THE CAMBRIAN TO PERMO-TRIASSIC ARAFURA BASIN, NORTHERN AUSTRALIA

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ABSTRACT

The Arafura Basin is on the northern margin of Australia, extending north towards New Guinea and contains a thick Cambrian to Permo-Triassic sedimentary sequence. The basin consists of a broad northern platform, a northwest trending graben, the Goulburn Graben (new name), and a southern platform that extends onshore into the Northern Territory. The basin sediments unconformably overlie the Proterozoic McArthur Basin and are overlain by mid-Jurassic and younger sediments of the Money Shoal Basin. The Palaeozoic section in the Goulburn Graben is over 10 km thick, while on the northern and southern platforms half that thickness is preserved.

During the Cambrian and Ordovician the Arafura Basin was a stable platform dominated by carbonate deposition. The Late Devonian and Late Carboniferous aged sediments are marine and non-marine clastics with minor carbonates. Initial movement of the graben bounding faults occurred in the early Carboniferous, but the major graben development and deformation occurred in the Permo-Triassic and was associated with westward tilting.

The six exploration wells in the basin have all been sited on structural targets along the Goulburn Graben. There were oil shows in most wells and four source rock intervals were intersected, but reservoir quality and fault seal were identified as major risks. The majority of the Cambrian and Permo-Triassic sequences remain untested and extensive areas of the basin outside the graben are virtually unexplored. Thermal maturation studies indicate a low geothermal gradient and that the greater part of the Palaeozoic sequence is prospective for hydrocarbons.

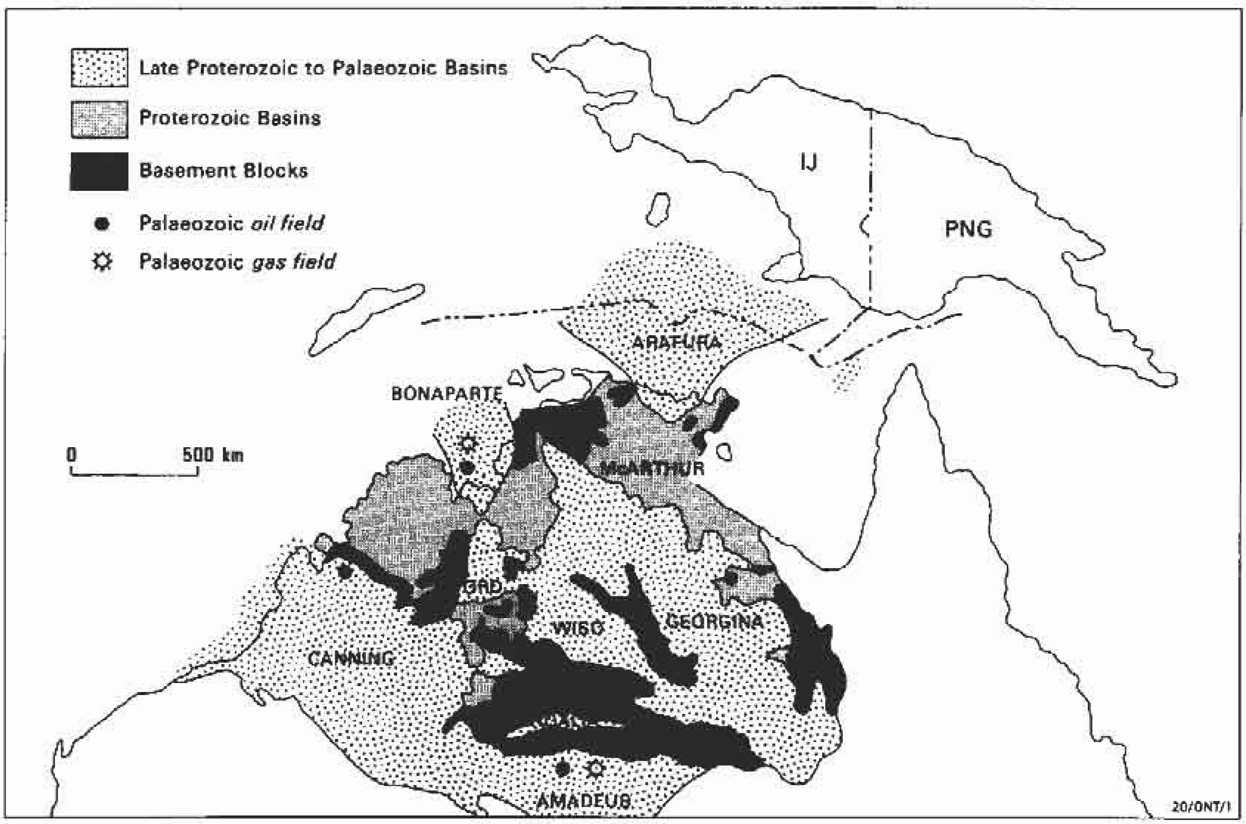


Figure 1 — Regional location map of the northern Australia Palaeozoic and Proterozoic basins.

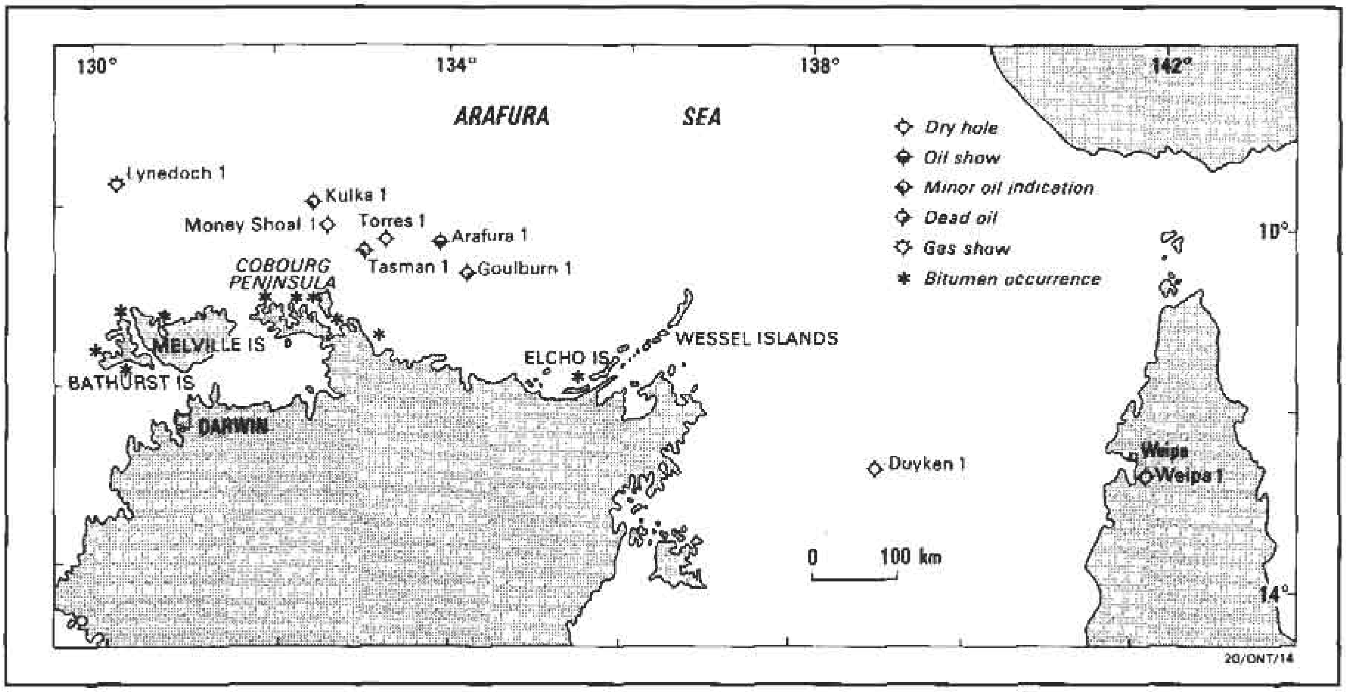


Figure 2 — Arafura Basin hydrocarbon shows and beach strandings.

INTRODUCTION

The Arafura Basin is situated on the northern margin of Australia, mostly beneath shallow waters of the Arafura Sea. It is at least 350 000 km² in size, extending from onshore Arnhem Land, Northern Territory, to north of the Australia-Indonesia border (Fig. 1). Structurally it consists of a northern and southern platform separated by a major graben. The Cambrian to Permo-Triassic Arafura Basin sequence is unconformably overlain by the Middle Jurassic to Recent sequence of the Money Shoal Basin and is underlain by Proterozoic sediments of the McArthur Basin. A Palaeozoic sequence over 10 km in thickness occurs in the Goulburn Graben (new name), whilst on the northern and southern platforms there are respectively at least 5 and 3 km of sediment preserved.

