depths over most of the area, even the earliest seismic data are of adequate quality to map the generally thin post-Palaeozoic sediments. But some of the earlier data are inadequate for mapping the deeper horizons in the northwest of the area, where the Mesozoic is appreciably thicker, and for mapping pre-Mesozoic horizons of interest in the central part of the Money Shoal Basin.

If the western boundary of the Money Shoal Basin is taken, very arbitrarily, as a line north-northwest from Bathurst Island, then the eastern part of the original Permit NT/P6, held by BOC of Australia (BOCAL) and its partners, falls within the area of this study. BOCAL have carried out a number of surveys in the area, of which the subsidized Calder-Evans seismic survey in 1972 is the most relevent. A 'Maxipulse' (small, deep explosive charge) energy source was used and the results were processed to give sum-2 24-fold CDP coverage. Data quality was good.

Australian Aquitaine Petroleum commenced seismic exploration in 1967 in the central portion of the Arafura Sea immediately east of the area explored by Shell since 1966. The first survey was a reconnaissance sparker seismic survey and this was followed in 1968, 1970, and 1973 by surveys using as energy source 'Flexotir' (explosive in iron cage), 'Aquapulse' (oxygen-propane gas chamber), and 'Sosie' airgun array respectively. The degree of multiple coverage employed increased from 6-fold in 1968 to 24-fold in 1973 and the quality of data obtained increased correspondingly as techniques improved.

To the south of the areas explored by Shell and Aquitaine C. and K. Petroleum held Permit NT/P22, which was a narrow east-orientated permit extending offshore from the northern coasts of Bathurst Island, Melville Island, Cobourg Peninsula, and northwest Arnhem Land. C. and K. Petroleum carried out two seismic surveys totalling 743 km, one northwest of Bathurst and Melville Islands in 1972 and the other east of Cobourg Peninsula in 1973. For both surveys an Aquapulse energy source was used and the data was recorded and processed digitally to give sum-2 12-fold CDP coverage. The results were fairly good in the western area but much poorer on the eastern survey.

In the western survey area basement was indicated at a depth of about 850 m in the south, dipping northwards to a maximum of about 2000 m in the north of the area. There was little indication of structure apart from faults at the deeper levels orientated north, perpendicular to the strike. In the eastern survey area the seismic data indicated that the Proterozoic sediments observed onshore probably extend offshore, where they are gently dipping but block-faulted. Only in the western part of the 1973 survey area are there indications of a thin sequence of Mesozoic sediments overlying the Proterozoic. The maximum thickness of Mesozoic sediments is only about 370 m and the top of the Proterozoic must be considered economic basement for petroleum exploration purposes.

As already indicated in connection with magnetic and gravity surveys, a regional geophysical reconnaissance traverse was surveyed in 1972 for Australian Gulf Oil Company through the Arafura Sea and the northwestern part of the Gulf of Carpentaria (Pls. 2, 4, & 5). In addition to magnetic and gravity data this survey recorded seismic data using an Aquapulse energy source and 24-fold CDP coverage. Seismic data quality was good in the Money Shoal Basin where there was a reasonable thickness of Mesozoic sediments present and poorer in the eastern part of the Arafura Sea.

In 1972 Beaver Exploration Australia NL and partners conducted the Wessel seismic survey of 950 km to the northeast of the Wessel Islands to investigate sediment thickness and structure in this little-known area. An Aquapulse energy source was used with sum-2 12-fold CDP coverage. Results were fair to good.

Gulf of Carpentaria and neighbouring areas. In the Gulf of Carpentaria region the earliest seismic survey was done onshore near the southeastern corner of the Gulf in 1958. In that year BMR carried out a series of seismic reflection and refraction investigations in the coastal belt between the Nicholson and Mitchell Rivers. The survey showed that the sediments gradually thicken from the inland basin margins towards a basin depression in the southeast of the Gulf, with a maximum of about 1000 m of sediments observed onshore south of the Mitchell River Mission (Robertson & Moss, 1959). Measurements made on this survey and on the Mid-Eastern Oil Karumba survey of 1963 indicated only two significant seismic velocity layers: sediments with an average vertical velocity of about 2100 m/s overlie a layer with refraction velocity of about 5700 m/s assumed to represent basement. The low velocity of the sediments suggests that they are young, probably Late Mesozoic - Cainozoic. The BMR survey showed that the basement has local irregularities and is subject to minor faulting, but that gravity anomalies in the area do not correspond with basement relief.

In 1960 the Scripps Institute, in their Argo expedition, did a refraction survey extending west-northwest from a point 170 km west of Cape York. The results indicated a refraction interface with an average velocity of 5600 m/s at a depth of 1500 m, which was interpreted as the base of the Mesozoic. A second interface, with an average velocity of 6300 m/s at a depth of about 6000 m, was interpreted as the base of the Palaeozoic.

The Cape Arnhem seismic survey was conducted in 1964 by Farmout Drillers NL using explosives and both reflection and refraction techniques. The survey consisted of several long marine seismic lines in the extreme northwest of the Gulf to determine sedimentary thicknesses. Reflection quality was very poor. A refractor with velocity greater than 5800 m/s, considered to represent basement, was recorded from shallow depths. Maximum basement depth of about 600-750 m was recorded in the southeast of the survey area.

In 1964 Marathon Petroleum Ltd carried out the ATP 104P seismic survey west of Torres Strait using both reflection and refraction techniques with explosives as energy source. About 1000 km was surveyed, and fair-quality reflections were obtained using mostly 2-fold multiple coverage. The general dip trend was westward and three low-relief basement 'highs' were defined. Basement depth was shallow. The maximum depth recorded was about 1600 m in the west of the area.

The Archer River seismic and gravity survey was conducted by Australian Aquitaine Petroleum Pty Ltd in 1965 on Cape York Peninsula near Weipa to investigate the possible presence of a sedimentary basin suggested by an aeromagnetic survey. The basement was found to be generally shallow, dipping westwards to a depth of 850 m near Weipa Bore. Gravity work done along the seismic lines showed some correlation with the seismic results. Basement depths indicated by the seismic work do not differ markedly from those interpreted from the Wenlock River aeromagnetic survey.

In 1966 Marathon Petroleum conducted the ATP 58P-R1 reflection and refraction seismic survey in the northeast of the Gulf of Carpentaria, offshore from Weipa. The survey involved more than 1800 km of seismic traverses using both analogue and digital recording and 2-fold and 3-fold multiple coverage reflection techniques. Reflection quality was poor to fair. The most prominent reflection was the Mesozoic-Cainozoic basement reflection recorded elsewhere in the basin, but in places several shallower reflections were recorded. Results indicate a Mesozoic-Cainozoic section ranging from about 700 m thick in the northeast of the area to 2000 m thick in the south-central part of the survey area southwest of Weipa. Some structural leads were indicated but no significant closed structures were mapped. The refraction profiles indicated that in general there are two velocity layers present, with velocities of approximately 2300 and 6000 m/s. The depth of the high-velocity layer corresponds well with the depth of the basement reflection.

The regional geophysical reconnaissance traverse surveyed in 1972 through the Arafura Sea for Australian Gulf Oil Company extended into the northwestern part of the Gulf of Carpentaria as far as the Queensland border (Pls. 2, 4 & 5). The seismic results in this area indicated a thin sequence of Mesozoic-Cainozoic sediments overlying a rugged erosional surface of probable Precambrian rocks. The maximum depth of this erosional surface is about 2000 m.

The Gulf of Carpentaria seismic and magnetic survey conducted by Kewanee Overseas Oil Co. in 1973 east of Caledon Bay in the northwest of the Gulf covered 2840 km using an Aquapulse seismic energy source and 24-fold CDP coverage. Seismic record quality was fair and a number of seismic reflections were recorded from above a strongly reflective and highly eroded basement at relatively shallow depths.

4. GEOLOGY

Money Shoal Basin

The onshore Money Shoal Basin has been the subject of geological observation and investigation since the early part of the last century. All previous investigations have been reviewed by Hughes (in press b). The most recent work was carried out in the Bathurst Island, Melville Island, and Cobourg Peninsula Sheet areas in 1972 as part of a continuing project which includes an investigation of the mineral potential of the area, and which included the drilling of five holes on Cobourg Peninsula in 1973. A progress report on the geology is given in Hughes & Senior (1973) and the drilling results are presented in Hughes (1973). A BMR Bulletin by R.J. Hughes entitled 'The geology and mineral occurrences of Bathurst Island, Melville Island and Cobourg Peninsula' which includes a 1:500 000 geological map, is in press. The area has been covered by BMR geological mapping at 1:250 000 scale (Malone, 1962; Dunn, 1962; Senior and Smart, in press; Hughes, in press a).

Two wells have been drilled in the offshore part of the Money Shoal Basin. As in the offshore Carpentaria/Karumba Basins interpretation of the geology relies heavily on extrapolation of stratigraphic control from adjoining areas, and support from geophysical data.

A map showing simplified geology, tectonic features and the location of petroleum exploration wells and BMR stratigraphic holes is presented as Plate 1. The drilling operations are listed in Appendices 2 and 3. Maps which have been published with explanatory notes and those in preparation and in press are listed in the bibliography, which contains a selection of the more important references and is not intended to be comprehensive.

The recent geological mapping by BMR on Bathurst Island, Melville Island, and Cobourg Peninsula has resulted in a revision of the stratigraphy of the area and the introduction of new stratigraphic names. The revised nomenclature was published by Hughes & Senior, (1974) and a further revision will be published by Hughes (in press b).

Table 1 and Figure 2 show the revised stratigraphy of Hughes & Senior (1974). Previously all the Cretaceous sediments in the northern part of the Northern Territory were assigned to the Mullaman Beds. The revision restricts the name to the Lower Cretaceous sediments on the mainland, and places the Upper Cretaceous sediments into the Bathurst Island Formation which is formally defined with the type section in Petrel No. 1 (ARCO, 1969) drilled in the Bonaparte Gulf Basin. The name had previously been used informally by ARCO and Australian Aquitaine in several unpublished well completion reports. The type section for the newly defined Van Diemen Sandstone is the cliffs on the northeast coast of Cape Van Diemen, Bathurst Island, and for the Tinganoo Bay Beds in Tinganoo Bay No. 1 (Flinders Petroleum, 1971), the only known occurrence of this unit.

Table 1a shows a further revision as proposed by Hughes (in press b) and is part of a table which will be presented in that publication. It is proposed that the term Mullaman Beds be discarded because the name has been rendered meaningless by misuse. In its stead two lithological units are distinguished - the Darwin Member of the Bathurst Island Formation, and the underlying Petrel Formation. The Darwin Member is equivalent to the Darwin Formation of the Mullaman Group as defined by Noakes (1949) and can be traced offshore to correlate with an interval at the base of the Bathurst Island Formation in Petrel No. 1. The type section for the underlying Petrel Formation is also in Petrel No. 1. The name was originally used informally by ARCO.

The following outline of the stratigraphy is largely based on the work of Hughes and Senior in the Bathurst Island, Melville Island, Cobourg Peninsula and the northern halves of the Darwin and Alligator River 1:250 000 Sheet areas (Hughes & Senior, 1973, 1974, and Hughes, in press b) and on Malone (1962) and Dunn (1962) in the Darwin and Alligator River 1:250 000 Sheet areas.

<u>Late Jurassic/Cretaceous</u> The Upper Jurassic to Neocomian Petrel Formation was deposited during a marine transgression from the west which covered the Bathurst Island and Melville Island Sheet areas and a large part of the northwestern Northern Territory but

TABLE 1. STRATIGRAPHY, BATHURST ISLAND, MELVILLE ISLAND, AND COBOURG PENINSULA SHEET AREAS

(after Hughes & Senior, 1974)

AGE	UNIT		LITHOLOGY	
QUATERNARY	Unnamed		Alluvial and colluvial sediments, beach deposits of sandy coquinite	
CAINOZOIC	(a) Van Diemen Sandstone	(b) Unnamed	(a) Quartzose cross-bedded sandstone, ferruginized in part	(b) Chemically weathered sediments, laterite
UPPER CRETACEOUS	Bathurst Island Formation Moonkinu Member		Fossiliferous sublabile sandstone, siltstone and mudstone, calcareous and carbonaceous in part	
	Wangarlu Mudstone Member		Mudstone, siltstone, pyritic in part	
	Marligur Member		Quartzose sandstone and siltstone	
LOWER CRETACEOUS	(a) Mullaman Beds (cropping out on mainland)	(b) Tinganoo Bay Beds (in Tinganoo Bay No. 1 well)	(a) Fine-grained sandstone, chert, porcellanite, conglomerate	(b) Coarse-grained quartzose sandstone a conglomerate grading down into fine-graine micaceous sandstone with minor shale laminae

TABLE 1a. REVISED STRATIGRAPHY OF THE BATHURST ISLAND, MELVILLE ISLAND, AND COBOURG PENINSULA SHEET AREAS (from Hughes, in press b)

Era	Age	Formation	Lithology	Max. thickness in mapped area (m)	Depositional environment	References
CAINOZOIC	QUATERNARY		Silt, fine sand, mud, minor gravel; alluvium	5	Fluvial, channel and flood plain sediments	
CAINOZOIC	QUATERNARY		Red sandy, and mottled grey to yellow sandy soils	10	Colluvial and eluvial	
CAINOZOIC	QUATERNARY		Quartzose sand, shell, and coral debris, saliferous organic mud and silt; coastal sediments	20	Littoral, aeolian, intertidal deltaic, and estuarine	
CAINOZOIC	Pleistocene		Coquina, calcarenite, conglomerate	8	Littoral to shallow marine	
CAINOZOIC	TERTIARY		Ferruginous to bauxitic pisolitic laterite	5	Humid, terrestrial, mechanical and chemical reworking of parent laterite	
CAINOZOIC	TERTIARY	Van Diemen Sandstone	Friable, white to yellow, medium to coarse quartzose sandstone, minor lenses of siltstone and granular conglomerate	60	Fluvial and paralic	Hughes & Senior, 1974
			U N C O N F O R M I T Y			
	UPPER CRETACEOUS (Cenomanian)	Bathurst Island Formation (kb): Moonkinu Member	Fine to very fine sublabile sandstone interbedded with grey carbonaceous mudstone and siltstone. Calcareous and limonitic concretions	400	Shallow marine deltaic	Hughes & Senior, 1974
		Bathurst Island Formation (kb): Wangarlu Mudstone Member	Mudstone, siltstone, and minor sub-labile sandstone, scattered nodular pyrite	550	Open marine	Hughes & Senior, 1974
	LOWER CRETACEOUS (Aptian)	Bathurst Island Formation (kb): Marligur Member	Fine to coarse quartzose sandstone interbedded with micaceous siltstone and mudstone in upper part	70	Paralic	Hughes & Senior, 1974
		Bathurst Island Formation (kb): Darwin Member	Fine argillaceous sandstone, radiolarian shale, claystone and minor conglomerate	50	Shallow marine	Noakes, 1949
			D I S C O N F O R M I T Y			

TABLE 1a. (Cont.)

	Age	Formation	Lithology	Max. thickness in mapped area (m)	Depositional environment	References
MESOZOIC	UPPER JURASSIC to Neocomian	Petrel Formation	Friable fine to medium quartzose sandstone with interbedded brown to grey shale (section only)	250	Fluvial to shallow marine	Laws & Brown, in press
		Tinganoo Bay Beds	Coarse quartzose sandstone and conglomerate with angular to rounded pebbles of quartz and quartzite, minor fine micaceous sandstone (section only)	100	Non-marine	Hughes & Senior, 1974

did not extend over the Cobourg Peninsula Sheet area. The Tinganoo Bay Beds are the lateral equivalent of the Petrel Formation. Neocomian marine fossils and Jurassic plant fossils have been described from exposures of the Petrel Formation on the mainland (Skwarko, 1966). A spore-pollen assemblage from the Tinganoo Bay Beds indicates that they are uppermost Jurassic (Burger, in Hughes, in press b). The Petrel Formation forms a thin blanket of sandstone across the Bathurst Terrace probably not exceeding 100 m in thickness, and crops out on the mainland below the Darwin Member of the Bathurst Island Formation. It rests unconformably on steeply dipping Proterozoic basement rocks. The facies change from the fine to medium-grained sandstone of the Petrel Formation to the coarse clastics of the Tinganoo Bay Beds reflects the change from paralic conditions in the west, to non-marine in the east.

The Bathurst Island Formation is disconformable on the Petrel Formation except in the Cobourg Peninsula Sheet area where it rests on Proterozoic metamorphic and igneous rocks of the Nimbuwah Complex. The basal Darwin Member is a thin (42 m in Tinganoo Bay No. 1) argillaceous unit which extends across the Bathurst Terrace and crops out on the mainland in the northwestern Northern Territory. It has been intersected as far east as BMR East Alligator No. 9 (Needham, in prep.). The Darwin Member is the lateral equivalent of the arenaceous Marligur Member which crops out in the southern Cobourg Peninsula Sheet area, and in the northeast Alligator River Sheet area. It extends in the subsurface at least as far north as Cobourg Peninsula No. 3, Figure 3 (Hughes, 1973). The facies change between the two Members reflects the change from shallow-marine conditions in the west to paralic conditions in the east.

The Darwin Member is typically rich in Radiolaria. The molluscan fauna found in the unit has been described in detail by Skwarko (1966). The Member also contains belemnites, brachiopods, echinoids, bryozoans, corals, and arenaceous foraminifera. Palynological evidence from cores in the Darwin Member (Burger, in Hughes in press b) indicates an age range from late ?Neocomian to Aptian.

The Darwin and Marligur Members are overlain by the Wangarlu Mudstone Member, a sequence of massive dark grey pyritic mudstone. It crops out in the cliffs along the southern coastline of Cobourg Peninsula, and is known from drill-hole information to extend in the subsurface into the southern Cobourg Peninsula Sheet area and westwards over the Bathurst Terrace.

Fragments of bivalves, gastropods, and Upper Cretaceous ammonites including Sciponoceras and Acanthoceras were abundant in several bore-holes. Palynological evidence from both outcrop and drill-hole samples indicate a Cenomanian age for the Wangarlu Mudstone Member in this area.

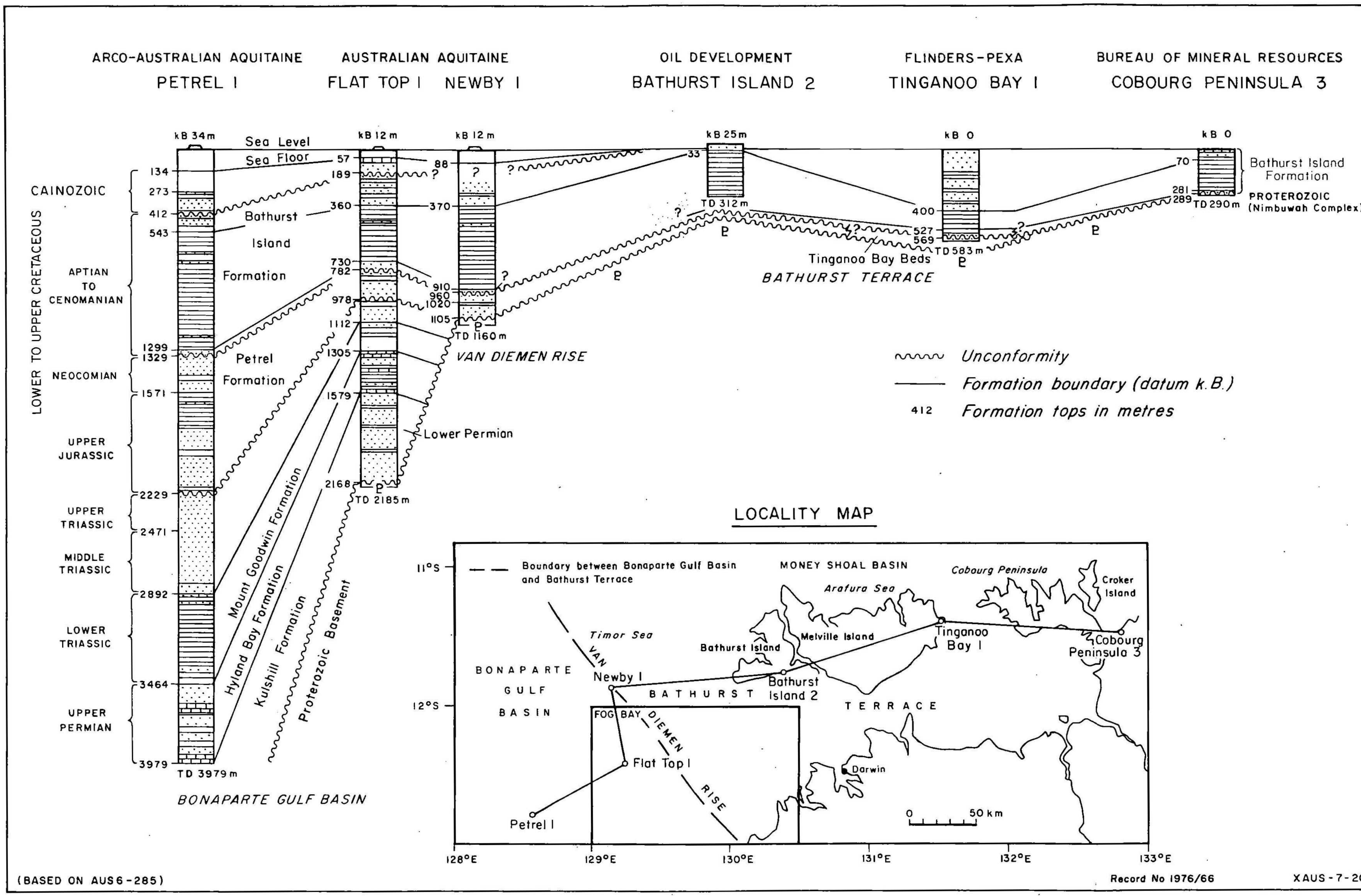


Fig. 2 Stratigraphic correlation from the Bonaparte Gulf Basin across Bathurst Terrace to Cobourg Peninsula (From Hughes in press b)

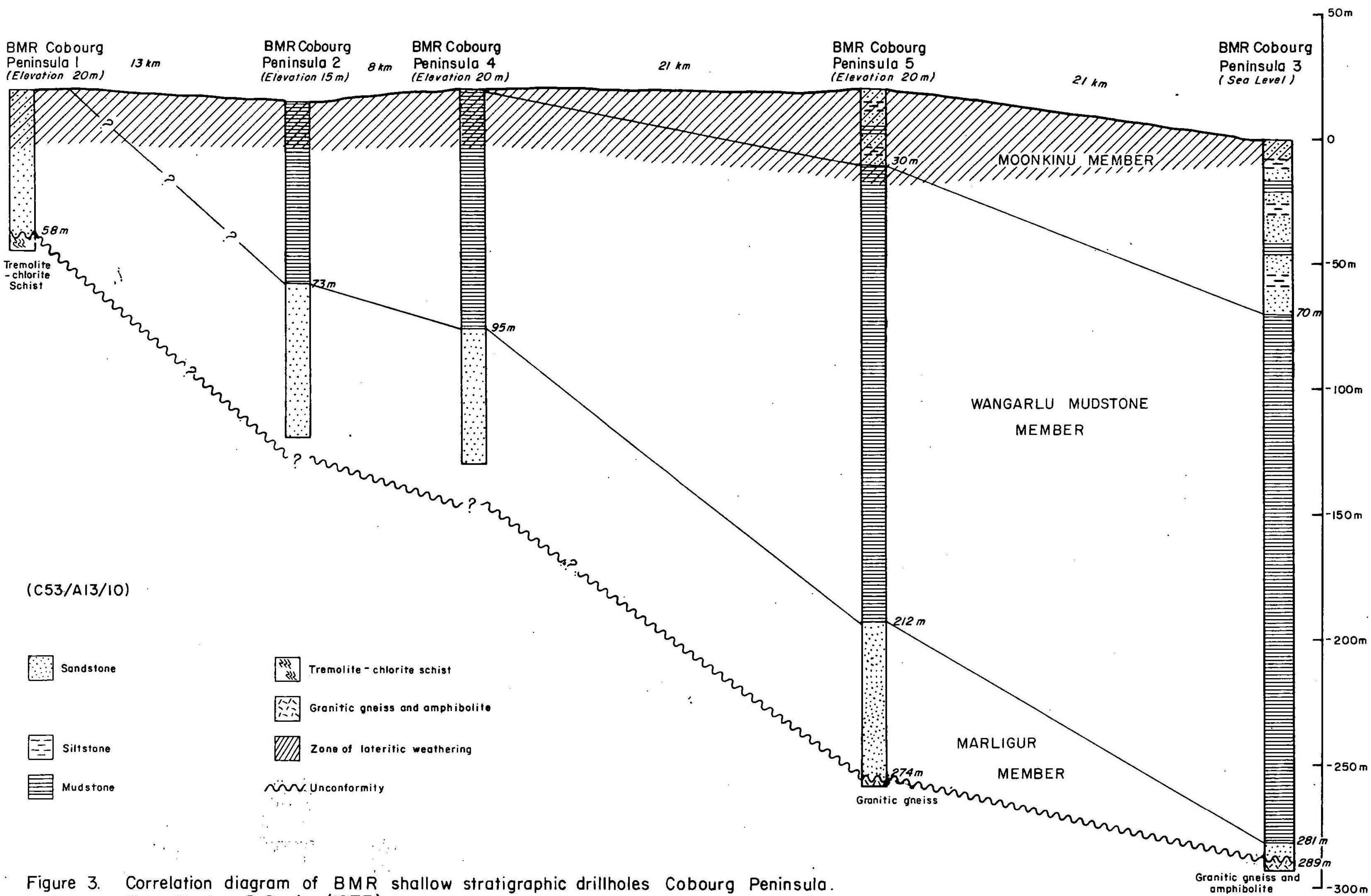


Figure 3. Correlation diagram of BMR shallow stratigraphic drillholes Cobourg Peninsula. From Hughes & Senior (1973)

The Moonkinu Member crops out in the Bathurst Island, Melville Island, and Cobourg Peninsula Sheet areas overlying the Wongarlu Mudstone Member. With the exception of Cobourg Peninsula 1, 2, and 3 bores (Hughes, 1973) it has been intersected in all the wells drilled in the area. It is interpreted as a deltaic sequence composed of interbedded fine-grained sublabile sandstone, siltstone, and mudstone.

Henderson identified the macrofauna collected from cliff exposures on the southern coasts of Bathurst and Melville Islands (Hughes, in press a) as of middle Cenomanian age, and part of a cosmopolitan fauna that was world-wide at that time. Palynological evidence, Burger (in Hughes in press b) and Norvik & Burger (in press), also indicates a Cenomanian age.

Tertiary The Van Diemen Sandstone is unconformable on the chemically weathered surface of the Moonkinu Member on Bathurst and Melville Islands. Tertiary rocks do not crop out in the Cobourg Peninsula Sheet area. The Van Diemen Sandstone thickens northwards and is more than 60 m thick at the type section on Cape Van Diemen. The unconformity at the base of the Van Diemen Sandstone correlates with a basal Tertiary horizon (S4) revealed by shallow seismic profiling offshore to the north and west of the islands (Jongsma, 1974). White (in Hughes, in press b) identified Tertiary plant fossils from the Van Diemen Sandstone as Eocene or younger. A laterite profile up to 30 m thick occurs in most of the exposures of Cretaceous and Tertiary rocks. The profile comprises a ferruginous crust grading downwards through a mottled zone to a leached zone. On the mainland, surficial deposits of Cainozoic age are widespread, and include laterite, sand, rubble, and ferruginous deposits.

Quaternary Quaternary alluvium is widespread or the mainland, and a wide variety of Quaternary deposits occur in the Bathurst Island, Melville Island, and Cobourg Peninsula Sheet areas (Table 1a). The red sandy soils are developed on the Van Diemen Sandstone and the grey to yellow soils more commonly over Cretaceous bedrock.

In the offshore Money Shoal Basin the limited stratigraphic control available combined with interpretation of geophysical data suggest that the sediments in the Arafura Sea area readily mappable by seismic means are predominantly Mesozoic and Tertiary. From outcrop in the Northern Territory the sequence thickens seawards in a northwesterly direction to over 6000 m in the basin depocentre, which approximately coincides with the area of greatest water depth on the margin of the Arafura Shelf. The sequence extends westwards across the Bathurst Terrace, over the Van Diemen Rise into the Bonaparte Gulf Basin (Fig. 2), and thins eastwards towards the Wessel Rise. Aeromagnetic data in the eastern part of the area, offshore between Cobourg Peninsula and the Wessel Islands, indicates a thick sedimentary sequence which on the basis of extrapolation of stratigraphic and seismic control from the west is believed to comprise a thin sequence of Mesozoic-Cainozoic sediments of the Money Shoal Basin overlying a thick pre-Mesozoic sequence belonging to the Arafura Basin. Recently discovered palaeontological evidence from the Elcho Island Formation (Wessel Group) on Elcho Island (Plumb et al., in press) has resulted in a revision of the age of the Wessel Group from Proterozoic to Cambrian. As the Wessel Group lies at the base of the Arafura Basin sequence onshore and palynological evidence indicates a Silurian age for the sedimentary section underlying the Mesozoic-sequence in the offshore well, Money Shoal No. 1 (Balke et al., 1973), Plumb et al. consider it reasonable to reassign the whole of the Arafura Basin succession to the Palaeozoic.

Two offshore wells, Money Shoal No. 1 and Lynedoch No. 1, have been drilled in the Money Shoal Basin (Pl. 1) and Heron No. 1 has been drilled in the immediately adjacent area of the Bonaparte Gulf Basin (Pl. 5). The details of the sections penetrated by the three wells are given in Table 2 and time correlations between the wells are shown in Figure 4. Of the three wells, only Money Shoal No. 1 penetrated below the Jurassic.