A short exploration phase from 1981 to 1986 lead to delineation of the basin sediments and structure (Petroconsultants, 1989). In the current study, extensive redating of the Cambrian to Devonian sequences and analysis of the regional geology has highlighted several new concepts for petroleum exploration in the area. These include the recognition of:

1 stratigraphic intervals that are of equivalent age to the source rocks in the Amadeus and Canning Basins,

2 untested intervals in the Permo-Triassic and in the Middle and Lower Cambrian,

3 the continuance of the upper and lower Palaeozoic sediments north of the graben to the Australia-Indonesia border,

4 the existence of the lower Palaeozoic sequence to the northeast of the Wessel Islands, and

5 relatively low geothermal gradients, thus raising the petroleum potential of the older sequences.

BRIEF EXPLORATION HISTORY

The existence of a large Palaeozoic basin to the north of Australia was suspected for many years from the outcropping Cambrian sequence on Elcho Island (Wade, 1924; Plum 1965; Plumb et al., 1976) and aeromagnetic surveys (Balke & Burt, 1976). Oil exploration began in the early 1920s with the drilling of several shallow holes (< 100 m) on Elcho Island in response to bitumen occurrences (Plumb, 1965). Offshore, Shell drilled Money Shoal-1 in 1971 (Fig. 2), which primarily tested a Mesozoic sequence. Tests of the Palaeozoic sequence of the Arafura Basin occurred between 1983 to 1986 with the drilling of Tasman-1, Torres-1, Arafura-1, Kulka-1 and Goulburn-1. All of these wells were sited offshore in the southern part of the basin along the Goulburn Graben. Of these wells, Arafura-1 was the most encouraging, encountering oil shows over a gross interval of 425 m in the Devonian and Ordovician and recording total organic carbon (TOC) values of up to 8.65% in the Middle Cambrian.

BASIN FRAMEWORK

REGIONAL STRUCTURE AND GEOGRAPHIC LIMITS

The structure of the southern part of the Arafura Basin is dominated by a northwest trending graben in which most of the recent exploration activity has been concentrated (Figs 3 & 4). Lower Palaeozoic sediments extend beyond the graben to the east where they underlie the Mesozoic and Cenozoic of the Carpentaria Basin and unconformably overlie the McArthur Basin (Fig. 5). To the north the

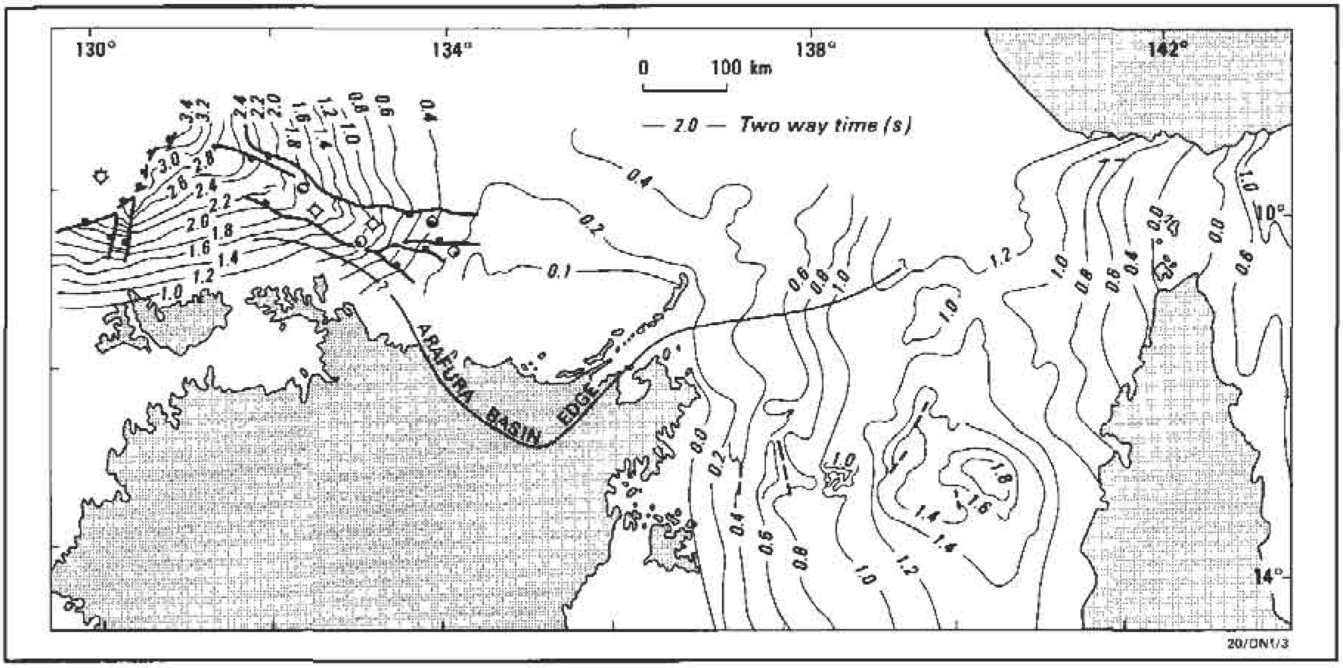


Figure 3 — Structure contour map in two way time to top of the Arafura Basin sequence, showing the southern boundary of the Arafura Basin. Compare with subcrop map in Fig. 5. Compiled from Petroconsultants (1989) and Palfreyman et al., (1976).

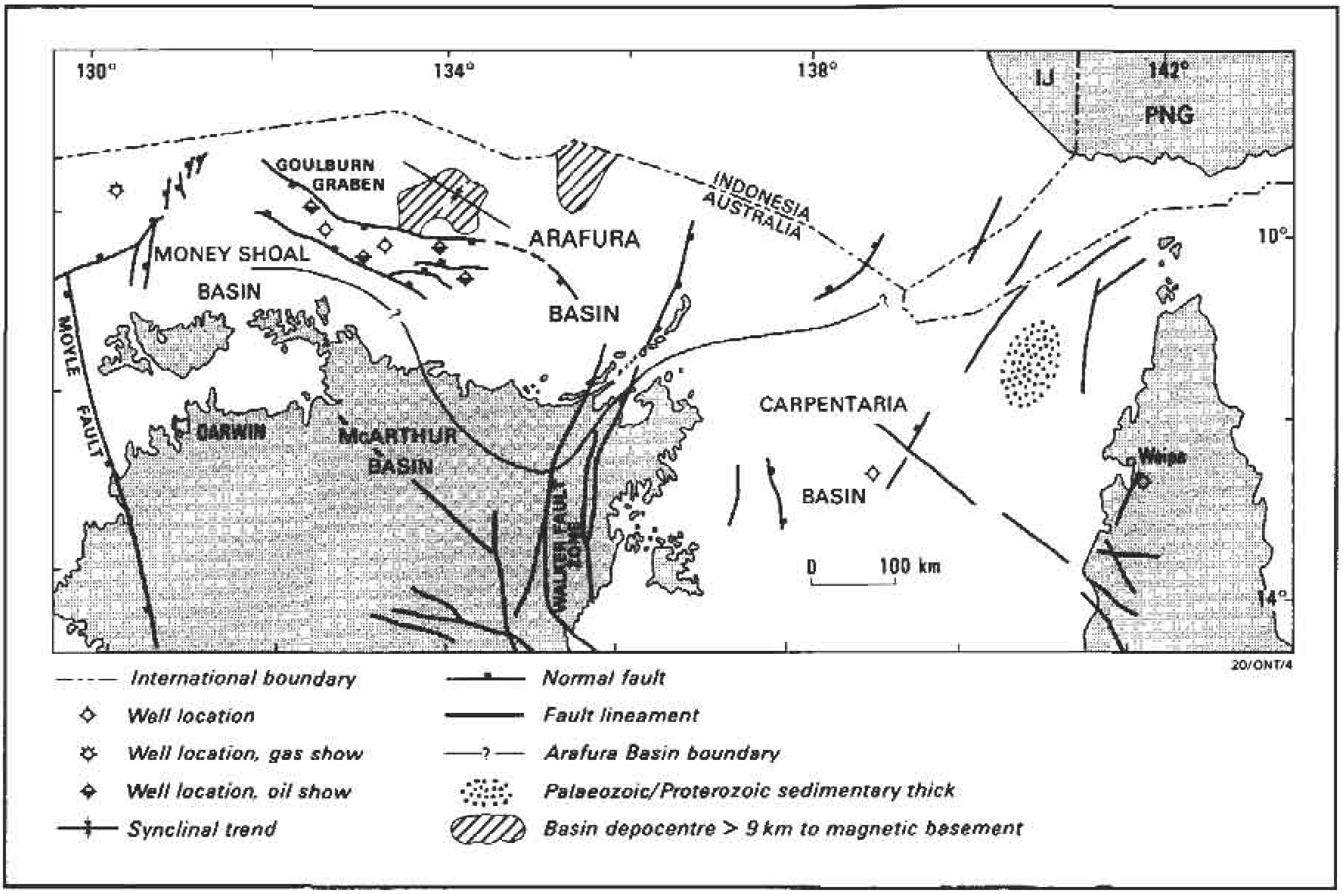


Figure 4 — Structural elements map northern Australia showing areas of thick sedimentary sequences (basin depocentre) identified by Balke & Burt (1976) from magnetics.

extent of the basin is very speculative but it may extend as far as the highlands of New Guinea where it would underlie Mesozoic and Cenozoic sediments (Fig. 1). In the Central Range of Irian Jaya, Ordovician graptolites have been described from outcrops of black shale (Fortey & Cocks, 1986). To the west the Arafura Basin sequence dips under the thickening Mesozoic and Cenozoic sediments of the Money Shoal Basin (McLennan et al., this volume). Onshore to the south, Middle to Lower Cambrian sediments of the Arafura Basin crop out and unconformably overlie the Proterozoic rocks of the McArthur Basin.

Early seismic and aeromagnetic data defined a series of thick sedimentary sequences extending from northern Australia towards New Guinea (Fig. 4) with a broadly defined 'pre-Mesozoic graben' (Balke & Burt, 1976). The graben is here called the Goulburn Graben after the North and South Goulburn Islands located immediately to the south of the structure. This term avoids duplication of pre-existing structural names (Money Shoal Basin/Graben and Arafura Basin/Graben) and prevents connotations which assume the terms Arafura Basin and Arafura Graben are interchangeable, as the graben represents only a very small component of the basin proper. Recent seismic data does not extend more than 15 km to the north of the graben, except for a few regional lines north and northeast of Arafura-1 which extend to the Australia–Indonesia border. The quality of these regional lines is poor, but they define a broad synclinal platform with regional highs, that is cut by localised fault blocks which contain at least 5 km of Palaeozoic sediments. Beyond the graben to the north and northwest of Torres-1, seismic character ties, regional structural trends and aeromagnetic data suggest that the majority of the thick Palaeozoic sequence is preserved (Fig. 6). This is contrary to previous interpretations which have largely ignored areas outside the graben, and thus raises a plethora of unexpected plays in that region.

To the north and northeast of the Wessel Islands (Figs 5, 7, 8 & 9), good quality early vintage seismic defines an extension of the Arafura Basin as far as the Indonesian border, where the sequence continues to dip and thicken to the north. The eastern limit of the basin is approximately a line between the English Company Islands and the junction of the Indonesia, Australia and Papua New Guinea border. The geologic nature of the eastern boundary is vague, but appears to principally be a truncation due to erosion of the Arafura Basin sequence. To the northwest of Weipa, northern Queensland, there is a seismically defined thickness (3–5 km) of truncated Palaeozoic and/or Proterozoic sediments that could be a remnant of the once more extensive Arafura Basin sediments (Fig. 4). By correlations

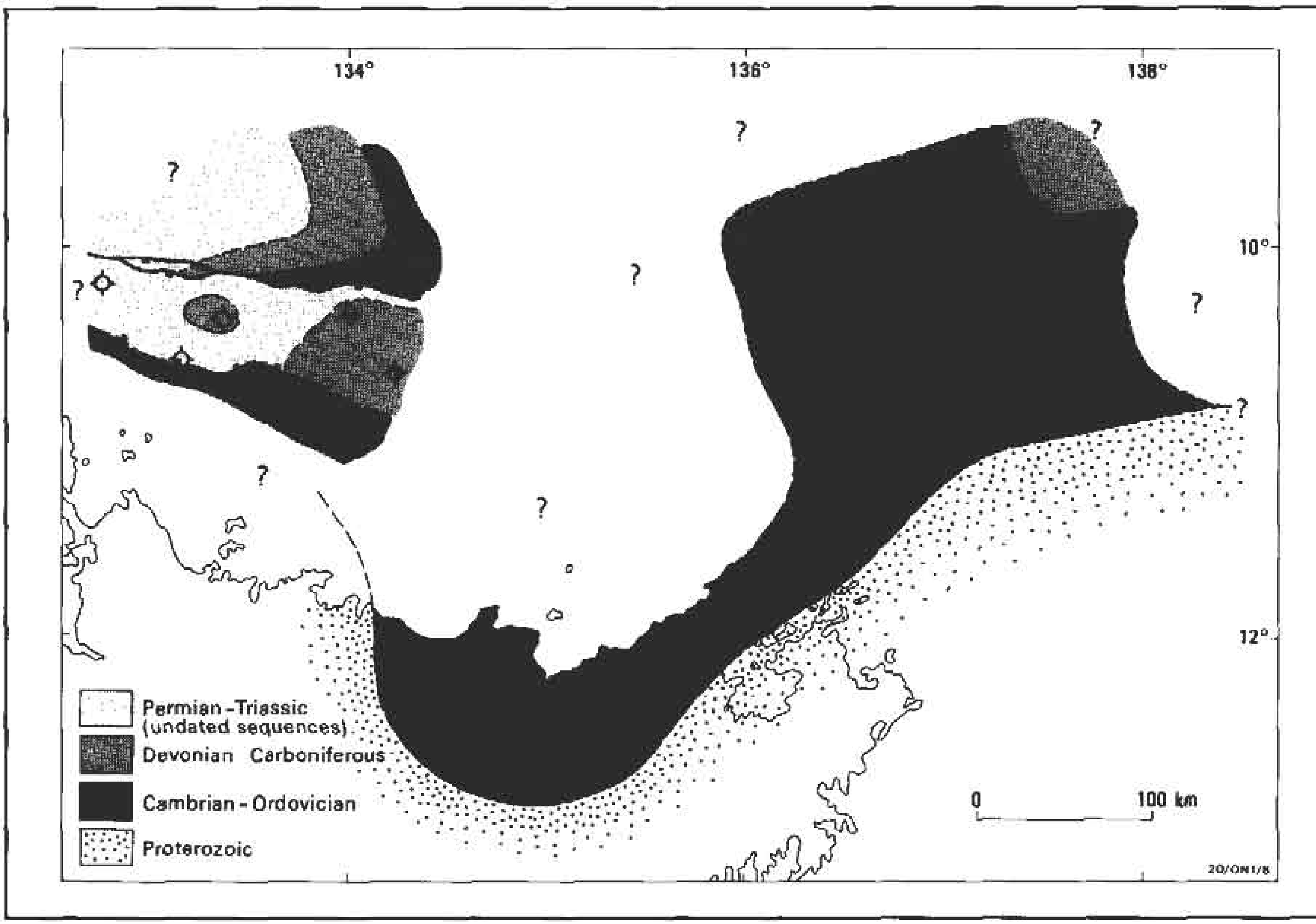


Figure 5 — Arafura Basin subcrop beneath the Mesozoic unconformity, compare with Fig. 3.

with magnetics (Robertson et al., 1976, Plate 3), additional remnants are believed to occur to the north in Papua New Guinea and elsewhere underlying the Carpentaria Basin.

STRATIGRAPHIC LIMITS

Initial identification of the Arafura Basin was based on mapping of the Wessel Group in the onshore segment of the basin which had variously been ascribed a range of ages from Permo-Carboniferous to Proterozoic (Plumb, 1965; Plumb et al., 1976). Isotopic dating of glauconite from the Elcho Island Formation (uppermost unit in the Wessel Group) on Elcho Island gave ages of 770 Ma (K-Ar) and 790 Ma (Rb-Sr), which were described as minimum ages (McDougall et al., 1965). These ages were used for the 1:250,000 geological map sheets over the region (Rix, 1964; 1965; Plumb, 1965; Dunnet, 1965). Subsequently, a trilobite fauna of Middle Cambrian age was recovered from the Elcho Island Formation, indicating a Middle to Lower Cambrian age for the Wessel Group (Plumb et al., 1976).

The base of the Arafura Basin sequence was believed to have been intersected in Arafura-1, where Upper Proterozoic sediments were interpreted from Rb-Sr radiometric dating of mica. The dates reported were 1750 to 2100 Ma ± 20 for detrital mica (coarse mica concentrates) and 760 to 480 Ma for post-depositional mica (whole rock) from