The stratigraphy and geological development of the post-Triassic strata have been inferred from the well data and seismic data, including interval velocities (Balke et al., 1973; ARCO, 1972; Shell, 1971 and 1973). The structure is reasonably well known from the seismic data.

The Money Shoal Basin can be divided into two distinct areas. The larger area is a shelf area of relatively thin, mainly fluviatile and paralic sediments in the south and southeast ('stable block', Balke et al., 1973). This is separated by a fault-controlled hinge-zone (Pl. 6) from an area of thick (over 6000 m) marine strata ('mobile block'). The hinge zone forms the southeastern flank of the northeast-trending Calder Graben, which is the site of the Mesozoic and Tertiary depocentre of the Money Shoal Basin. Money Shoal No. 1 is located on the southeastern shelf area or stable block, and Lynedoch No. 1 was drilled on the mobile block to the northwest, within the Calder Graben.

A number of seismic reflecting horizons have been mapped in the portion of the Arafura Sea investigated by Shell Development. East of the hinge zone, one of the most prominent reflections, horizon 'C' of Shell, is associated with a pronounced unconformity at the base of the Mesozoic, as identified in Money Shoal No. 1 well (Pl. 6). The reflection tends to lose its strong character westwards towards the hinge zone as the uncon-

TABLE 2. STRATIGRAPHIC TABLES, HONEY SHOAL BASIN WELLS AND HERON NO. 1

HERON NO. 1

AGE	UNIT	Depth(s) K.B.	Thickness (m)	Lithology	Depositional Environments (from palaeontological and) (palynological data)	Hydrocarbons
Sea Bed		50				
				No samples taken		
		198				
UPPER MIOCENE	Undifferentiated		55	Interbedded, fossiliferous carbonates and claystone	198 - 338 m: Inner neritic	
		253				
LOWER-MIDDLE MIOCENE			280	Interbedded calcilutite and calcarenite underlain by calcareous claystone at depths greater than 332 m	388 - 494 m: Inner neritic, good communication with open sea	
		533				
EOCENE TO PALAEOCENE	Undifferentiated		495	Interbedded limestone and dolomite with minor shale. Below 686 m, sequence is predominantly limestone with minor interbeds of sandstone and shale		
		1028				
UPPER CRETACEOUS	Bathurst Island Formation	2798(?)	1770	Sand and shale predominate in upper section, shale becomes more abundant with depth and in the basal section grade to argillaceous limestone in places	1113 - 2489 m: Neritic with fluctuations in water depth	1158 - 2824 m: Poor to fair gas shows (methane and propane) during drilling
LOWER CRETACEOUS			357			2824m-TD: Fair to good gas shows (methane through pentane)
		3155				
UPPER JURASSIC	Petrel Formation		1054	Generally grey, calcareous shale with thin limestone stringers common down to 3962 m. Below are a few thin sandstone interbeds and siliceous tight basal sandstone		
		T.D. 4209				

TABLE 2. (contd)

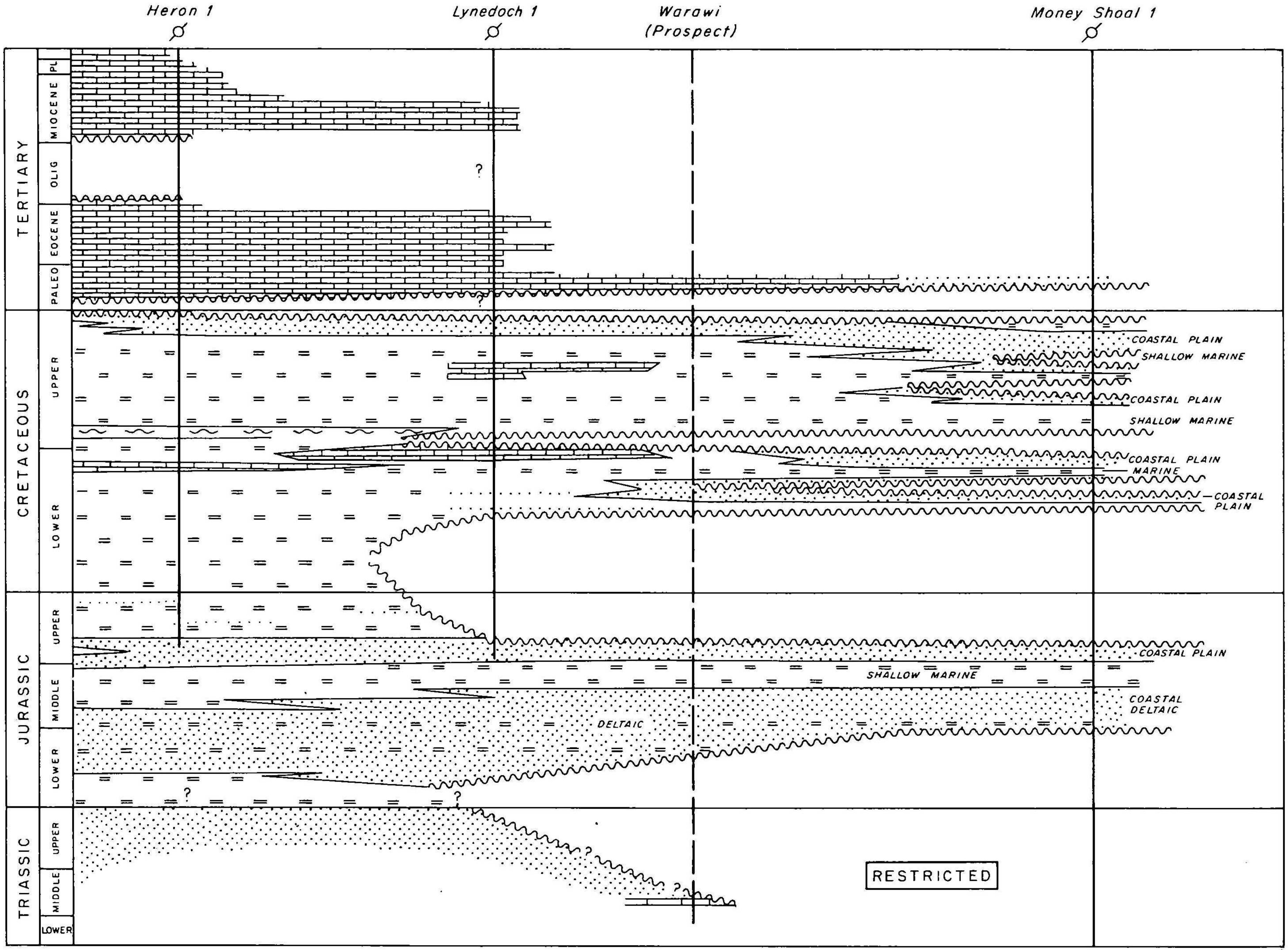
LYNEDOCH NO. 1 (RESTRICTED)

	AGE	Depth (m) R.T.	Thickness (m)	Lithology	Depositional environments (From palaeontological and Palynological data)	Hydrocarbons
	Sea-bed	247				
			262	No samples		
		509				
	Not dated		43	Bioclastic limestone		
		552				
TERTIARY	L. MIOCENE		338	Lime mudstone, marl, minor shale near base	Overall shallowing with transgressive oscillation at about 750 m	
		890				
	?L. MIOCENE & OLDER TERT.		661	Thin sands near top and base, dominantly limestone and dolomite with minor marl and anhydrite	Very shallow marine to coastal below about 1200 m, followed by regressive cycle; inner neritic limestone, lagoonal carbonates, intratidal and supratidal limestone, dolomite, and anhydrite	
		1551				
	U. CRETACEOUS (UNDIFFERENTIATED)		659	Sandstone grading to basal siltstone and shale	Paralic to very shallow restricted marine. Perhaps part of transgressive - regressive cycle seen in Money Shoal No. 1 and Heron No. 1	
		2210				? 1577 m
	Campanian		733	Shale with minor siltstone	MARINE REGRESSION - Overall shallowing, with minor transgressive oscillations to coastal plain environment	
		2943				
	Santonian		556	Shale and argillaceous limestone		
		3499				
CRETACEOUS	?Coniacian, Turonian		34	Shale, cherty limestone	MARINE TRANSGRESSION - Outer neritic becoming bathyal	
		3533				
	Cenomanian		142	Shale, minor limestone		
	Possible disconformity at about 3650 m					Hydrocarbon-bearing zone, probably gas, between 3676 and 3718 m
		3675				
	Cenomanian - Albian		34	Limestone	Outer neritic	
		3709				
	Albian-Aptian		116	Shale	Progressive deepening of sea. Albian shale deposited in relatively deep water, restricted environment	
		3825				
	Barremian		92	Shale becoming silty near base		
		3917				
JURASSIC			30	Sandstone	Fluviatile and coastal	
		3947				
	Oxfordian		20	Sandstone and shale		
		T.D. 3967				

TABLE 2. (contd) HONEY SHOAL NO. 1 (RESTRICTED)

	AGE	Depth (m) R.T.	Thickness (m)	Lithology	Depositional environments (from palaeontological and) (palynological data)	Hydrocarbons
SEA BED		69				
TERTIARY	Basal Eocene or Palaeocene			Fine sandstone and silt	Middle or outer neritic	No hydrocarbons recorded during drilling All intervals are 100% waterbearing
		307				
UPPER CRETACEOUS	Lower Maastrichtian		98	Siltstone and clay	Very shallow inner neritic/paralic, becoming open marine inner neritic; then restricted marine inner neritic	
		405				
	Campanian to Santonian		77	Sandstone and clay		
		482				
			48	Sandstone	Paralic or nearshore becoming restricted marine, then open marine inner neritic; followed by probable paralic	
		530				
	Santonian to Coniacian		92	Silt, thin sand, clay		
		622				
			201	Silt and clay overlying sandstone	Shallow restricted marine becoming coastal	
		823				
	Coniacian-Turonian		244	Claystone and silt	1152 - 829 m - Middle neritic becoming restricted marine, then coastal to non-marine	
		1067				
	Upper Cenomanian		113	Siltstone and clay		
		1180				
LOWER CRETACEOUS	Upper Albian		618	Sandstone	1242 - 1152 m - Middle neritic, becoming coastal	
		1798				
	Lower Albian - Upper Aptian		152	Sandstone and siltstone	1361 - 1242 m - Paralic becoming non-marine 1950 - 1882 m - Probably entirely fluviatile	
		1950				
	Aptian		25	Sandstone		
		1975				
	Barremian-Hauterivian		71	Sandstone and clay	Inner neritic becoming non-marine	
		2046				
MIDDLE JURASSIC			277	Shale overlying sandstone	Single transgressive marine phase, commencing with paralic sedimentation and ending with middle neritic open marine	
		2323				
LOWER JURASSIC			118	Siltstone, sandstone, clay, and coal		
		2441				
SILURIAN			119	Sandstone, silt, shale, weathered extrusives		
		2560				
PRE-CAMBRIAN			28	Quartzite and indurated shale		
		T.D. 2588				

FIG. 4 TIME CORRELATION - MONEY SHOAL BASIN



(AFTER SHELL, 1975)

Record No 1976/66 XAUS-7-14

formity becomes less pronounced. Reflection horizon 'B' defined at Money Shoal No. 1 as top Early Cretaceous overlies horizon 'C'. Shorewards from that well it wedges out against horizon 'C', while to the northwest it eventually deteriorates and becomes unmappable. Near Money Shoal No. 1 well horizon 'B' is the strongest, most reliable of the deeper reflections. It is evident from the sonic log and velocity survey in the well that it is associated with a sharp increase in seismic velocity of about 850 m/s.

East of approximately 134^{O}E horizons 'B' and 'C' are too shallow to map seismically. They become gradually deeper to the west (in the north) and to the northwest (in the south). Horizon 'C' becomes unmappable west of the hinge zone (Pl. 6). It reaches a maximum depth of about 4000 m northeast of Lynedoch. Apart from fairly uniform regional dips the Mesozoic-Cainozoic sediments east of the hinge zone show little structural deformation.

The sparse seismic information available eastwards from 134^{O}E indicates a very thin (less than 300 m) Mesozoic-Cainozoic section extending to about 138^{O}E. The quality of deeper seismic data in this area is rather poor, even for the most recent survey, which was the regional geophysical reconnaissance line surveyed by Australian Gulf Oil in 1972. However, reflections from below the thin Mesozoic-Cainozoic cover indicate generally flat-lying sediments of unknown age. It seems likely from comparison with onshore areas to the south that these deeper sediments are Early Palaeozoic (Plumb et al., in press).

The most interesting structural feature in the Arafura Sea area east of the hinge zone is a graben about 300 km in length which contains very large thicknesses of pre-Mesozoic sediments. The graben is northeast of Cobourg Peninsula (Pl. 1). Faulting associated with the graben is extensive and complex and the width of the graben varies from about 10 to more than 50 km.

Within the graben strong, conformable reflections were recorded from depths of more than 6000 m. Several structurally high areas were mapped on these pre-Mesozoic horizons, including a dome about 10 km in diameter near the centre of the graben.

Money Shoal No. 1 well was located on an upthrown fault-block on the southwest margin of the graben and did not therefore penetrate the graben sequence. Because the thin Palaeozoic sequence penetrated in Money Shoal No. 1 is separated from the graben by a fault, the pre-Mesozoic seismic horizons in the graben cannot be correlated with the deeper sediments penetrated by the well. The nature and age of the pre-Mesozoic sediments within the graben are thus uncertain. Seismic interval velocity studies within the graben indicate velocities which would be consistent with a Palaeozoic age for the graben sediments. There is some evidence that the velocities of pre-Mesozoic rocks outside the graben are higher than those within the graben. A Proterozoic age has therefore been suggested by Australian Aquitaine Petroleum for basement rocks outside the graben, but since the discovery of Cambrian sediments in the Wessel Islands, the possibility must be considered that these rocks are Early Palaeozoic.

On the seismic record sections for both the 1970 and 1973 surveys of Aquitaine six seismic reflecting horizons are recognizable. Horizon 'A' of Aquitaine is a Mesozoic horizon and horizon 'B' represents a pre-Mesozoic erosional surface on which Jurassic sediments were deposited near Money Shoal No. 1 well. These horizons dip fairly uniformly to the west or northwest. Horizon 'B' varies in depth from about 750 m at 133°30'E to about 200 m at 134°30'E. Horizon 'A' onlaps onto horizon 'B' at a depth of about 450 m.

The deeper horizons 'C', 'D', 'E', and 'F' are recorded only in the area of the pre-Mesozoic graben. Horizon 'C' of Aquitaine is present only in the northern section of the graben. It dips northwards and shows no closed structures. Horizon 'D' extends farther southwards, but is of poor quality. Horizons 'E' and 'F' are of fair quality except in the southeast of the area where horizon 'E' cannot be mapped. These deeper horizons within the graben exhibit a regional north or northwest dip but they are extensively folded and faulted. The fault pattern is complex and shows a predominant northwest trend. Most of the folding and faulting occurred after the deposition of horizon 'E'.