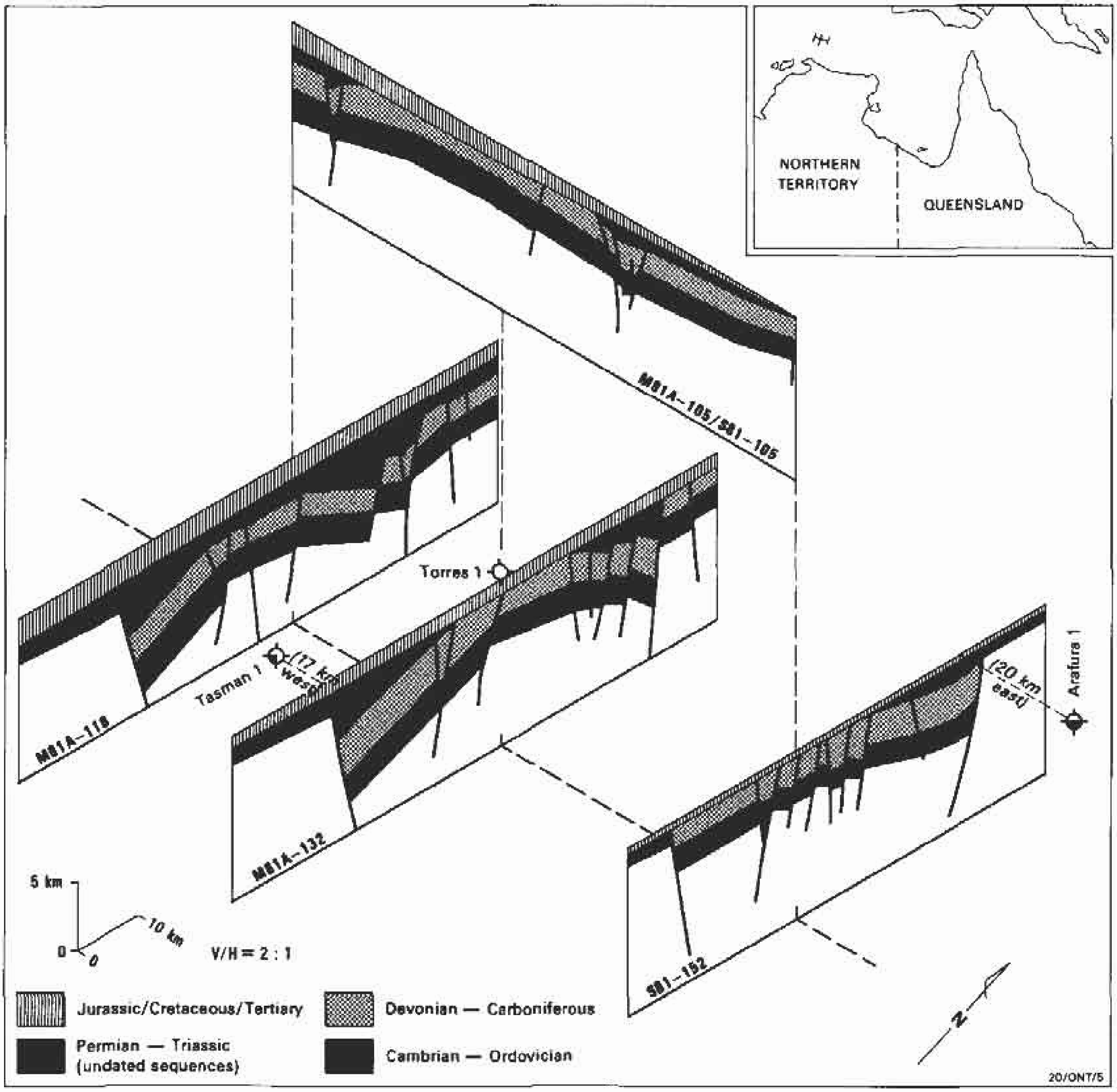


Figure 6 — Orthorhombic block diagram (in depth) of the central part of the Goulburn Graben.

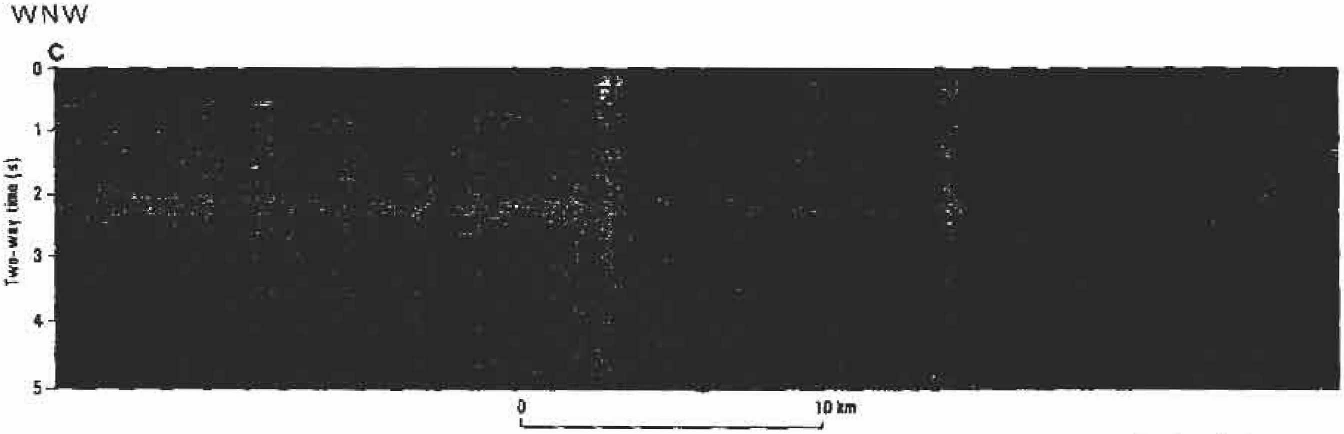


Figure 7 — Seismic line WM-2 (BEAVER), showing the offshore extension of the Walker Trough, dolerite sills in the Malay Road Group

a junk-sub sample of shale at 3614 m (Compston et al., 1982; Van Roye, 1983). A wide range of ages was quoted for the post-depositional mica as the relative proportions of post-depositional and detrital mica in the whole rock sample were not determined, and thus the age of the post-depositional mica is only a rough estimate. Subsequent examination in this study of cuttings and junk-sub samples, revealed a trilobite fauna, similar to that described from the Elcho Island Formation, over the interval of 3150 m to 3635 m (total depth), indicating that Arafura-1 only penetrated to the Middle Cambrian (Shergold, J., (BMR) & Bischoff G., (Macquarie University), personal communication, November 1989). Comparison of the lithostratigraphy at the base of Arafura-1 with the onshore sequence also strongly suggests that Arafura-1 terminated in the Elcho Island Formation (Fig. 10). Thus the radiometric dates derived from mica in Arafura-1 can be considered to be spurious, as was the dating of the glauconite on Elcho Island.

The top of the Arafura Basin sequence is represented by a major angular unconformity (Mesozoic unconformity – Figs 6, 11 & 12). The oldest date above the unconformity is Middle Jurassic (Bathonian – Tasman-1), whilst the youngest date beneath the unconformity is Late Carboniferous or Early Permian (Tasman-1). However, above the top Carboniferous horizon and below the unconformity on the downthrown side of the southern bounding fault of the Goulburn Graben, there is a 4–5 km (2 seconds TWT) section that has not been penetrated or dated (Figs 6, 11 & 12). Additional section would also undoubtedly have been deposited and subsequently eroded along the unconformity. As the Middle Cambrian to Carboniferous interval is only 5 km thick, the undated sequence must extend up through the Permian and Triassic. The age of the unconformity is probably Late Triassic to Early Jurassic. Drilling in the offshore Arafura Basin has penetrated sediments of Cambrian, Early Ordovician, Late Devonian, Late Carboniferous and Early Permian ages (Figs 13 & 10). The Arafura Basin sequence thus ranges from the Cambrian to the Permo-Triassic.

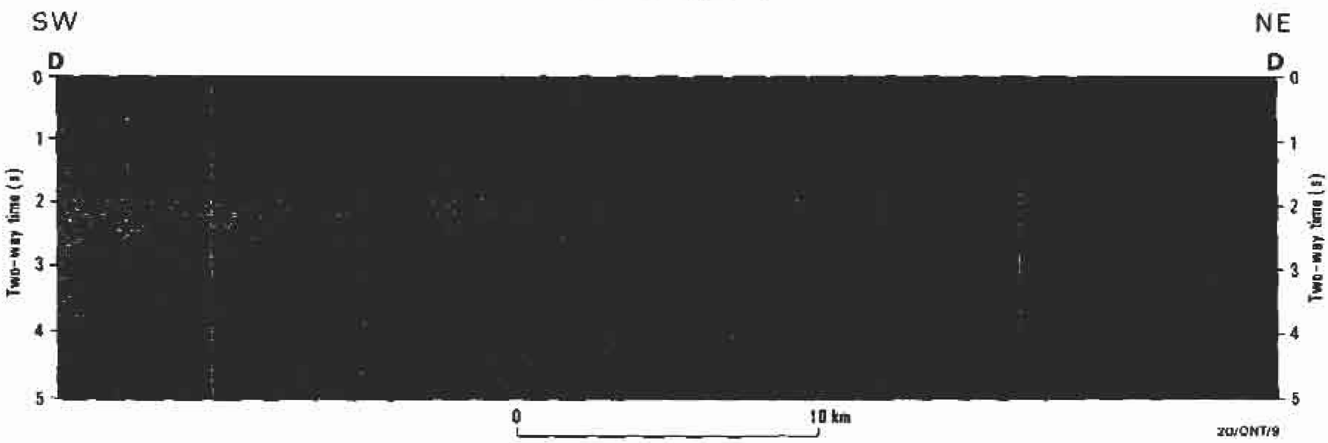


Figure 8 — Seismic line W-3ext (BEAVER), showing regional thickening of Proterozoic and Palaeozoic sequences to the Indonesian border. See Fig. 9 line D for location.

and fault blocks in the Wilberforce Beds. See Fig. 9 line C for location.

STRATIGRAPHY AND PALAEOGEOGRAPHY

CAMBRIAN

The Wessel Group crops out on the southern margin of the basin in Arnhem Land where a series of coarse to fine clastic rocks, with an aggregate thickness of 1500 m, has been recognised (Plumb, 1965; Plumb et al., 1976). It rests unconformably on the Proterozoic sediments of the McArthur Basin. The basal unit is the Buckingham Bay Sandstone which consists of coarse to fine grained sandstones and greywacke, and in its lower part contains the trace fossil *Skolithos* and is thus considered to be of Cambrian age. It is overlain by the Raiwalla Shale which is poorly exposed and is composed mostly of black to grey shale with minor beds of sandstone. This is overlain by the Marchinbar Sandstone and the uppermost unit exposed is the Elcho Island

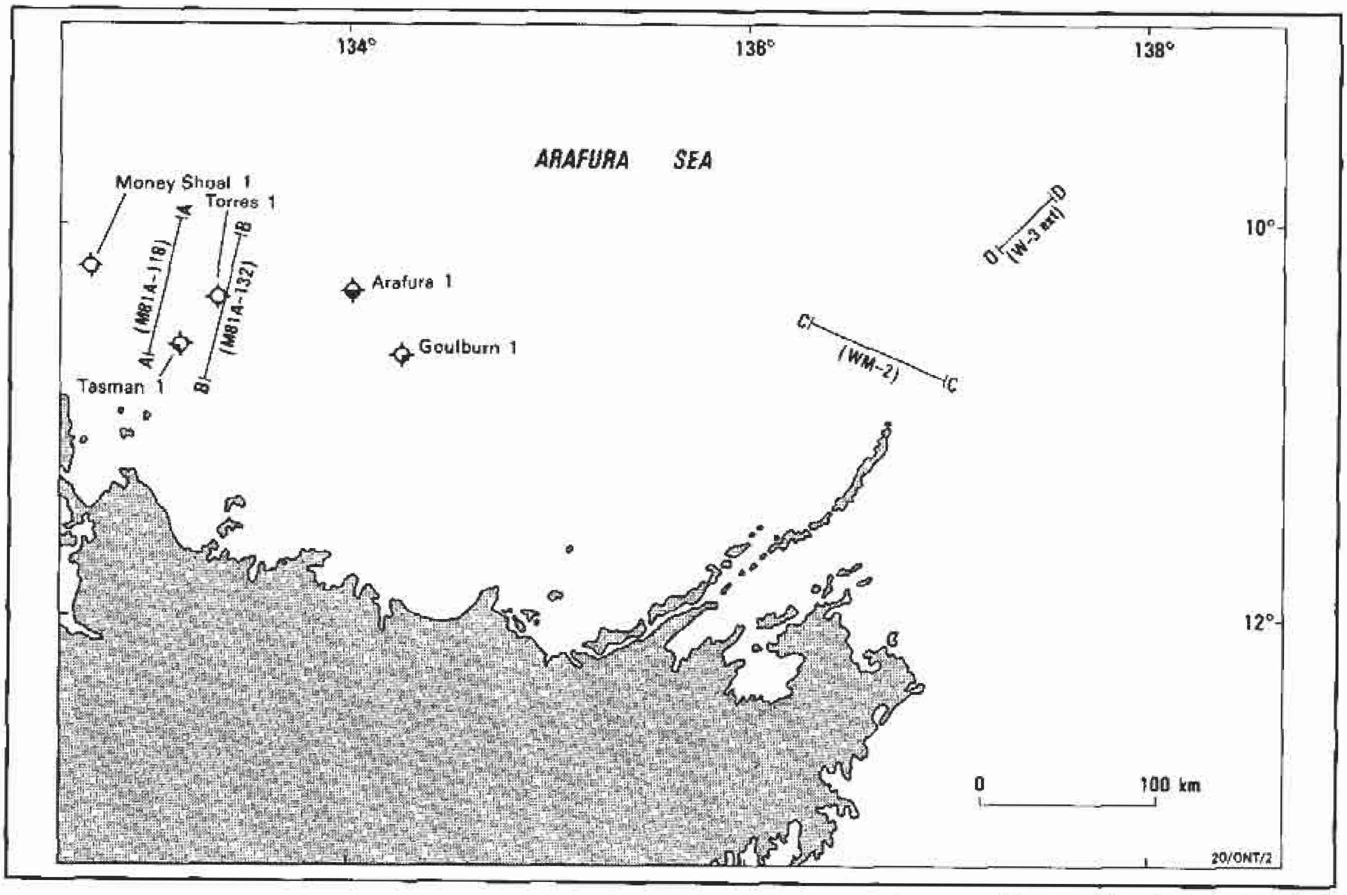


Figure 9 — Location map of Arafura Basin showing position of exploration wells and seismic lines illustrated in Figs 7, 8, 11 and 12.

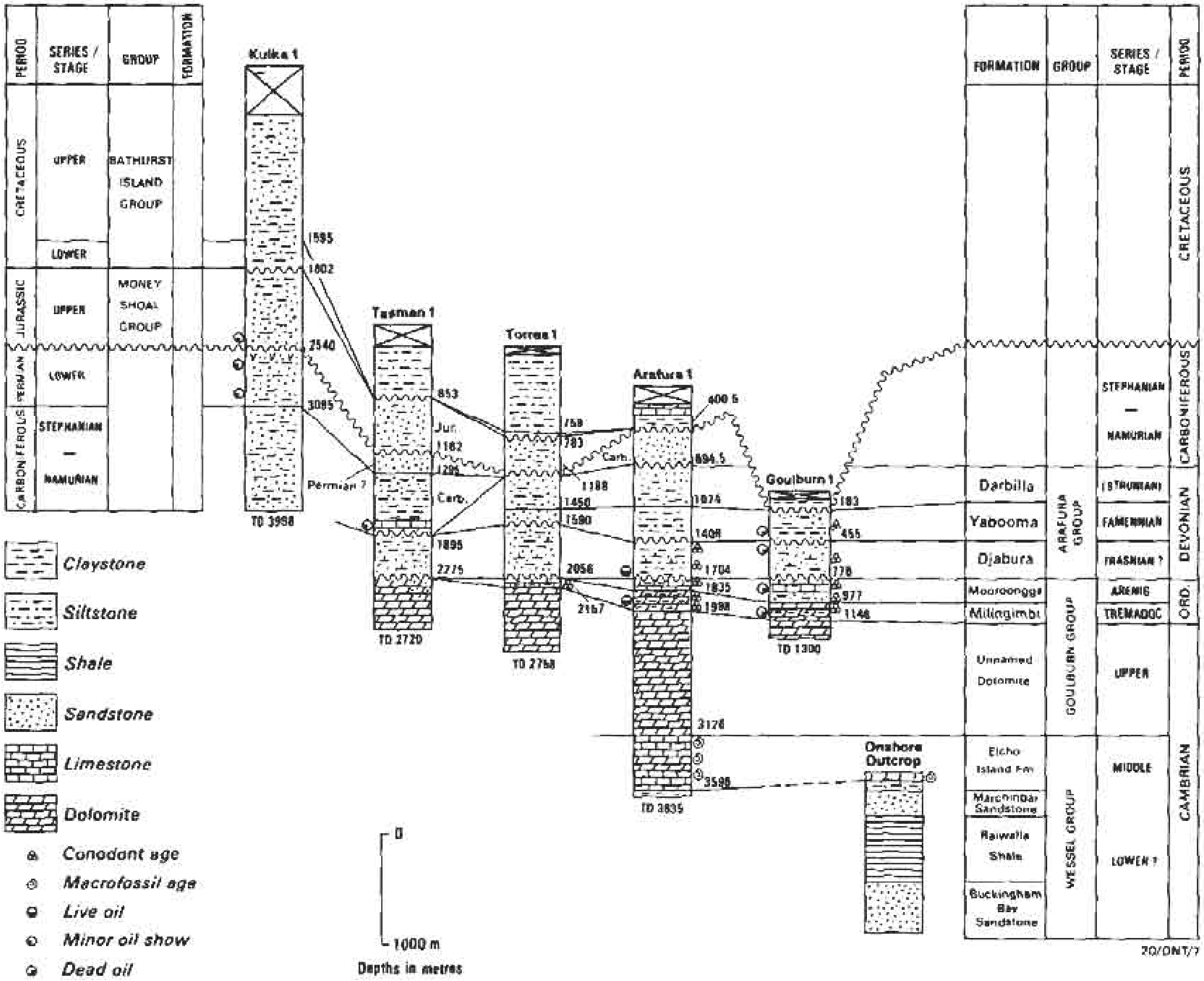


Figure 10 — Stratigraphic correlations from offshore wells and onshore outcrop in the Arafura Basin, showing location of detailed palaeontology and oil shows.