Over the area extending west from about 132°30'E Shell has mapped a seismic horizon (horizon 'A') which has been identified through well-ties as base of Tertiary. This horizon extends from the stable block across the hinge-zone and over the mobile block. Dips are mostly uniform to the northwest or north with no indication of closed structures. The depth of this horizon increases from very shallow in the east to a maximum of about 1600 m in the northwest of the area. From Money Shoal No. 1 to Lynedoch No. 1 the Tertiary section changes from predominantly sandstone and silt to carbonate.

West of the hinge-zone the most persistent deep seismic horizon (horizon 'P' of Shell and BOCAL) was identified in Lynedoch No. 1 and Heron No. 1 as originating from interbedded carbonate and shale in the upper Early Cretaceous. The 'P' horizon has sometimes been referred to (particularly by BOCAL) as a 'near base of Upper Cretaceous' horizon. This reflection is strong west of the hinge-zone, but becomes attenuated as it approaches the zone, possibly because of a lithological facies change across the hinge-area. The horizon reaches a maximum depth in excess of 3700 m in the Lynedoch area (Pl. 6). The 'P' horizon exhibits a moderate degree of structural deformation. The gentle folding which is mapped on this intra-Lower Cretaceous reflection gradually dies out upwards so that little or no structural deformation is seen on the base of the Tertiary seismic horizon. The folding may be due to either drape over deep-seated faults or shale flowage in pre-Lower Cretaceous strata in response to Tertiary loading. Two of the largest structures on the 'P' horizon have been tested for hydrocarbons without success by Heron No. 1 and Lynedoch No. 1 wells. Several other structures have been indicated by seismic mapping in the area.

An abrupt change in the seismic character of the 'P' reflection across the hinge-zone is interpreted as marking an abrupt change in depositional environment from shore-line and deltaic to deeper-water marine over the mobile block. The effect of the structural hinge-zone is most marked in the Lower Cretaceous and pre-Lower Cretaceous sequences which thicken rapidly across it. It appears to have had little effect on the depositional trends during the Cainozoic to Recent.

In the northeastern half of the Calder Graben, west of the hinge-zone, there is a lack of mappable reflections from below the 'P' horizon. The sequence below the reflector is inferred from regional stratigraphic considerations to be mainly Lower Cretaceous and Upper to Middle Jurassic shales grading into a deeply buried Lower Jurassic and Triassic sand and shale sequence. In the southern portion of the Calder Graben, south of about 10°20'S, BOCAL have mapped a seismic horizon ('S' horizon) which they have referred to as 'near top Permian'. This horizon dips generally to the north and is affected by numerous down-to-the-northwest faults. In the central portion of the Calder Graben this horizon becomes very deep and is lost from the seismic records. It is not known whether Permian sediments are anywhere present beneath the Money Shoal Basin.

CARPENTARIA AND KARUMBA BASINS

The onshore Carpentaria and Karumba Basins have been the subject of intermittent geological investigation since the turn of the century. In more recent years the geology has been reviewed in Hill & Denmead (1960), Meyers (1969), and Doutch (1973).

The most significant recent work is a regional geological mapping project undertaken jointly by BMR and the Geological Survey of Queensland (GSQ) between 1969 and 1974 which has completed the coverage of the onshore area at 1:250 000 scale. The results of the combined GSQ/BMR regional mapping project are presented in progress reports (Doutch et al., 1970, 1972 and 1973), drilling reports (Grimes & Smart, 1970; Needham et al., 1971; Gibson et al., 1973 and 1974; and Smart et al., 1974), and in the explanatory notes for the 1:250 000 scale geological maps, some of which are in press and in preparation. An index to drill-hole data has also been compiled (Smart et al., in prep.). Preparation of a BMR Bulletin on the geology of the basins is in progress (Doutch et al., in prep.). In addition a number of papers have been published in geological journals and others are in preparation or in press (Smart et al., 1971 and 1972; Smart, 1972; Powell et al., in prep.; Doutch in press, and in prep. a and b; Grimes and Doutch in prep.; and Smart in press). A preliminary geological map of the area south of lat. 15°S is in press.

Eight petroleum exploration wells were drilled between 1956 and 1966, and 30 stratigraphic holes were drilled during the regional mapping project. Interpretation of the stratigraphy has also been greatly aided by gamma-ray logs and drillers logs of numerous water bores.

In the offshore Carpentaria/Karumba Basins, no wells have been drilled in Australian waters. Current interpretation of the geology is based on extrapolation of geological knowledge from the adjacent onshore and offshore areas, supported by the offshore geophysical data.

Carpentaria Basin

The Carpentaria Basin contains a Mesozoic sequence ranging in age from ?Middle and Late Jurassic, to Albian and possibly Cenomanian. The current stratigraphic nomenclature and previous nomenclature is shown in Table 3. The current nomenclature was established by Smart et al., (1971, 1972), Smart (1972), and Powell et al., (1974, and in prep.). Stratigraphic correlations between the older units of the southern Carpentaria and northern Eromanga Basins are given in Smart (in press).

The dating of the Carpentaria Basin sequence has been based mainly on the interpretation of palynological evidence from drill core by D. Burger (palynmorphs) and D. Haig (foraminifera). Much of these data has been presented as a personal communication in BMR records on the area, and most are unpublished as yet. The results of studies of macrofossils being carried out by S. Skwarko and R.W. Day have been presented as Appendices or personal communications in BMR records.

TABLE 3. CURRENT STRATIGRAPHIC NOMENCLATURE AND PREVIOUS NOMENCLATURE, CARPENTARIA BASIN
(Smart, pers. comm.)

AGE	PREVIOUS NOMENCLATURE			CURRENT NOMENCLATURE			
	Laing & Power (1959)	Reynolds (1960)	Woods (1961)	Smart et al., (1971, 1972); Smart (1972); Senior et al. (in press); Powell et al. (in prep.)			
				SOUTHERN AREA	CAPE YORK PENINSULA		
Cretaceous late Albian	Normanton Formation			Rolling Downs Group Normanton Formation Allaru Mudstone			
	Kamileroi Limestone			Toolebuc Formation		Rolling Downs Group	
Aptian to early Albian	Blackdown Formation	Roma Formation	Trimble Fm.	Trimble Member Wallumbilla Formation		? ?	
Aptian	Gilbert River Fm. & Wrotham Park Sandstone	Gilbert River Formation		Gilbert River Formation Coffin Hill Member Yappar Member	Gilbert River Formation	Helby Beds (Four informal members)	Albany Pass Beds
Late Jurassic				Eulo Queen Group Loth Formation	Garraway Beds		
?Middle to Late Jurassic				Hampstead Sandstone			

The following brief summary of the stratigraphy is based largely on Smart (in press.) and Smart (in Doutch et. al., in prep.).

The stratigraphic units defined in the northeastern Eromanga Basin continue northwards into the southern Carpentaria Basin (Table 3).

?Middle to Late Jurassic The Jurassic sequence in the Carpentaria Basin occurs in a series of basement depressions, the Millungera, Canobie (northern lobes of Eromanga Basin), and Burketown in the south, and the Weipa Depression in the north (Pl. 1). The Eulo Queen Group in the south is equivalent to the Garraway Beds in the Weipa Depression (Table 3). The sequence comprises continental quartzose sandstone with subordinate siltstone and conglomerate. North of about latitude 12°, the whole Mesozoic sequence changes from a predominantly continental to a marginal marine facies, the Helby Beds. Farther north, at about latitude 11° the sequence reverts to a continental facies represented by the Albany Pass Beds which occur over and around exposed basement of the Cape York-Oriomo Ridge (Powell et al., 1974 and in prep.). In the southeast of the Millungera Depression the Eulo Queen Group overlies older ?Jurassic which appear to be continuous with the Hutton Sandstone of the Eromanga Basin, and in the Burketown Depression it overlies ?Mesozoic units underlain by Precambrian or Lower Palaeozoic dolomite (Mid-Eastern Oil N.L. 1964; Ingram, 1972).

Attempts to date the ?Mesozoic units and the dolomite by microfossils have not been successful.

In the Olive River Basin at least the upper half of the 1100-m thick sequence is composed of Garraway Beds, Gilbert River Formation, and possibly their lateral equivalents, the Helby Beds. The lower part of the sequence (Willmott & Powell, in press) may consist of older Mesozoic (?Triassic) rocks, or Upper Palaeozoic sedimentary and volcanic rocks. The Peninsula Trough may contain a Mesozoic sequence similar to that of the Papuan Basin. Anchor Cay No. 1 (Pl. 1) (TENNECO, 1969) penetrated about 1500 m of Upper Jurassic and Lower Cretaceous rocks below 2100 m of Cainozoic without reaching basement.

Early Cretaceous The Lower Cretaceous Gilbert River Formation and its stratigraphic equivalent (Table 3) form a widespread blanket of continental and marine quartzose sandstone which rests on the Eulo Queen Group and its equivalents or on basement. The Coffin Hill Member of the Gilbert River Formation marks the beginning of the Cretaceous marine transgression into the area.

Marine conditions became stabilized during the deposition of the lower part of the overlying Lower Cretaceous Rolling Downs Group (Table 3) which consists of a sequence of marine mudstone (Wallumbilla Formation and Allaru Mudstone) split in the southern part of the basin by the calcareous Toolebuc Formation, overlain by the regressive sandstone, siltstone and shale sequence of the Normanton Formation.

The Toolebuc Formation crops out in the southern part of the basin and extends in the subsurface northwards to about latitude 16oS. It seems on limited lithological evidence to consist mainly of calcareous, bituminous shale, with thin limestone beds common in the upper part. The massive crystalline coquinite characteristic of outcrops of the unit does not appear to be widespread in the subsurface.

The Normanton Formation marks a major marine regression and the end of deposition in the Carpentaria Basin.

A period of erosion preceded Cainozoic deposition in the overlying Karumba Basin.

Karumba Basin

The following brief treatment of the stratigraphy is based mainly on Doutch et al. (1973) and Doutch (in prep. b).

Early Tertiary The Bulimba Formation (Table 5) consists of continental clayey quartzose, sandstone, and sandy claystone. It occurs in Cape York Peninsula, and extends under the Gulf of Carpentaria. The formation rests unconformably on Lower Cretaceous marine mudstone and labile sandstone of the Rolling Downs Group of the Carpentaria Basin, and on older rocks of the Georgetown Inlier (Smart & Bain, in prep; Smart, in prep. a). The greatest known thickness is 139 m in BMR Holroyd No. 1 (Gibson et al., 1974). 'Piano key' block-faulting and associated broad folding of the Bulimba Formation along the northern flanks of the Georgetown Inlier joint to the tectonic origin of the unconformity. It is thought that uplift occurred in Palaeocene time in Cape York Peninsula and New Guinea and reflected the breaking apart of Australia and Antarctica. The emerged area in New Guinea and the ancestral Great Dividing Range are taken as the northern and eastern structural margins of the Karumba Basin in the Early Tertiary. In the west, water sheds near the present Parsons and Mitchell Ranges in Arnhem Land; the Davenport Range/Tennant Creek/Ashburton Range area in the southwest; and the Mount Isa Block and Euroka Arch in the south are thought to have formed the southern and western margins.

a.

TABLE 4a & b: STRATIGRAPHIC TABLE, CARPENTARIA BASIN WELLS

AGE	UNIT	Burketown No. 1 Depth (m)	Burketown No. 1 t(m)	AAO No. 8 (Karumba) Depth (m)	AAO No. 8 (Karumba) t(m)	Mornington Is. No. 1 Depth (m)	Mornington Is. No. 1 t(m)	Mornington Is. No. 2 Depth (m)	Mornington Is. No. 2 t(m)	GENERALIZED LITHOLOGY (Grimes, 1974)	DEPOSITIONAL ENVIRONMENT	HYDROCARBONS
										surface		
*CAINOZOIC			27		39		17		9	Beach deposits, lateritic sandstone, iron-stained clay	Continental (and marine?)	
		27		39		17		9				
LOWER CRETACEOUS	Normanton Fm.		144		244		236		7	Consists of interbedded siltstone, medium to fine, rarely coarse-grained labile sandstone, and minor mudstone and limestone; glauconite is present in places		
		171		283		253		326				
	Allaru Mudstone		214		192		296		296	Dark grey pyritic mudstone with siltstone and minor very fine to fine glauconitic and labile sandstone; the upper boundary of this unit is transitional into the sandier Normanton Fm.	Marine and paralic	Karumba: 232-274 m and 469-497 m, electrical logs suggest possibilities of oil, gas, or salt water but no separate tests were made. A small gas show was observed at 486 m.
		385		475		549		622				
	Toolebuc Fm.		14		22		21		24	Flaggy, light grey, finely crystalline limestone and interbedded mudstone overlying a dark brown, soft, bituminous, pyritic shale with thin seams of limestone; unit is fossiliferous containing shells, fish scales, teeth, spines, and plates		Burketown: 384-399 m, petroliferous odour and traces of dead oil Mornington Is 1:547-565 m, bituminous shale and limestone gave off tarry odour
		399		497		570		646				
	Wallumbilla Fm.		164		197		171		171	Mainly dark grey mudstone with minor beds of grey and grey-green glauconitic and labile fine to very fine sandstone and siltstone, and grey to brown cone-in-cone limestone; glauconitic sandstone is most common at formation base and in places grades into the quartzose sandstone of the underlying Gilbert River Fm	Marine	Mornington Is 2:630-648 m, Bituminous shale and limestone gave off tarry odour
		563		694		741		817				
LOWER CRETACEOUS TO JURASSIC	Gilbert River Fm.		77	(equivalent?)	25		97		95	Grey-brown to white and red-brown poorly sorted quartzose sandstone with interbedded grey shale and siltstone, and pebble and granule conglomerate		Mornington Is 2: 907-912 m, porous sandstone with dead oil staining
		640		719		838		912				
UPPER JURASSIC	Eulo Queen Grp Equiv.		104	absent		absent		absent		640-700 ('Jb'): soft sandstone-siltstone unit 700-744 ('Ja'): very fine sandstone unit	Continental and marine	
		744										
?PERMIAN	'Tilloidal Sediments'		131	absent		absent		absent		Perryman (Mid-Eastern, 1964) thought the sequence is suggestive of a massive mud-flow; Meyers (1969), however, considered the sequence to have a tilloidal texture and could represent glacial deposits. These tentative observations are based on badly broken core		
		875		719		839		912				
PRE-JURASSIC	Basement		139		2		5		2	Burketown 1: weathered chert and cavernous dolomite Karumba 8: granitized quartz Mornington Is 1: adamellite Mornington Is 2: quartzite		
		T.D. 1014		T.D. 721		T.D. 843		T.D. 914				

Stratigraphic interpretations from Ingram (1972) and Smart (pers. comm.)

*Karumba Basin sequence (Doutch, in prep. b) b.