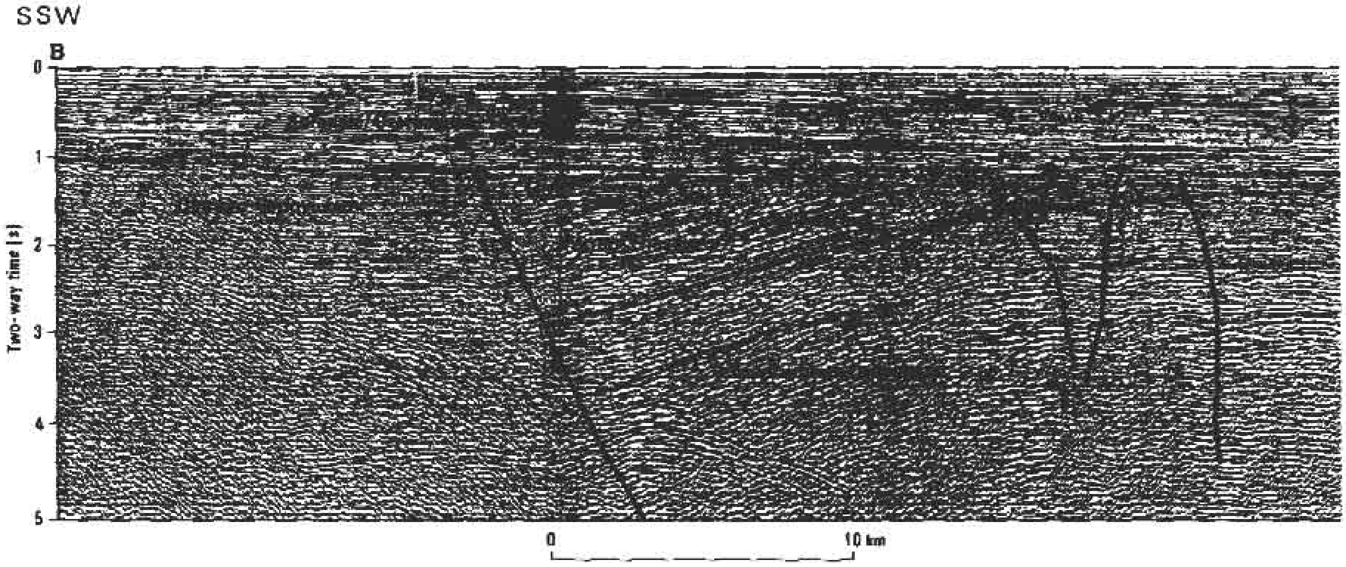


Figure 11 — Seismic line M81A-132 (ESSO) across the central part of the Goulburn Graben. See Fig. 9 line B for location.

Formation. The Elcho Island Formation consists of siltstones, glauconitic sandstones and dolomitic siltstones. Trilobites recovered from the top of the unit have been dated as Middle Cambrian (Plumb et al., 1976), which is the oldest precise date in the basin. Offshore seismic data shows eastward thickening of the lower part of the Cambrian sequence (Wessel Group) from east of Torres-1 along the graben towards the Wessel Islands (M81A-105 & S81A-105).

In the subsurface Cambrian sediments have been identified in four wells; Tasman-1, Torres-1, Arafura-1 and Goulburn-1 (Fig. 10). The most complete section is in Arafura-1 where 1637 m of dolomite and mixed carbonate and clastic sediments were penetrated. The other wells terminated at shallower depths in the upper part of the Cambrian. In Arafura-1 the interval 3126–3635 m (total depth) consists of interbedded limestone, shale and dolomite and contains a fauna (trilobites, phosphatic brachiopods) that correlates with the trilobite fauna recovered from the top of the Elcho Island Formation on Elcho Island.

The Elcho Island Formation is overlain by an unnamed dolomite that is 1128 m thick in Arafura-1 and was penetrated in Tasman-1 (445 m), Torres-1 (601 m) and Goulburn-1 (154 m). The dolomite unit lacks biostratigraphic control, but fauna in the base of the overlying unit provide a basal Ordovician (Tremadoc = Datsonian) age. This dolomite unit was previously considered to be of Ordovician age (Petroconsultants, 1989) and was included as the basal part of the Goulburn Group. The conodont fauna from the overlying Milingimbi Formation indicates that the top of the dolomite unit must be located within a very few metres of the base of the Ordovician. Regionally the dolomite unit correlates with the Chatsworth Limestone–basal Ninmaroo Formation of the Georgina Basin to the south and the Fengshan Formation (dolomitic carbonates) of the Sino–Korean platform to the west (Nicoll & Totterdell, 1990).

In the Cambrian the Arafura Basin was part of a broad, shallow continental shelf on the margin of the Australian block of the Gondwana continental mass (Nicoll & Totterdell, 1990). This shelf margin extended from what is now eastern Australia across the Arafura Basin and into the Sino–Korean Platform of North China. In the Early to Middle Cambrian the Arafura Basin area was the site of coarse to fine clastic sedimentation. By the Late Cambrian the Arafura and Sino–Korean areas had become the sites of extensive shallow water carbonate platforms.

ORDOVICIAN

The Ordovician is divided into two units, a lower Milingimbi Formation and an upper Mooroongga Formation. The Milingimbi Formation consists of mixed carbonate and clastic sediments and appears to be conformable on the underlying unnamed dolomite. The lower part is dolomitic, but becomes more terrigenous upward, with thin sandstones interbedded with carbonates and shales. The Milingimbi Formation has a maximum thickness of 169 m in Goulburn-1, thins by post-depositional (Devonian) erosion to 101 m in Torres-1 and is erosionally absent in Tasman-1 (Fig. 10). The Mooroongga Formation consists of shale at its base, but grades upward into more calcareous sediments with some chert. The top of the Mooroongga Formation was truncated by erosion prior to deposition of the overlying Devonian. The Mooroongga Formation is 201 m thick in Goulburn-1, erosionally thins to 131 m in Arafura-1 and is absent in both Tasman-1 and Torres-1. The conodont fauna from the Ordovician of Torres-1, Arafura-1 and Goulburn-1 indicate that the formations range in age from the earliest Ordovician to the mid-Arenig. Earlier identification of a Caradoc (Late Ordovician) age (Petroconsultants, 1989) for this interval was based on limited material from cuttings samples, but additional material has been examined from core 3 in

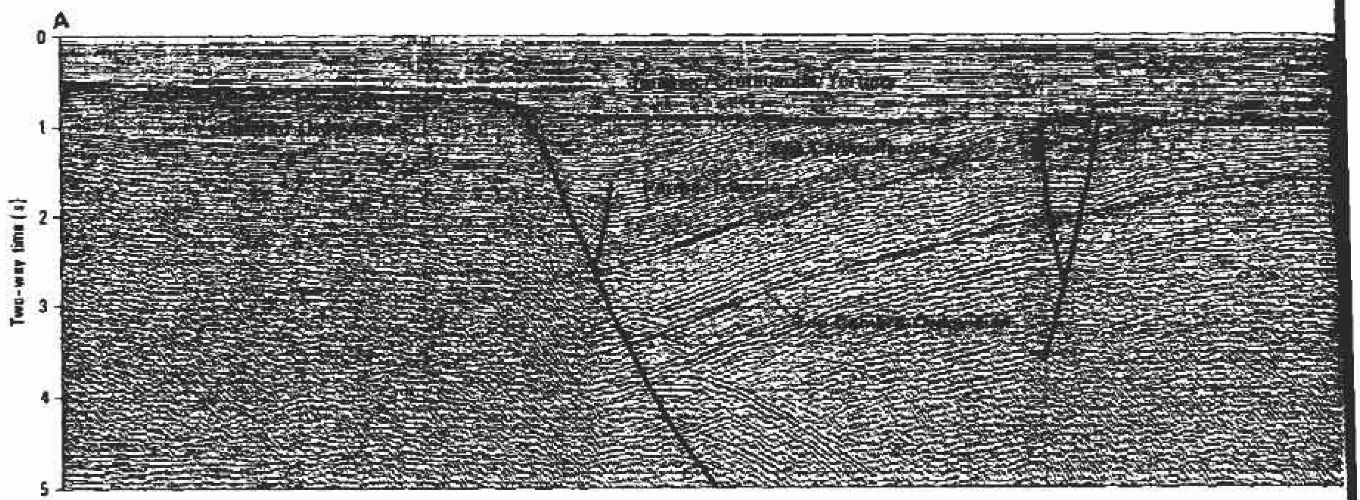


Figure 12 — Seismic line M81A-118 (ESSO) across the central part of the Goulburn Graben, 40 km northwest of Fig. 11. See Fig. 9 thickness of the Money Shoal Basin sequence above the unconformity relative to Fig. 11.

Arafura-1 (1714–1722.7 m) and confirms the Arenig age of the eroded top of the Ordovician.

During the Ordovician the character of the sediments changed from the carbonate platform of the Late Cambrian to a marginal shelf that was the site of mixed clastic and carbonate deposition. The southern part of the Arafura Basin represents the nearshore portion of the shelf and exposures of graptolitic black shale in the Central Range of Irian Jaya (Fortey & Cocks, 1986) represent the outer shelf margin or continental slope. Ordovician sediments were probably considerably thicker in the Arafura Basin prior to the episode of erosion before the deposition of the Devonian sediments. By comparison with sedimentation patterns in the Ordovician of the Canning and Amadeus Basins, an additional 100 to 200 m of marine sediments would have been expected to have been deposited by the end of the Early Ordovician (Darriwilian = Llandeilo).