AGE	UNIT	Weipa No. 1 Depth(m)	Weipa No. 1 t(m)	Wyaaba No. 1 Depth(m)	Wyaaba No. 1 t(m)	Normanton Scouts 1 & 2 Depth(m)	Normanton Scouts 1 & 2 t(m)	LITHOLOGY	Depositional Environments	Hydrocarbons
QUATERNARY						0(Surface)	6	Surface alluvial deposits		No hydrocarbons recorded during drilling
TERTIARY	Wyaaba Beds			0(Surface)	100	6	113	Fine to coarse friable quartz sandstone with a clay matrix in parts, interbedded gravel and conglomerate	Continental (and ?marine)	
	Bulimba Fm.	0(Surface)	19	100	50	119	0	Poorly-sorted, clayey quartz sandstone with minor beds of siltstone and clay	Continental	
LOWER CRETACEOUS	Normanton Fm.	19	319	150	100		0	Fine to coarse-grained grey-green labile sandstone with minor interbeds of grey silty shale	Shallow marine and paralic	
	Allaru Mudstone	338	193	250	305		0	Grey, micaceous silty shale	Marine	
	Toolebuc Fm.	531	0	555	22		*	Calcareous shale and limestone		
	Wallumbilla Fm.	531	117	577	223	119	160	Grey silty shale with interbedded glauconitic, quartzose sandstone, and lesser amounts of limestone	Shallow marine	
LOWER CRETACEOUS TO JURASSIC	Gilbert River Fm.	648	144	800	42	279	0	Feldspathic, in places glauconitic, quartzose sandstone; few conglomerate and clay bands	Shallow marine (L. Cret.) to	
UPPER JURASSIC?	'Wreath Sandstone'	792	89	842	0		0	As above, becoming increasingly coaly and micaceous towards basement	continental (U. Jur.)	
?	Basement	881	107.	842	18	279	185	Weipa No. 1 - deeply weathered, metamorphosed sediments. Wyaaba No. 1 - sheared andesine-chlorite-quartz greenstone. Normanton Scouts 1 & 2 - quartzite		
		T.D. 988		T.D. 850		T.D. 464				

Stratigraphic interpretations from Doutch et al. (1970; 1972, 1973)
*Toolebuc Formation should be present at about 130 m (Simpson, 1973).

TABLE 5. STRATIGRAPHY, KARUMBA BASIN (QUEENSLAND)
(after Doutch, in prep. b)

AGE	UNIT
HOLOCENE	Younger river deposits, younger fans, younger beach ridges and coastal plains
	- - - - - - - - - - -Holroyd Surface- - - - - - -
PLEISTOCENE	Older fans, older beach ridges and coastal plains (Wondoola, Armraynald, and Claraville Beds)
Late PLIOCENE	- - - - - - - - - -Campaspe Surface- - - - - - - -
Early PLIOCENE	Part Floraville Fm., oldest fan deposits (Wondoola, Armraynald and ?Claraville Beds)
	- - - - - - - - - -Strathgordon Surface- - - - - -
MIOCENE (mid. to ?late)	Wyaaba Beds; Floraville Formation
	- - - - - - - - - -Aurukun Surface- - - - - - - -
PALAEOCENE - ?EOCENE	Bulimba Formation
	- -
	CARPENTARIA BASIN SEQUENCE

Early Tertiary deposition ceased when the uplifted area was reduced by erosion. Subsequent laterization produced the Aurukun Surface (Table 5).

Late Tertiary The Wyaaba Beds and their equivalents (Table 5) were deposited during the second phase of deposition in the Karumba Basin which began with uplift along the eastern and south-western margins and downwarping to form the Gilbert-Mitchell Trough in the southeast. Extensive erosion of the Bulimba Formation preceded the downwarping. The Wyaaba Beds which consist mainly of continental clayey quartzose sand and sandstone were deposited in the Gilbert-Mitchell Trough onshore, overlying the Bulimba Formation or the Rolling Downs Group. The formation thickens offshore, and may make up most of the Cainozoic sequence beneath the Gulf of Carpentaria which is estimated to reach about 300 m in thickness (Pinchin, 1973). Evidence of marine deposition in the form of fossiliferous lime mudstone has been found in one water-bore drilled in the Gilbert-Mitchell Trough, and calcareous sandy clay and limestone were intersected during shallow drilling offshore from Weipa. The macrofossil assemblage in the bore had an age range from Late Cretaceous to Holocene (Day in Doutch et al., 1973) and the microfauna was of Late Tertiary to Holocene (Palmieri in Doutch et al., 1973). A low-energy carbonate mud flat or lagoonal flat environment is indicated.

The second phase of deposition also culminated in a period of deep weathering which produced the silicified Strathgordon Surface (Table 5), probably in the early Pliocene, and bauxitization of the previously laterized Bulimba Formation.

The tectonism that initiated the second phase of deposition is thought to have begun in Oligocene to early Miocene time, associated with orogenic events of that age in New Guinea (Dow, in prep.). The northern boundary of the basin during the Late Tertiary has not been determined. The ancestral Great Dividing Range formed the eastern margin, and the basin margins were probably pushed farther westwards and southwards by pediplanation contemporaneous with that which produced the Strathgordon Surface.

Pliocene to Holocene The third set of deposits in the Karumba Basin comprise sandy and clayey delta-like fan deposits of the Gilbert, Mitchell, and smaller rivers, and the sediments of the alluvial plains south of the Gulf of Carpentaria. Elsewhere onshore in the Queensland part of the basin Pliocene to Holocene time was a period of erosion.

Five main episodes of fan-growth have been interpreted, controlled by changes in climate and sea level. Two erosional surfaces, the Campaspe and the Holroyd are recognized which appear to represent a much smaller time-span than the Aurukun and Strathgordon Surfaces.

Current knowledge of the geology of the offshore parts of the Carpentaria and Karumba Basins is based almost entirely on extrapolation of onshore geology and on geophysical evidence. There is no seismic coverage in the southern half of the Gulf of Carpentaria but, as indicated in Chapter 3, the results of onshore surveys and wells around the southeastern corner of the Gulf indicate that the thickness of sediments increases offshore (Pl. 6).

As previously indicated, seismic work in the northeast of the Gulf of Carpentaria offshore from Weipa indicates a Mesozoic-Cainozoic sedimentary sequence thickening from 700 to

2000 m southwest of Weipa. The east-west sections across this area show numerous small faults on the basement horizon, but only a few are observed on north-south sections. Farther north, west of Torres Strait, seismic data indicates a general westward dip. Basement depth is shallow, the maximum recorded being about 1300 m in the western part of the area.

In the northwestern part of the Gulf, west of the Queensland border, seismic results indicate a thin Mesozoic-Cainozoic sedimentary sequence overlying a rugged erosional surface which lies at a maximum depth of about 2000 m. To the east of Caledon Bay, the highly eroded basement horizon varies in depth from about 300 m in the west near the coast, to about 1500 m in the east of the area surveyed. Low-relief folding, and some structural closures were mapped in the overlying sediments. Results of magnetic surveys in this area indicate that magnetic basement is considerably deeper than the eroded seismic basement, suggesting the possible presence of Palaeozoic or Precambrian sedimentary rocks, under the Mesozoic-Cainozoic sequence. Seismic data confirm this.

Northeast of Cape Wessel seismic results indicate that the Mesozoic-Cainozoic sediments are thin, the thickness increasing to the north and to the east from practically zero near Cape Wessel. A considerable thickness of relatively undeformed pre-Mesozoic sediments were indicated, which generally thicken from south to north. Two pre-Mesozoic horizons were mapped from the Wessel seismic survey results in addition to the base of Mesozoic. All three horizon maps show indications of a structurally high area about 100 km northeast of Cape Wessel.

Seismic data in the northwestern part of the Gulf of Carpentaria show that the lower part of the Mesozoic-Cainozoic section wedges out to the west along an approximately north-south line about 180 km east of Cape Wessel and Cape Arnhem. It is suggested in a confidential report by Keewanee Oil Company (1975), whose author evidently had access to the results of a well near this line in Indonesian waters to the northeast of Cape Wessel, that the Mesozoic is absent to the west of this line. Similarly, it is known from seismic data to the northwest of Cape Wessel that the Mesozoic-Cainozoic section of the Money Shoal Basin thins to the east, the lower part of the section wedging out against pre-Mesozoic basement. It seems possible, therefore, that only Cainozoic sediments are present in a broad zone centred approximately on the Wessel Islands.

5. PETROLEUM PROSPECTS

Money Shoal Basin

Exploration to date Only two offshore petroleum exploration wells, Money Shoal No. 1 and Lynedoch No. 1, have been drilled in the Money Shoal Basin (Pl. 1). Money Shoal No. 1 was drilled in 69 m of water to a total depth of 2588 m by Shell Development (Australia) Pty Ltd in 1971 as the first offshore test of the basin. Lynedoch No. 1 was drilled by Shell in 1973 to a depth of 3967 m in 236 m of water and was the first Australian well to be drilled using the deepwater drillship Sedco 445. Neither well was subsidized. Heron No. 1 was a subsidized well drilled in the Bonaparte Gulf Basin by Arco Australia Limited and partners in 1972. It was located in the Calder Graben immediately adjacent to the Money Shoal Basin.

The structure tested by Money Shoal No. 1 is interpreted to have resulted from faulting and drape-folding over a major Lower Cretaceous river channel and alluvial plain complex. Closure is mapped on the top Lower Cretaceous seismic horizon, and on an intra-Upper Cretaceous seismic horizon. The seismic evidence does not support closure on the base Mesozoic seismic horizon. Money Shoal No. 1 (Table 2) intersected Jurassic and Cretaceous sandstones with good reservoir potential but all porous zones proved to be water-bearing (approximate salinity 100 000 ppm). No significant hydrocarbon shows were recorded during drilling and no formation testing was warranted. The Lower Cretaceous reservoir sands are capped by Upper Cretaceous shale, but in the Upper Cretaceous sequence the reservoirs lack a capping shale or other seal. The silurian sandstones (Arafura Basin) have poor reservoir characteristics, and the ?Precambrian quartzites no reservoir potential.

The lack of hydrocarbons in the Lower Cretaceous sequence, which is structurally closed and sealed by the basal Upper Cretaceous shale, may indicate that the structure is too far up-dip from the major basin depocentre to have received any hydrocarbons generated there (Balke et al., 1973).

Lynedoch No. 1 was drilled as a test of an anticlinal structure with a vertical closure of about 100 m and an area of about 150 km^2 mapped on the intra-Lower Cretaceous 'P' seismic horizon. The horizon was encountered at 3674 m (RT) and the potential hydrocarbon interval was penetrated below this level. The stratigraphic section is generally similar to that encountered in Heron No. 1. Non-commercial hydrocarbons were recorded in a thin carbonate interval in the Lower Cretaceous from 3674 to 3715 m. The interval appears to be predominantly water-bearing with only local occurrences of hydrocarbons below 3698 m. The porosity ranges between 8 and 18 percent, while hydrocarbon saturation is estimated at no more than 50 percent (av. 20%). There is lack of closure in the Upper Cretaceous and Tertiary porous sandstone and carbonate intervals, and also in the Lower Cretaceous and Jurassic sequence. Over a thin interval from 3930 to 3937 m, possibly representing the Cretaceous/Jurassic unconformity, the penetration rate increased and a gas show of about 50 percent saturation in 5 percent porosity was recorded.

The structure tested by Lynedoch No. 1 is one of several seismic anomalies mapped in the Calder Graben. Another is a small domal structure in the area explored by Shell, about 40 km west-northwest of Lynedoch. Seismic surveys by the BOCAL group have revealed the presence of a large anticline in the northeast corner of the original permit NT/P6 (South Lynedoch prospect) about 35 km southwest of Lynedoch No. 1. Portion of BOCAL's Kendrew-Cootamundra seismic survey in 1974 was aimed at investigating tilted fault-blocks on the edge of the Bathurst Terrace in the south of the permit. No significant prospects were indicated.

In Heron No. 1 well several gas shows were recorded below 1158 m in the upper Cretaceous and Upper Jurassic sections. From 1158 to 2824 m poor to fair shows of methane and propane were recorded, which appeared to be shale gas or gas associated with limestone or sandstone stringers in shale. Several fair to good gas shows of methane and pentane were detected at depths between 2824 m and total depth. None of the zones with gas shows were tested. The only potential reservoir in the well section was a carbonate-shale-sandstone sequence in the upper 1186 m (Tert. to U. Cret.) of the well. Because the underlying shale and highly indurated sandstone intervals are poorly permeable, the deliverability of hydrocarbons to the reservoir interval is low.

Three unsubsidized onshore exploration wells have been drilled in the Money Shoal Basin. In 1960, Alliance Oil Development N.L. drilled a continuous corehole, Bathurst Island No. 1, on the southern side of Bathurst Island to establish the thickness of sediment above basement. The well was prematurely abandoned at 252 m after penetrating a mainly Upper Cenomanian mudstone sequence. A second corehole, Batnurst Island No. 2, was drilled in 1961 just east of Bathurst Island No. 1. This well was planned to 610 m but terminated in Cenomanian mudstone at 312 m when a small flow of methane associated with water caused severe deterioration of the hole (Alliance Oil Development N.L., 1961). Tinganoo Bay No. 1 was drilled on the eastern side of Melville Island by Flinders Petroleum and Pexa Oil in 1970/71 (Flinders Petroleum N.L., 1971). The well objective was to obtain detailed stratigraphic information on the maximum sediment section in the permit area, as indicated by geophysical information. The well penetrated a section ranging in age from Recent to Upper Cretaceous (Lower Cenomanian marine shale, silt and sandstone) and was abandoned at 583 m before reaching a programmed depth of 914 m. No hydrocarbon shows were encountered.

The upper part of the Cretaceous section penetrated in all three wells lacks porosity and permeability. However, the Lower Cretaceous, marine-transgressive, sandy and conglomeratic Mullaman and Tinganoo Bay Beds deposited at the southern margin of the basin may have potential reservoir properties (Hughes & Senior, 1973). This apparent interval in Tinganoo Bay No. 1 flowed very brackish water. The only positive evidence of hydrocarbons in the southern part of the Money Shoal Basin is the adhereance of bitumen to rocks at eastern Mountnorris Bay, Cobourg Peninsula. This is thought to be due to subsea seepage from a nearby fault, offshore, between the mainland and Valencia Island.

Future Prospects Sediments near the southern margins of the basin are thin and must largely depend for hydrocarbon accumulation on up-dip migration of hydrocarbons from depocentres of the Money Shoal and Bonaparte Gulf Basins. The existence of structural traps onshore is unlikely as there has been virtually no folding of sediments, with only gentle warping in the Cretaceous. If fault traps are present, fault displacements are likely to be small. Stratigraphic traps may be present around the periphery of the basin where the basin sediments wedge-out against the Australian craton. If structural traps are found to contain encouraging quantities of hydrocarbons then stratigraphic traps may warrant investigation.

From Melville and Bathurst Islands the basement is interpreted as deepening appreciably towards the north and to a lesser amount towards the northeast and northwest. Results of geophysical investigations carried out over the basin suggest the chances of finding large new structures are slight. The Mesozoic and Cainozoic sequences in the 'stable area' are structurally undisturbed, except near Money Shoal where the structure is interpreted to be the result of faulting and drape folding (Balke et al., 1973).

The graben in the 'stable area' contains some 300 to over 4000 m of strongly faulted pre-Mesozoic strata. Velocity analysis of the 1971 seismic data indicated interval velocities ranging from about 4500 to 5500 m/s for the graben sediments. These high velocities suggest the presence of compacted, possibly metamorphosed sediments and/or limestones and volcanics. The velocities are consistent with a Palaeozoic age. Fault-block movements and folding within the graben may have produced early hydrocarbon traps. However, the high seismic velocities, suggesting compaction and diagenesis, and the presence of a major erosional surface at the base of the Mesozoic downgrade the prospects of such structures.

Balke et al. (1973) interpret the hinge-zone during the Early Cretaceous as a zone of abrupt change in depositional environments between the deep-water marine environment in the basin depocentre and the deltaic environments in the stable area. The abundance of clastic material deposited along the shore-line in the Early Cretaceous (Warris, 1973) would have provided an ideal situation for the development of beaches and dunes. Seismic surveys carried out over the proposed hinge-zone/shore-line area have indicated the presence of two anomalies.

The larger of these, the Warawi prospect (Fig. 4), is a small anticlinal feature at the top Lower Cretaceous level, which is bounded in the east by a north-northeast-trending fault. It has a vertical closure of about 250 m and an area of about 30 km^2 at this level. The depth of water over the structure is about 180 m. A smaller structure is located 12 km to the south along the hinge-zone.

The objectives in Warawi are expected to be located in Lower Cretaceous and Jurassic clastics. As depths would be similar to the depths of those formations in Lynedoch No. 1, the porosities may be comparably low. But if Warawi is located in a shore-line environment there is a possibility that better porosities may be encountered. The Warawi prospect is situated in a similar position to Troubadour No. 1 and Sunrise No. 1, near the edge of the Calder Graben (opposite side), and may therefore be expected to contain a gas and/or condensate accumulation rather than an oil accumulation if hydrocarbons are present.

In the area west of the hinge-zone there are few good structural prospects. In this area near the depocentre of the basin the Lower Cretaceous sediments are gently folded, but folding dies out upwards and is almost non-existent at the base of the Tertiary. Seismic mapping of the area has indicated several closed anticlines, one of which has been tested. The presence of only a thin reservoir zone in the Lower Cretaceous and the low porosity of the Jurassic sandstones in Lynedoch No. 1 reduce the hydrocarbon potential of this part of the basin.

The smaller domal structure mapped to the west-northwest of Lynedoch at the top Lower Cretaceous level has a vertical closure of about 80 m and an area of about 100 km^2. It is smaller than Lynedoch, structurally lower, and at a water depth of more than 300 m. It cannot, therefore, be considered an attractive drilling target (Shell, 1975).

A more attractive prospect is the South Lynedoch structure to the southwest of Lynedoch No. 1. This is updip from Lynedoch and is of considerable size, having some 300 km^2 of closed area at the level of the 'P' horizon. The structure is also closed at the 'near top Triassic' level, but at this level it is cut by northeast-trending faults and bifurcated by a small graben. However, as South Lynedoch is in a rather similar situation to the large structure tested unsuccessfully by Heron No. 1 well, it cannot be regarded very optimistically. The only potential reservoir in Heron No. 1 was in the upper part of the well. Unfortunately there is practically no structural closure at corresponding depths at South Lynedoch.

In conclusion, the paucity of structural prospects in the Mesozoic and Cainozoic in the Arafura Sea and the fact that two of the most favourable structures have been tested without success seriously downgrade the hydrocarbon potential of the area. However, post-Palaeozoic wedge-out and stratigraphic traps, if they exist, may offer prospects. Additional exploration drilling may be warranted in the deformed sediments in the pre-Mesozoic graben, where fault traps and combination stratigraphic-fault traps may be present. Because of its position on the hinge-zone the Warawi prospect is possibly the most favourable untested structure recognized in the Money Shoal Basin. More seismic work is required on this structure to determine the optimum location for a drill-site.

Carpentaria/Karumba Basins

Exploration to date Geological work in connexion with petroleum exploration began in 1954. In 1957 Zinc Corporation Ltd drilled Weipa No. 1. By 1958 Frome-Broken Hill Co. Pty Ltd had drilled F.B.H. No. 1 (Wyaaba), in conjunction with Associated Australian Oilfields N.L. and Associated Freney Oil Fields N.L., and the Associated Companies drilled AAO No. 8 (Karumba). Between 1958 and 1963 Delhi Australian Petroleum Ltd and Santos Ltd drilled the exploratory wells Mornington Island Nos. 1 and 2. During 1963-64 Mid-Eastern Oil N.L. drilled three wells, Normanton Nos. 1 and 2 and Burketown No. 1.

Three wells have been drilled in the basin in Indonesian waters by the Pexamin Group. There were no hydrocarbon shows. Details of the sequences penetrated are not available but the locations are given in a report by the Kewanee Oil Company on the petroleum prospects of NT/P24 and neighbouring areas (BMR file 72/3240).

All of the eight petroleum wells which have been drilled in the Australian part of the Carpentaria Basin have been located onshore (Pl. 1). Four of the wells (AAO No. 8 (Karumba), Mornington Is. Nos. 1 and 2, Burketown No. 1) were subsidized under the Petroleum Search Subsidy Acts. The results of all eight wells have been published by GSQ (1961, 1962, 1964, 1966) and the hydrocarbon potential reviewed by Meyers (1969), Doutch et al. (1970, 1972, 1973), and Doutch (1973).

The eight wells all bottomed at depths of about 800 m in pre-Jurassic basement (Table 4a & b). Shallow stratigraphic wells drilled by the BMR (Gibson et al., 1973 and 1974; Grimes & Smart, 1970; and Needham et al., 1971) produced useful cores of Allaru Mudstone, Toolebuc Formation, Wallumbilla and Gilbert River Formations, and Eulo Queen Group. The maximum thickness of the Cainozoic and Mesozoic sequence intersected onshore is not much greater than 900 m (refer to Table 4).

There have been no significant hydrocarbon recoveries obtained in the Carpentaria Basin to date. All shows recorded in the wells are listed in Table 4a & b.

No hydrocarbon shows have been recorded from the Cainozoic intervals although the existence of aquifers indicates suitable reservoirs may be present. The Cainozoic sediments comprise mainly clayey sands of low porosity and permeability and are too shallow and thin over most of the basin to be considered as a prospective source for hydrocarbons. These sediments do, however, thicken to about 300 m due west of Weipa, according to Pinchin (1973).

The Cainozoic sediments disconformably overlie the Lower Cretaceous Rolling Downs Group, the members of which are mostly impermeable labile sandstone and mudstone. The marine Cretaceous Toolebuc Formation (Senior et al., in press) member, which crops out only in the southern part of the basin (Swarbrick, 1974) and has been identified in the subsurface as far north as Wyaaba No. 1 and as far west as Mornington Island Nos. 1 and 2, and the BMR Westmoreland bores, is generally a thin unit with associated bituminous shale. Hydrocarbon shows were reported in this unit in exploration wells Mornington Island No. 2 and AAO No. 8 (Karumba) and also in numerous water-bores. However, the limestone lacks suitable reservoir characteristics onshore and prospects offshore are speculative.

The bituminous shale of the Toolebuc Formation has been identified in many BMR stratigraphic wells - Croydon 1, Normanton 2, Dobbyn 1 and 2, Westmoreland 2 and 3, Lawn Hill 2 (Grimes and Smart, 1970; Needham et al., 1971; Gibson et al., 1973). It is up to 25 m thick and underlies vast areas onshore at depths of from 30 m (the depth of oxidation) to probably less than 700 m. (According to Senior and Smart (1973) the Toolebuc Formation onshore has a sediment cover of less than 600 m and a unit thickness of 3 to 25 m).

In the exploratory well Burketown No. 1, a shale interval from 384 to 399 m within the Toolebuc Formation bore traces of dead oil and gave off a strong petroleum asphalt odour. Core analysis by BMR in 1965 showed a residual oil content of 1 to 5 percent of total porosity. Total porosity was measured at 22% but this value was considered unreliable owing to the extensive drying fractures in the shale (Senior & Smart, 1973). The only petrochemical analysis available (Powell, in Senior and Smart, 1973) was carried out on a sample taken from BMR Croydon No. 1 at 104 m depth, the results of which are as follows: weight of extract 1.15%, composition of extract in weight percent - asphalts 32.4, paraffinic hydrocarbons (C_{17}-C_{24}) 4.4, aromatics 2.2, polar compounds 41.1, and oxygen, nitrogen, and sulphur compounds absorbed on alumina 20.0. In the top 8 m of the oil shale in Croydon No. 1 Fischer assays show an average oil content of 55 litres/tonne. The vanadium content of the shale is as high as 0.4% by weight (3000 ppm) (Smart, pers. comm.).

Exploration carried out on the margins of both the Carpentaria and Eromanga Basins and on the Euroka Arch, where the prospective unit is at shallow depth, discovered large reserves of low-grade vanadium-bearing oil shale near Julia Creek. The grade is generally less than 100 litres of oil/tonne but there is an apparent increase, basinward, into the Eromanga Basin. Vanadium content of the oil shale is as high as 0.5% by weight.

No oil has been produced from oil shale on a commercial scale in the area. The Julia Creek deposit appears to be the only one of potential commercial size. An Australian consortium of companies (TOSCO, Pacminex Pty Ltd, and Aquitaine (Aust.) Pty Ltd) had taken a leading role in the proposed development of the projected combined shale oil-vanadium prospect and reserves have been estimated by TOSCO at 90 million barrels of oil. In 1974 ("Financial Review", 13.2.74, p. 23) it was estimated that the cost of the Julia Creek oil would be between $A7 and $A13 a barrel and that the international price of crude oil would need to be in excess of $US15 before the project became economically feasible. Recently however, there have been signs of renewed interest in the project following the increase in overseas oil prices. Vanadium is still an important factor in the venture and on production oil may be produced as a by-product in vanadium extraction (Swarbrick, 1974).

Future prospects. Sandstones in the Gilbert River Formation (U. Jurassic to L. Cretaceous) and the underlying Upper Jurassic Eulo Queen Group have the best reservoir potential in the basin. The mudstones of the Rolling Downs Group as well as being potential source rocks also act as cap rocks for these permeable beds. Oil traces have been reported in the AAO No. 8 (Karumba) well and in the Gilbert River Formation in Mornington Island No. 2. Reservoir beds penetrated by bores in the relatively thin sedimentary sequence onshore have invariably yielded fresh or brackish waters and it seems that suitable onshore traps have all been flushed by meteoric waters.

The Cainozoic and Mesozoic section is thicker offshore but probably does not exceed 2000 m. It is possible that unflushed structures occur offshore in this section. During the deposition of the Gilbert River Formation bar sands and slump structures may have developed in association with a nearshore environment and, if structure was favourable, these may provide suitable reservoirs. The drilling of offshore prospects would not be hampered by water depth, because nowhere in the basin does it exceed 65 m.

There are few structures in the Mesozoic and Cainozoic other than faults and folds which, because they have apparently resulted from regional faulting and warping, tend to be broad, open-ended, and of low amplitude. Basement structures probably had a strong influence on the evolution of the basin. Seismic mapping to date, which is generally sparse, has not revealed any major closed structures which would present attractive drilling targets. Petroleum prospects would seem to be limited to traps in association with positive basement features, fault traps, and stratigraphic traps.

In summary, the hydrocarbon potential of the Carpentaria Basin would appear to be low because the Cainozoic and Mesozoic sequence is thin. Although the mudstones in the Rolling Downs Group may act as potential source and cap rocks, any onshore traps have probably been water-flushed. These factors, coupled with the shallow depth of sediment burial and the general lack of closed structures considerably reduce petroleum prospects onshore. However petroleum prospects offshore, particularly in the Lower Cretaceous and Jurassic, appear to be slightly better.

6. FUTURE EXPLORATION REQUIRED

Geophysical

The Arafura Sea area has been well covered by aeromagnetic surveys and most of it has been adequately covered by reconnaissance seismic work. East of 132°E there is practically no gravity information offshore. From the point of view of advancing general tectonic knowledge of the Arafura Sea area, the greatest need in future geophysical exploration is for regional gravity coverage. This need should be met by the BMR combined marine geophysical survey planned to take place within the next few years.

However, gravity coverage of the Arafura Sea is likely to contribute little to the search for petroleum at this stage. For petroleum search the most immediate need is for seismic work to detail future drilling locations, for example at Warawi, South Lynedoch, and in the pre-Mesozoic graben. Limited additional seismic work to fill gaps in present reconnaissance cover is also warranted. The seismic grid is sparse northwest of Cobourg Peninsula, but the Mesozoic contours indicated by existing surveys are smooth and undisturbed and it is doubtful whether additional lines would add significantly to the structural picture. However, additional reconnaissance lines are required to supplement sparse cover in the eastern Arafura Sea east of about $134^{o}30'E$.

There is little gravity information to date on the Gulf of Carpentaria and areas to the north of it. Reconnaissance gravity coverage to be provided by the proposed BMR combined marine geophysical survey will be a useful addition to regional knowledge of the area, although work onshore suggests that its value for offshore petroleum search will be limited.

Additional magnetic traverses designed to fill gaps in the existing aeromagnetic coverage of the Carpentaria Basin (Pl. 2) could make a useful contribution to regional structural knowledge and could be useful in indicating the presence or otherwise of volcanic rocks.

Apart from several areas in the north, seismic coverage of the Gulf of Carpentaria is sparse or non-existent. A reconnaissance seismic coverage of the unexplored areas of the Gulf would be a useful step in exploration of the area. Basement can be expected to be relatively shallow, and the area is probably free of major structural disturbances, so that a fairly wide line spacing of, say, 30 km is all that is warranted initially. Such a reconnaissance seismic survey should indicate the existence of any sizable grabens containing thicker sedimentary sections than the basin in general and could provide structural leads requiring more detailed investigation with a view to establishing drilling sites.

Drilling

In Chapter 4 several petroleum drilling prospects in the Money Shoal Basin have been mentioned. The decisions on whether and when these various prospects should be drilled are economic decisions as well as geological decisions and no specific recommendations on their drilling can be given here. In the Carpentaria Basin there are no known prospects which could be drilled with the hope of obtaining hydrocarbons in commercial quantities.

With regard to the more general objective of advancing geological knowledge in the region, there is a need for several wells to provide stratigraphic information on little-known areas. A deep well would be desirable to investigate the sedimentary sequence in the pre-Mesozoic graben on the 'stable area' of the Money Shoal Basin. Indications are that the sediments in the graben may be relatively unprospective for petroleum. Nevertheless, a suitable location for a well in the graben would be on a small domal structure which has been mapped near the centre of the graben. A well at this location which would penetrate the deepest mappable seismic reflection (Horizon 'D') would need to be drilled to a depth of about 4400 m.

A much shallower stratigraphic well (1000 m or less) in the eastern part of the Arafura Sea would be useful to confirm the age and nature of the generally flat-lying sediments which underlie the thin Mesozoic-Cainozoic section.