SILURIAN

Sediments of Silurian age were reported in Money Shoal-1 (Balke & others, 1973) but subsequent dating (Robertson Research, 1982) indicates that the interval is probably Devonian. The time from the close of sedimentation in the Ordovician until the Late Devonian transgression is interpreted as a period of non-deposition with erosion over large areas of the basin. This is similar to the depositional history of the Amadeus Basin (Nicoll et al., in press) where the Silurian is represented, at least in part, by the aeolian Mereenie Sandstone, which was deposited over a long period of time under stable conditions.

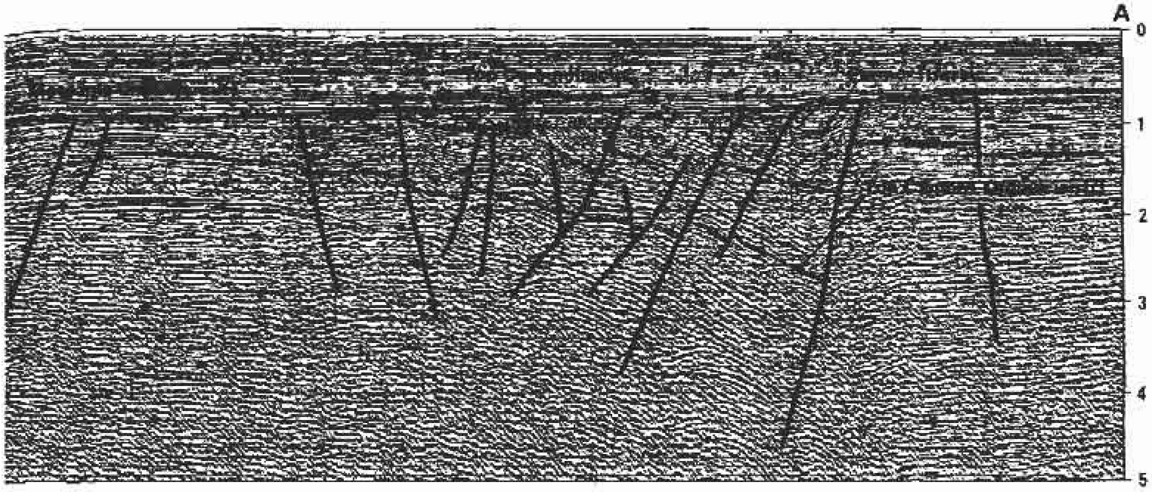
DEVONIAN

Devonian sediments were encountered in the Goulburn-1, Arafura-1, Torres-1 and Tasman-1 wells. There may be a thin interval of Devonian rock in Money Shoal-1 but this has not been definitely established. The Devonian is thickest in Arafura-1 (1009.5 m) but is thinner in the other wells as a result of erosion prior to the deposition of the succeeding Carboniferous sediments.

The Devonian rests unconformably on eroded Cambrian and Ordovician sediments and is represented by two transgressive intervals, separated by a relatively short period of emergence with only minor erosion (Nicoll et al., in prep.). The Devonian can be divided into three units. The lowest, the Djabura Formation, consists of interbedded shales, siltstone and thin limestones, and has been dated as Late Devonian in Arafura-1 and Goulburn-1. Palynology studies in Tasman-1 and Torres-1 indicate that the base of this interval could be as old as late Givetian, but the conodont faunas strongly support the younger age. The Djabura Formation is 466 m thick in Torres-1, but this may include some thickness of the overlying Yabooma Formation. The unit is 295 m thick in Arafura-1, 380 m in Tasman-1 and 321 m in Goulburn-1. Some of this variation in thickness may be related to the west to east transgressive nature of the Devonian, and to the possibility of erosion prior to deposition of the overlying Yabooma Formation.

The Yabooma Formation consists of interbedded sandstones, siltstones and shales with minor amounts of carbonate. Conodonts from core in Arafura-1 at the top of the Djabura Formation and from core at the base of the Yabooma Formation in Goulburn-1 wells establish a stratigraphic break between the two units. The Yabooma Formation is 335 m thick in Arafura-1, 272 m in Goulburn-1, 140 m in Torres-1, but is absent in Tasman-1 as a result of erosion prior to deposition of the Carboniferous (Namurian) sediments.

The Darbilla Formation consists of siltstones, sandstones



line A for location. Note the continuation of the Arafura Basin sequence outside the graben to the north, and the increase in the

and shales and is preserved only in Arafura-1 where it is 379.5 m thick and in Torres-1 where it is 262 m thick. The unit does not contain marine fossils and may represent a non-marine regressive sequence (Petroconsultants, 1989).

The Devonian sediments in the Arafura Basin were deposited in a shallow water, nearshore marine environment. Two sequences are evident which correspond to two maximum flooding events in the Late Devonian sea level curve (Johnson et al., 1985). The Devonian probably thickens to the west or northwest towards the shelf margin. The uppermost unit of the Devonian was deposited during the regression prior to a period of emergence and erosion in the Early Carboniferous.

CARBONIFEROUS

Upper Carboniferous sediments (Namurian to Stephanian) have been intersected in Arafura-1 and Tasman-1 (Fig. 10). The basal 89 m of the Carboniferous section in Tasman-1 is composed of Namurian micritic and peloidal limestones interbedded with thin sandstones, claystones and siltstones. Both limestones and sandstones are glauconitic and lacking in visible porosity. Overlying the limestones is over 500 m of non-marine clastics, predominantly siltstones with minor sandstone and shale, and occasional fresh volcanic fragments. In Arafura-1 only the non-marine clastics are represented and are coarser grained, being predominantly sandstones with minor grey and red claystone bands. No Carboniferous was identified in Torres-1 or Goulburn-1. The dating in Kulka-1 is poor, but includes probable Late Carboniferous ages, for approximately 900 m above total depth. The section is composed of interbedded very fine grained glauconitic sandstones, siltstones and silty and carbonaceous claystones. Volcanic rock fragments are common.

The limestones in Tasman-1 indicate that there was a Late Carboniferous marine transgression from the west that penetrated into the Arafura Basin. Limestones of similar age have been identified in Irian Jaya (Nicoll, 1981), documenting the widespread nature of this transgression on the northern shelf of the Australian block. During the following regressive phase, fluvial clastics were deposited in the eastern part of basin, while finer grained marine clastics were deposited in the west. The palaeoshoreline shifted westwards to lie somewhere between Tasman-1 and Kulka-1.

PERMO-TRIASSIC

Possible Permian sediments (Stage II) have been identified in Tasman-1 and Kulka-1. In both cases the diagnostic Late Carboniferous *S. ybertii* palynomorph occurs within these sediments but is interpreted as having been reworked. In Tasman-1 the Permian section consists of over 100 m of grey pyritic siltstones with minor glauconitic sandstones and shales, that are partly carbonaceous. Fine grained glauconitic clastics with volcanic fragments that characterise the Upper Carboniferous continue into the Permian section in Kulka-1. A dolerite dyke was intersected 15 m below the Mesozoic unconformity, and its date of 293 ± 3 Ma (K-Ar) (Diamond Shamrock, 1985) supports a Permian age for the sediments according to the revised Carboniferous time scale of Jones (in prep.). The limited well data indicate that Early Permian environments in the western Arafura Basin were marine to paralic with contemporaneous volcanic activity.

Seismic records show that 4 to 5 km of sediment interpreted as being Permo-Triassic in age (Fig. 6) lies stratigraphically above the penetrated Carboniferous section. This sequence is preserved beneath the Mesozoic unconformity in wedges adjacent to the bounding faults in the central parts of the graben (Figs 11 & 12). Correlations with neighbouring basins (Fig. 13) suggest that the sediments may be predominantly clastics of mixed terrestrial to marine facies, with the strong likelihood of Early Triassic shale deposition, related to elevated sea levels.

During the Permian and Triassic, the Arafura Basin was one of a number of northwest facing embayments along the Australian margin of Tethys (Bradshaw et al., 1988). The influence of the Late Carboniferous–Early Permian Gondwanan glaciation was less pronounced than in the Bonaparte and Canning basins (Fig. 13) that were located closer to the pole.

JURASSIC AND YOUNGER

Unconformably overlying the Arafura Basin is the Jurassic and younger sequence of the Money Shoal Basin. The oldest sediments immediately overlying the unconformity, as indicated by well control, are Bathonian. The Money Shoal sequence is flat lying and thickens to the west. It is composed of Jurassic and Cretaceous clastics and Cenozoic carbonates.