The offshore portion of the Carpentaria Basin constitutes a huge area with sediments up to 2000 m thick and without a single well. Although petroleum prospects are not promising the area can hardly be dismissed as unprospective without the drilling of one or more wells. More seismic work is the first priority, in order to define drilling locations which will test the hydrocarbon potential of the offshore sediments and provide stratigraphic information which is lacking at present.

7. CONCLUSIONS

Although geological and geophysical exploration of the Arafura Sea - Gulf of Carpentaria region has been carried out for more than fifteen years, significant gaps in knowledge of the region remain. There is a need for further seismic work in the eastern Arafura Sea and the Gulf of Carpentaria and for stratigraphic wells in these areas and also in the pre-Mesozoic graben located northeast of the Cobourg Peninsula. At the present time it seems that overall, the petroleum prospects of the region are not promising. Some possible hydrocarbon traps have been indicated within the Calder Graben and on its margins. In that area the petroleum prospectivity is considered fair, but over the remainder of the vast Arafura Sea - Gulf of Carpentaria region the prospectivity must be regarded as poor.

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APPENDIX 1

GEOPHYSICAL SURVEYS

APPENDIX 1

GEOPHYSICAL SURVEYS

Survey name and type	Year	Operator	Contractor	No. of km surveyed	Reference
Carpentaria Basin (land) seismic	1958	BMR	-	90	BMR Records 1959/4, 1975/73
Underwater gravity survey, Bramble Cay to Cape Arnhem	1958	BMR	-	-	BMR Record 1958/102
Underwater gravity survey, Cape Arnhem to Darwin	1958	BMR	-	-	BMR Record 1959/71
RV Argo(2), Lusiad and Monsoon Expedition, Magnetic and gravity	1960-1963	Scripps Institution of Oceanography	-	100+	See bibliography
Bathurst Island (land) seismic	1962	Alliance Oil Development	General Geophysical	38	PSSA 62/1615
Karumba aeromagnetic	1962	Mid-Eastern Oil	Aero Service	14700	PSSA 62/1721
Gulf of Carpentaria aeromagnetic	1962	Delhi Australian Petroleum	Aero Service	15600	PSSA 62/1719
Melville Island aeromagnetic	1963	Alliance Oil Development	Adastra Hunting Geophysics	3615	PSSA 63/1711
Karumba (land) seismic	1963	Mid-Eastern Oil	Austral Geo Prospectors	456	PSSA 63/1520
USNS Sgt Curtis F. Shoup, Project 'Magnet', Magnetic and gravity	1963-1964	US Naval Oceanographic Office	-	2000+	See bibliography

Appendix 1 (continued)

Survey name and type	Year	Operator	Contractor	No. of km surveyed	Reference
Wenlock River aeromagnetic	1964	Australian Aquitaine Petroleum	Adastra Hunting Geophysics	7950	PSSA 64/4603
Cape Arnhem seismic*	1964	Farmout Drillers	Western Geophysical	315	PSSA 64/4526
North-East Carpentaria aeromagnetic	1964	Marathon Petroleum Australia	Adastra Hunting Geophysics	35300	PSSA 64/4607
ATP 104P seismic	1964	Marathon Petroleum Australia	Western Geophysical	995	PSSA 64/4554
Arafura Sea aeromagnetic	1965	Shell Development (Australia)	Adastra Hunting Geophysics	12000	PSSA 65/4616
Dundas Strait seismic	1965	Anacapa Corporation	Geophysical Services International	132	PSSA 65/11011
Archer River seismic	1965	Australian Aquitaine Petroleum	Compagnie Generale de Geophysique	304	PSSA 65/11019
Arafura Sea seismic	1965	Shell Development (Australia)	Western Geophysical	1448	PSSA 65/11044
ATP 58P R1 seismic	1966	Marathon Petroleum Australia	Western Geophysical	1840	PSSA 66/11123
Lynedoch Bank seismic	1966-1967	Shell Development (Australia)	Western Geophysical	1047	PSSA 66/11117
Timor Sea gravity, magnetic and seismic	1967	BMR	United Geophysical	20900	BMR Records No. 1968/132 No. 1969/40

* seismic surveys are marine seismic surveys unless specified as land seismic

Appendix 1 (continued)

Survey name and type	Year	Operator	Contractor	No. of km surveyed	Reference
Money Shoal seismic	1967	Shell Development (Australia)	Compagnie Generale de Geophysique	1740	PSSA 66/11141
Volsella Shoal seismic	1967	Australian Aquitaine Petroleum	Compagnie Generale de Geophysique	1336	PSSA 67/11149
Arafura D1 seismic	1968	Shell Development (Australia)	Geophysical Services International	1090	PSSA 68/3020
New Year Island seismic	1968	Australian Aquitaine Petroleum	Compagnie Generale de Geophysique	1036	PSSA 68/3025
Arafura D2 seismic	1969	Shell Development (Australia)	BIPM (Shell)	1230	PSSA 69/3006
Van Diemen Gulf aeromagnetic	1969	Flinders Petroleum	Compagnie Generale de Geophysique	3000	PSSA 69/3040
Arafura D3 seismic	1969	Shell Development (Australia)	Geophysical Services International	1249	P(SL)A 69/6
New Year Island I1 seismic	1970	Australian Aquitaine Petroleum	Western Geophysical	670	P(SL)A 70/18
Arafura D4 seismic	1971	Shell Development (Australia)	Geophysical Services International	2228	P(SL)A 71/9
Calder-Evans seismic	1972	BOC of Australia	Western Geophysical	634	PSSA 72/3038
Gulf regional geophysical reconnaissance survey	1972	Australian Gulf Oil	Gulf Research and Development	3354	P(SL)A 72/8

Appendix 1 (continued)

Survey name and type	Year	Operator	Contractor	No. of km surveyed	Reference
Timor Sea seismic	1972	C and K Petroleum	Western Geophysical	371	P(SL)A 72/22
Arafura D5 seismic	1972	Shell Development (Australia)	Seismograph Service	492	P(SL)A 72/37
Wessel seismic	1972	Beaver Exploration Australia	Western Geophysical	950	P(SL)A 72/3
Goulburn seismic	1973	Australian Aquitaine Petroleum	Geophysical Services International	322	P(SL)A 73/8
Arafura D6 seismic	1973	Shell Development (Australia)	Geophysical Services International	910	P(SL)A 73/10
Gulf of Carpentaria seismic	1973	Keewanee Overseas Oil	Western Geophysical	2843	P(SL)A 73/13
Arafura Sea seismic	1973	C and K Petroleum	Western Geophysical	373	P(SL)A 73/18
Kendrew-Cootamundra seismic	1974	BOC of Australia	Geophysical Services International and Western Geophysical	477 (prospect P only)	P(SL)A 74/31

APPENDIX 2

PETROLEUM EXPLORATION WELLS,

CARPENTARIA AND MONEY SHOAL BASINS

APPENDIX 2

PETROLEUM EXPLORATION WELLS, CARPENTARIA AND MONEY SHOAL BASINS

BASIN COMPANY Well Name BMR file no. is subsidized	Latitude South Longitude East o	"	'	1:250 000 Sheet Area	Elevation (m) GL/WD DF/KB/RT	Date spudded TD reached	T.D. (m)	Status
CARPENTARIA								
ASSOCIATED AUSTRALIAN OILFIELDS								
AAO No. 8 (Karumba)	17	24	36	E 54-6	Gl -	6 2 58	721	PA
BMR file 62/1006	140	52	21.9		KB 9	3 3 58		
DELHI AUSTRALIAN PETROLEUM LTD								
Mornington Island No. 1	16	32	44	E 54-1	GL 14.4	22 5 61	842	PA
BMR file 62/1065	139	15	27		KB 17.4	3 6 61		
Mornington Island No. 2	16	29	13	E 54-2	GL 7.3	19 6 61	914	PA
BMR file 62/1065	139	31	11		KB 10.4	26 6 61		
FROME-BROKEN HILL CO. PTY LTD								
Wyaaba No. 1	16	29	30	E 54-3	-	1957	860	PA
	141	37	22					
MID-EASTERN OIL NL								
Burketown No. 1	18	03	43	E 54-10	GL 19	17 5 64	1013	Completed as
BMR file 63/1049	139	32	16		KB 23	10 8 64		a water well
Normanton Scout No. 1	17	39	-	E 54-7	GL 0	22 10 63	243	PA
	141	32	-		RL 0.6	2 12 63		

Appendix 2 (continued)

BASIN COMPANY Well Name BMR file no. is subsidized	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD DF/KB/RT	Date spudded TD reached	T.D. (m)	Status
CARPENTARIA						
MID-EASTERN OIL NL						
Normanton Scout No. 2	17 39 08 141 31 38	E 54-7	GL 0 RT 0.6	12 12 63 suspended 22 10 64 4 6 64	464	PA
ZINC CORPORATION						
Weipa No. 1	12 43 00 141 55 50	D 54-3	GL 34 KB 51	20 5 57 12 10 57	988	PA
MONEY SHOAL FLINDERS PETROLEUM NL						
Tinganoo Bay No. 1	11 23 42 131 29 02	C 52-16	GL 1.5	18 12 70 19 4 71	583.4	PA
OIL DEVELOPMENT N.L.						
Bathurst Island No. 1	11 47 40 130 13 30	C 52-15	GL 0.6	14 6 60 16 8 60	252	Abandoned
Bathurst Island No. 2	11 45 30 130 32 -	C 52-13	Collar Elevation - 25.3 above mean high tide	20 7 61 8 9 61	312	Abandoned

Appendix 2 (continued)

BASIN COMPANY Well Name BMR file no. is subsidized	Latitude South Longitude East o " '	1:250 000 Sheet Area	Elevation (m) GL/WD DF/KB/RT	Date spudded TD reached	T.D. (m)	Status
MONEY SHOAL						
SHELL DEVELOPMENT (AUSTRALIA) PTY LTD						
Money Shoal No. 1	10 18 57 132 44 11	G 53-9	WD 68.6 RT 9.4 (above sea level)	15 6 71 19 7 71	2590.2	PA
Lynedoch No. 1	9 51 43 130 18 45	C 52-7	WD 236.5 RT 11.3 (above sea level)	14 2 73 3 6 73	3967	PA

APPENDIX 3

BMR STRATIGRAPHIC HOLES, CARPENTARIA AND MONEY SHOAL BASINS

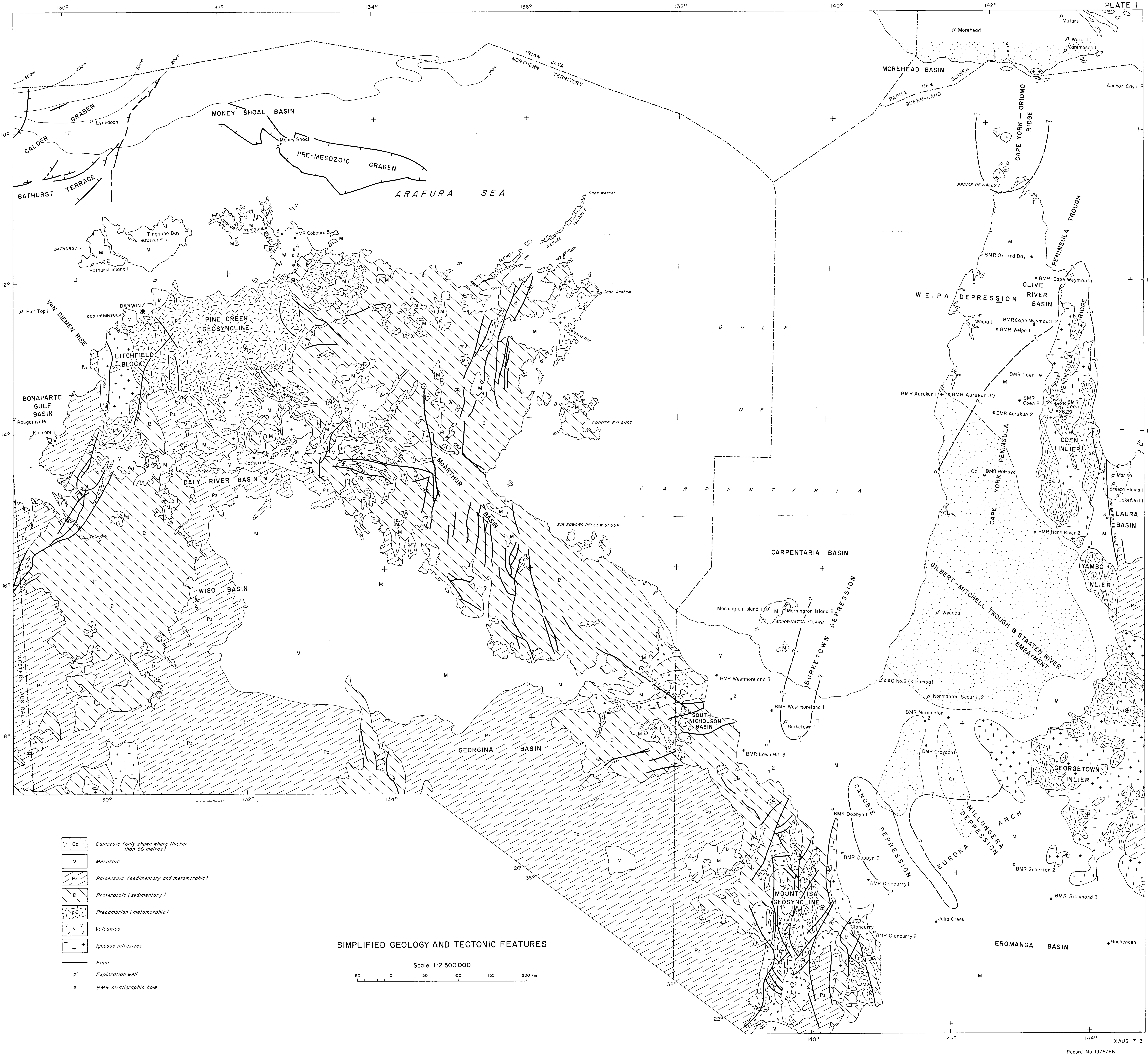
APPENDIX 3

BMR STRATIGRAPHIC HOLES, CARPENTARIA AND MONEY SHOAL BASINS

Basin Strat. hole name	Latitude South Longitude East o " '	1:250 000 Sheet area	T.D. (m)	Reference
CARPENTARIA				
BMR Cloncurry 1		F54-2	152	Grimes & Smart (1970)
BMR Cloncurry 2		"	42.7	"
BMR Croydon 1	18 18 - 141 30 -	E54-11	153.9	Needham et al. (1971)
BMR Dobbyn 1	19 11 - 140 13 -	E54-14	152.4	Grimes & Smart (1970)
BMR Dobbyn 2	19 46 - 140 22 -	"	152.4	"
BMR Gilberton 1	19 51 -))C 143 44 -)	E54-16	113.7	Needham et al. (1971)
BMR Gilberton 2	19 51 - 142 48 -	"	243.8	"
BMR Hann River 1	15 35 - 143 38 -	D54-16	105.77	Gibson et al. (1973)
BMR Hann River 2	15 25 - 142 53 -	"	165.6	"
BMR Hann River 3	15 11 - 143 52 -	"	213.97	"
BMR Lawn Hill 1	18 20 - 139 16 -	E54-9	152.4	Needham et al. (1971)

Appendix 3 (continued)

Basin Strat. hole name	Latitude South Longitude East o	 "	 '	1:250 000 Sheet area	T.D. (m)	Reference
CARPENTARIA						
BMR Lawn Hill 2	18 139	41 19	- -	"	152.4	Needham et al. (1971)
BMR Lawn Hill 3	18 138	25 58	- -	"	48.67	Gibson et al. (1973)
BMR Normanton 1	17	56	-	E54-7	153	Needham et al. (1971)
BMR Normanton 2	17 141	59 28	- -	"	154	
BMR Richmond 3				F54-4	152-4	Grimes & Smart (1970)
BMR Westmorland 1	17 139	53 20	- -	E54-5	151.8	Needham et al. (1971)
BMR Westmorland 2	17 138	44 46	- -	"	207.57	Gibson et al. (1973)
BMR Westmorland 3	17 138	25 35	- -	"	196.37	"
MONEY SHOAL						
BMR Cobourg Peninsula 1	11 132	55 53	- -	C53-13	67.5	
BMR Cobourg Peninsula 2	11 132	47 53	30 -	"	C.134	
BMR Cobourg Peninsula 3	11 132	29 44	- -	"	290.5	
BMR Cobourg Peninsula 4	11 132	42 54	- -	"	138.68	
BMR Cobourg Peninsula 5	11 132	33 55	- -	"	276.14	



SIMPLIFIED GEOLOGY AND TECTONIC FEATURES

Scale 1:2 500 000

XAUS-7-3

Record No 1976/66


PLATE 2
ARAFURA SEA – GULF OF CARPENTARIA
MAGNETIC TRAVERSES
50 0 50 100 150 200 km
Boundary of survey area
U.S. Naval Oceanographic Office 1967, survey by U.S.N.S. Sgt. Curtis F Shoup 1963-64
Gulf of Carpentaria, survey by Dehli Australian Petroleum, 1962
Scripps Institution of Oceanography (1964) survey by Argo 1963
TIMOR SEA (BMR, 1967)
(AUSTRALIAN GULF OIL COMPANY, 1972)
ARAFURA SEA (SHELL DEVELOPMENT AUSTRALIA, 1965) (N-S flight-line spacing 20·1 km)
MELVILLE ISLAND (ALLIANCE OIL DEVELOPMENT AUSTRALIA, 1963)
VAN DIEMEN GULF (FLINDERS PETROLEUM, 1969)
TIMOR SEA (BMR, 1965)
GULF OF CARPENTARIA (DELHI AUSTRALIAN PETROLEUM, 1962)
A C54-11 (E-W flight-line spacing 3·2 km)
C54-12
N.E. CARPENTARIA (MARATHON PETROLEUM, 1965)
B (E-W flight-line spacing 3·2 km)
WENLOCK RIVER (AUSTRALIAN AQUITAINE PETROLEUM, 1964) (E-W lines 4 km apart in bands of 5 separated by 20 km)
(N-S tie-lines 30 km apart)
CARPENTARIA BASIN (BMR, 1973-74) (E-W lines 1·5 or 3 km apart onshore & 6 km apart offshore)
WESTMORELAND (BMR 1973) (N-S lines 1·5 km apart)
GEORGINA BASIN (BMR, 1966) (E-W lines 3·2 km apart N-S tie lines 27·4 km apart)
KARUMBA (MID-EASTERN OIL, 1962) (E-W flight-lines 3·2 km apart in bands of 4, each band of 4 lines separated by approx 9·6-16·1 km N-S tie-lines 35 km apart)
GULF OF CARPENTARIA
PNG
Thursday Island (Horn Island)
CAPE YORK
PRINCE OF WALES I.
Bathurst Island
Melville Island
Cobourg Peninsula
CROKER I.
Junction Bay
Wessel Islands
Truant Island
WESSEL ISLANDS
Jardine River
Orford Bay
Fog Bay
Darwin
DARWIN
Alligator River
Milingimbi
Maningrida
Elcho Island
Arnhem Bay
Gove
Yirrkala Mission / Gove Aerodrome
Weipa
Cape Weymouth
Iron Range
Aurukun
Coen
Cape Scott
Pine Creek
Mt Evelyn
Mt Marumba
Blue Mud Bay
Port Langdon
GROOTE EYLANDT
Cape Beatrice
Holroyd
Ebagoola
Cape Melville
Port Keats
Fergusson River
Katherine
Urapunga
Roper River
Roper River Mission
Hodgson Downs
Mt Young
Pellew
Rutland Plains
Hann River
Cooktown
Auvergne
Delamere
Larrimah
SIR EDWARD PELLEW GROUP
Mitchell River Mission
Waterloo
Victoria River Downs
Daly Waters
Tanumbirini
Bauhinia Downs
Robinson River
Mornington
Cape van Diemen
Galbraith
Dunbar
Walsh
Mossman
O.T. Downs
MORNINGTON ISLAND
Wrotham Park
Newcastle Waters
Beetaloo
Mallapunyah Springs
Wallhallow
Calvert Hills
Westmoreland
Burketown
Normanton
Red River
Atherton
Limbunya
Wave Hill
Karumba
Gilbert
Nicholson River
Brunette Downs
Creswell Downs
Mt Drummond
Lawn Hill
Donor's Hill
Croydon
Georgetown
Einasleigh
Birrindudu
Winnecke Creek
Tanami
Tanami East
Green Swamp Well
Tennant Creek
Alroy
Rockhampton Downs
Ranken
Alexandria Downs
Camooweal
Dobbyn
Millungera
Gilberton
Clarke River
WESTERN AUSTRALIA
NORTHERN TERRITORY
NORTHERN TERRITORY
QUEENSLAND
The Granites
Mt Solitaire
Lander River
Bonney Well
Frew River
Avon Downs
Mt Isa
Cloncurry
Julia Creek
Richmond
Hughenden
129° 132° 135° 138° 141° 144°
11° 14° 17° 20°
Record No 1976/66
XAUS-7-1

PLATE 3


ARAFURA SEA
(SHELL DEVELOPMENT AUSTRALIA, 1965)
Broken contours & faults
GULF OF CARPENTARIA
(DELHI AUSTRALIAN PETROLEUM, 1962)
VAN DIEMEN GULF
(FLINDERS PETROLEUM, 1969)
Magnetic basement <1000m below sea level
NORTH-EAST CARPENTARIA
(MARATHON PETROLEUM, 1965)
WENLOCK RIVER
(AUSTRALIAN AQUITAINE PETROLEUM, 1964)
GULF OF CARPENTARIA
GEORGINA BASIN
(BMR, 1973)
KARUMBA
(MID-EASTERN OIL, 1962)
C54-11
C54-12
PNG
ARAFURA SEA — GULF OF CARPENTARIA
MAGNETIC BASEMENT DEPTH CONTOURS
50 0 50 100 150 200 km
Contours in metres below sea level
Survey name and reference shown
NORTHERN TERRITORY
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
Bathurst Island
Melville Island
Cobourg Peninsula
Junction Bay
Wessel Islands
Truant Island
Fog Bay
Darwin
DARWIN
Alligator River
Milingimbi
Arnhem Bay
Gove
Cape Scott
Pine Creek
Mt Evelyn
Mt Marumba
Blue Mud Bay
Port Langdon
Port Keats
Fergusson River
Katherine
Urapunga
Roper River
Cape Beatrice
Groote Eylandt
Auvergne
Delamere
Larrimah
Hodgson Downs
Mt Young
Pellew
Sir Edward Pellew Group
Waterloo
Victoria River Downs
Daly Waters
Tanumbirini
Bauhinia Downs
Robinson River
Mornington
Cape van Diemen
Mornington Island
Limbunya
Wave Hill
Newcastle Waters
Beetaloo
Walhallow
Calvert Hills
Westmoreland
Burketown
Birrindudu
Winnecke Creek
South Lake Woods
Helen Springs
Brunette Downs
Mt Drummond
Lawn Hill
Donor's Hill
Nicholson River
Tanami
Tanami East
Alroy
Ranken
Camooweal
Dobbyn
Tennant Creek
The Granites
Mt Solitaire
Lander River
Bonney Well
Frew River
Avon Downs
Mt Isa
Cloncurry
Julia Creek
Richmond
Hughenden
Jardine River
Orford Bay
Thursday Island (Horn Island)
Cape York
Prince of Wales I.
Weipa
Cape Weymouth
Iron Range
Coen
Aurukun
Holroyd
Ebagoola
Cape Melville
Rutland Plains
Hann River
Cooktown
Mitchell River Mission
Galbraith
Walsh
Mossman
Wrotham Park
Normanton
Red River
Atherton
Karumba
Gilbert
Croydon
Georgetown
Einasleigh
Millungera
Gilberton
Clarke River
Ord River
Victoria River
Record No 1976/66
XAUS-7-2

Record No 1976/66 XAUS-7-4


PLATE 5
ARAFURA SEA – GULF OF CARPENTARIA
SEISMIC SURVEYS AND DRILLING
50 0 50 100 150 200 km
Seismic reflection lines
Seismic sparker lines
Seismic refraction lines
AU-53 Regional geophysical reconnaissance traverse (Australian Gulf Oil Company, 1972)
Exploration well
BMR refraction depth probe (Robertson and Moss, 1958)
NEW YEAR ISLAND I (AUSTRALIAN AQUITAINE, 1968)
VOLSELLA SHOAL (AUST. AQUITAINE PETROLEUM, 1967)
GOULBURN (AUST AQUITAINE PETROLEUM 1973)
BMR sparker seismic lines 1965 & 1967 shown on Plate 2
TIMOR SEA (CBK PETROLEUM, 1972)
BATHURST ISLAND (ALLIANCE OIL DEVELOPMENT, 1962)
DUNDAS STRAIT (ANACAPA CORP, 1965)
ARAFURA SEA (CBK PETROLEUM, 1973)
FOR ADDITIONAL INFORMATION IN THIS AREA – SEE PLATE 5A
A.T.P. 104P SURVEY (MARATHON PETROLEUM, 1964)
A.T.P. 58P SURVEY (MARATHON PETROLEUM, 1966)
WESSEL (BEAVER EXPLORATION AUST, 1972)
CAPE ARNHEM SURVEY (FARMOUT DRILLERS, 1964)
GULF OF CARPENTARIA (KEEWANEE OVERSEAS OIL, 1973)
ARCHER RIVER SURVEY (AUST. AQUITAINE PETROLEUM 1965)
KARUMBA SURVEY (MID-EASTERN OIL, 1963)
Normanton Scout 1
AAO No 8 (Karumba)
GULF OF CARPENTARIA
Lyndoch 1
Heron 1
Money Shoal 1
Weipa 1
Marina 1
Breeza Plains 1
Lakefield 1
Maremosab 1
Mornington Island 1
Mornington Island 2
Burketown 1
Wyaaba 1
PNG
Darwin
Bathurst Island
Melville I
Cobourg Peninsula
Wessel Islands
Groote Eylandt
Sir Edward Pellew Group
Mornington Island
Prince of Wales I
Cape York
Thursday Island (Horn Island)
NORTHERN TERRITORY
WESTERN AUSTRALIA
QUEENSLAND
Record No 1976/66
X AUS-7-7


ARAFURA SEA — SEISMIC SURVEYS
COMPANY AND SURVEY
Australian Aquitaine Petroleum —
New Year Island Ⅰ (NY prefix), 1968
New Year Island Ⅱ (NZ prefix), 1970
Volsella Shoal (VS prefix), 1967
Anacapa Corporation —
Dundas Strait (OP prefix), 1965
Shell Development (Aust.) —
Money Shoal (AS66 prefix), 1967
Other Shell lines have prefix A followed by four digits, the first two of which indicate year
B.O.C. of Australia —
Lines indicated by 4 to 6 digit numbers The two digits before the dash indicate the year e.g. 69-268
Seismic reflection line
Seismic sparker line
10 0 30 60km
MELVILLE I.
BATHURST I.
Cobourg Peninsula
CROKER I.
Goodrich Bank


PLATE 6
ARAFURA SEA — GULF OF CARPENTARIA
SEISMIC DEPTH CONTOURS
50 0 50 100 150 200 km
Contours in metres below sea level
Base of Mesozoic
Intra-Lower Cretaceous horizon 'P'
Tennant Creek
GULF OF CARPENTARIA
Note: Contours in this area lack control
NORTHERN TERRITORY
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
PNG
129°
132°
135°
138°
141°
144°
11°
14°
17°
20°
Lynedoch I
Money Shoal I
Bathurst Island
Melville Island
Cobourg Peninsula
CROKER I
Junction Bay
Wessel Islands
Truant Island
WESSEL ISLANDS
BATHURST I
MELVILLE I
Fog Bay
Darwin
DARWIN
Alligator River
Milingimbi
Maningrida
Elcho Island
Arnhem Bay
Gove
Yirrkala Mission / Gove Aerodrome
Cape Scott
Pine Creek
Mt Evelyn
Mt Marumba
Blue Mud Bay
Port Langdon
GROOTE EYLANDT
Pine Ck
Port Keats
Fergusson River
Katherine
Urapunga
Roper River
Cape Beatrice
Roper River Mission
Mataranka
Auvergne
Delamere
Larrimah
Hodgson Downs
Mt Young
Pellew
SIR EDWARD PELLEW GROUP
Birdum
Waterloo
Victoria River Downs
Daly Waters
Tanumbirini
Bauhinia Downs
Robinson River
Mornington
Cape van Diemen
MORNINGTON ISLAND
O.T. Downs
Mallapunyah Springs
Ord River
Victoria River
Limbunya
Wave Hill
Newcastle Waters
Beetaloo
Wallhallow
Calvert Hills
Westmoreland
Burketown
Birrindudu
Winnecke Creek
South Lake Woods
Helen Springs
Brunette Downs
Creswell Downs
Mt Drummond
Nicholson River
Lawn Hill
Donor's Hill
Rockhampton Downs
Tanami
Tanami East
Alroy
Ranken
Alexandria Downs
Camooweal
Dobbyn
The Granites
Mt Solitaire
Lander River
Bonney Well
Frew River
Avon Downs
Mt Isa
Cloncurry
Julia Creek
Richmond
Hughenden
C54-11
C54-12
Thursday Island (Horn Island)
PRINCE OF WALES I.
CAPE YORK
Jardine River
Orford Bay
Weipa
Cape Weymouth
Iron Range
Aurukun
Coen
Holroyd
Ebagoola
Cape Melville
Rutland Plains
Hann River
Cooktown
Mitchell River Mission
Galbraith
Dunbar
Walsh
Mossman
Wrotham Park
Normanton
Red River
Atherton
Gilbert River
Croydon
Georgetown
Einasleigh
Millungera
Gilberton
Clarke River
Record No 1976/66
XAUS-7-9