STRUCTURE AND TECTONICS

PROTEROZOIC

A Middle Proterozoic phase of extension produced the Batten and Walker Troughs which trend north-south (Plumb and Wellman, 1987). The rocks deposited in the Walker Trough were uplifted and eroded later in the Proterozoic in the Walker Fault Zone, a feature that can be extrapolated offshore from the Wessel Islands to the north (Fig. 4). Its offshore seismic expression (Wessel Rise-Nicol, 1970) is very poor, but onshore the Cambrian sediments appear to have been deposited across this feature with minimal onlap or thinning. Thus the Wessel Rise is confined mostly to the Proterozoic with very minor reactivation in the Phanerozoic. To the north of the Wessel Islands the Proterozoic McArthur Basin sequence, underlying the Arafura Basin, is very distinctive on seismic lines (Figs 7 & 8), showing probable Proterozoic dolerite sills and regional unconformities. The Arafura Basin disconformably overlies the Malay Road Group (Roper Group equivalent – Jackson et al., 1988), representing a 900 Ma hiatus between the Cambrian and Middle Proterozoic. The Wilberforce Beds (McArthur Group equivalent – Jackson et al., 1988) unconformably underlie the Malay Road Group with a contact that is either a peneplained angular unconformity, or perhaps consists of tilted fault blocks over which the Malay Road Group was deposited.

Northwest striking lineaments dominate the onshore and offshore geology of the northern half of the Northern Territory, overprinting both the Arafura Basin and McArthur Basin sediments. It is a fundamental direction of weakness that recurs across northern Australia (Fig. 4), and may pre-date the Middle Proterozoic Batten and Walker Trough (Plumb & Wellman, 1987). The Goulburn Graben is aligned northwest, paralleling this structural trend and the current coastline. Faulting within the graben also is dominantly aligned sub-parallel to this trend (Petroconsultants, 1989). Outside the graben the data is too sparse to reliably comment on the trend and extent of faulting.

ORDOVICIAN

A major time break is evident from the biostratigraphy between the Early Ordovician & Late (or late Middle) Devonian (Fig. 13), and correlates with the Rodingan Movement in the Amadeus Basin (Bradshaw & Evans, 1988). Comparison of Tasman-1 and Goulburn-1 (Fig. 10) suggests that a minimum of 400 m of the Ordovician and Upper Cambrian in the Arafura Basin was eroded at this stage. More uplift and erosion may have occurred given the length in time of the hiatus and by correlation with the Amadeus and Canning Basins where there was significant uplift and erosion (Fig. 13). As the erosional thinning of the Ordovician in the Arafura Basin is from the east to the west (Fig. 10), tilting and uplift must have occurred in the west, opposite to the current northwesterly regional dip.

DEVONIAN AND CARBONIFEROUS

The Devonian to Carboniferous time break in the Arafura Basin (Fig. 13) may equate with the Mt Eclipse Movement, which was the major folding event in the Amadeus Basin (Bradshaw & Evans, 1988). As Tasman-1 contains less total Devonian sediments than Arafura-1, Torres-1 or Goulburn-1 (Fig. 10), it appears that tectonic movement occurred on the southern bounding fault between the Late Devonian and middle Carboniferous. The presence of a significant thickness of Lower Carboniferous sediments in the Bonaparte Basin, internally separated by an angular unconformity (Mory, 1988), and their absence in the Arafura Basin indicates that the effects of the Mt Eclipse Movement in central Australia were recorded on the northern margins of Australia.

PERMO-TRIASSIC

Maturation data from conodonts suggests that substantial burial occurred at Torres-1 (from 3–6 km on top of the Mesozoic unconformity) and to a lesser extent at Tasman-1 (from 2 to 4 km on top of the Mesozoic unconformity) (Fig. 14) prior to uplift and erosion. These thicknesses compare favourably with the estimated thickness of Permo-Triassic that seismic data indicates should have buried these areas (4–5 km) (Figs 6, 11 & 12). In Arafura-1 and Goulburn-1, conodont colour alteration index (CAI) data indicate that this part of the basin has not been buried much deeper than presently recorded (Fig. 14), suggesting that there was little Permo-Triassic sedimentation in the east.

On the southern flank of the anticline on which Torres-1 was drilled, and adjacent to the southern bounding fault, there is a sequence boundary marked by truncation within the Permo-Triassic sequence (1.3 seconds (TWT) above the top Carboniferous seismic line M81A-109) with successively more of the sequence having been eroded in a southeasterly direction. This horizon is also the level at which a subsidiary of the southern bounding fault terminates, indicating movement in the Permo-Triassic. In Kulka-1 a dolerite sill intrudes these sediments (Diamond Shamrock, 1985) and has a K-Ar radiometric date of 293 ± 3 Ma (Early Permian – Jones, in prep.). A brief thermal event has been postulated at around 290 Ma for the Arafura Basin from analyses of fission track data (Petroconsultants, 1989). The significance of these events can not be fully evaluated because this

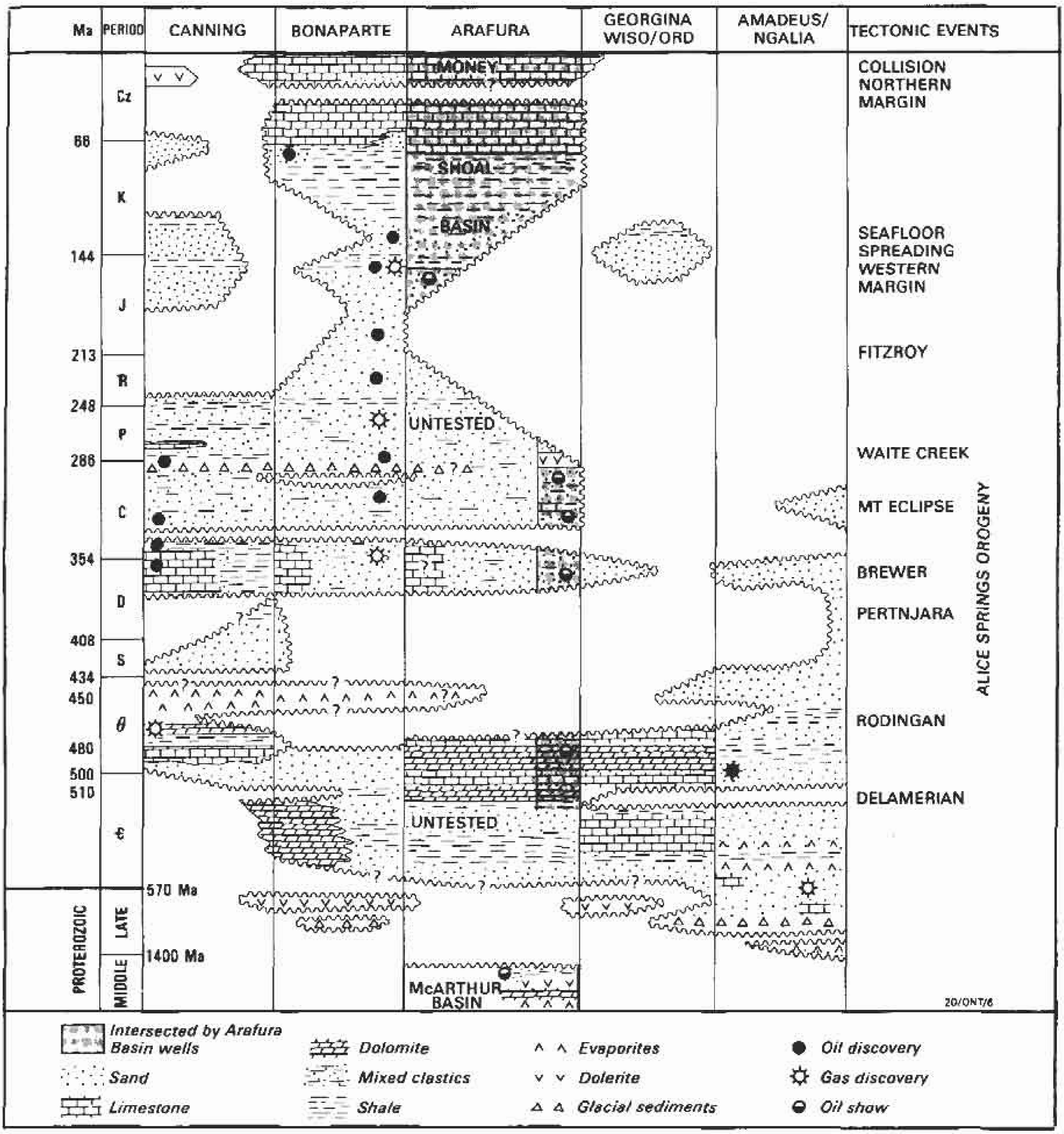


Figure 13 — Lithostratigraphy, petroleum occurrences and key tectonic events of northern Australian basins, shading indicates section penetrated in the Arafura Basin. Compiled from Bradshaw & Evans (1988), Goldstein (1989), Jackson et al., (1988), Lavering & Ozimic (1989), Shergold et al., (1985) and Wells & Moss (1983).

interval is rarely preserved, being eroded by the unconformity. However, when compared with the maturation data suggesting a thicker Permo-Triassic sequence in the northwest, and evidence of increased truncation in the southeast, it suggests that tilting to the northwest commenced during the Permo-Triassic.

POST MID-JURASSIC

The combination of uplift and erosion produced a peneplained unconformity surface that dips at one degree to the northwest in the western part of the basin (Fig. 3). Subsequent differential subsidence has occurred to allow thicker development of post mid-Jurassic sedimentation within the Goulburn Graben, as well as minor reactivation along the major faults.

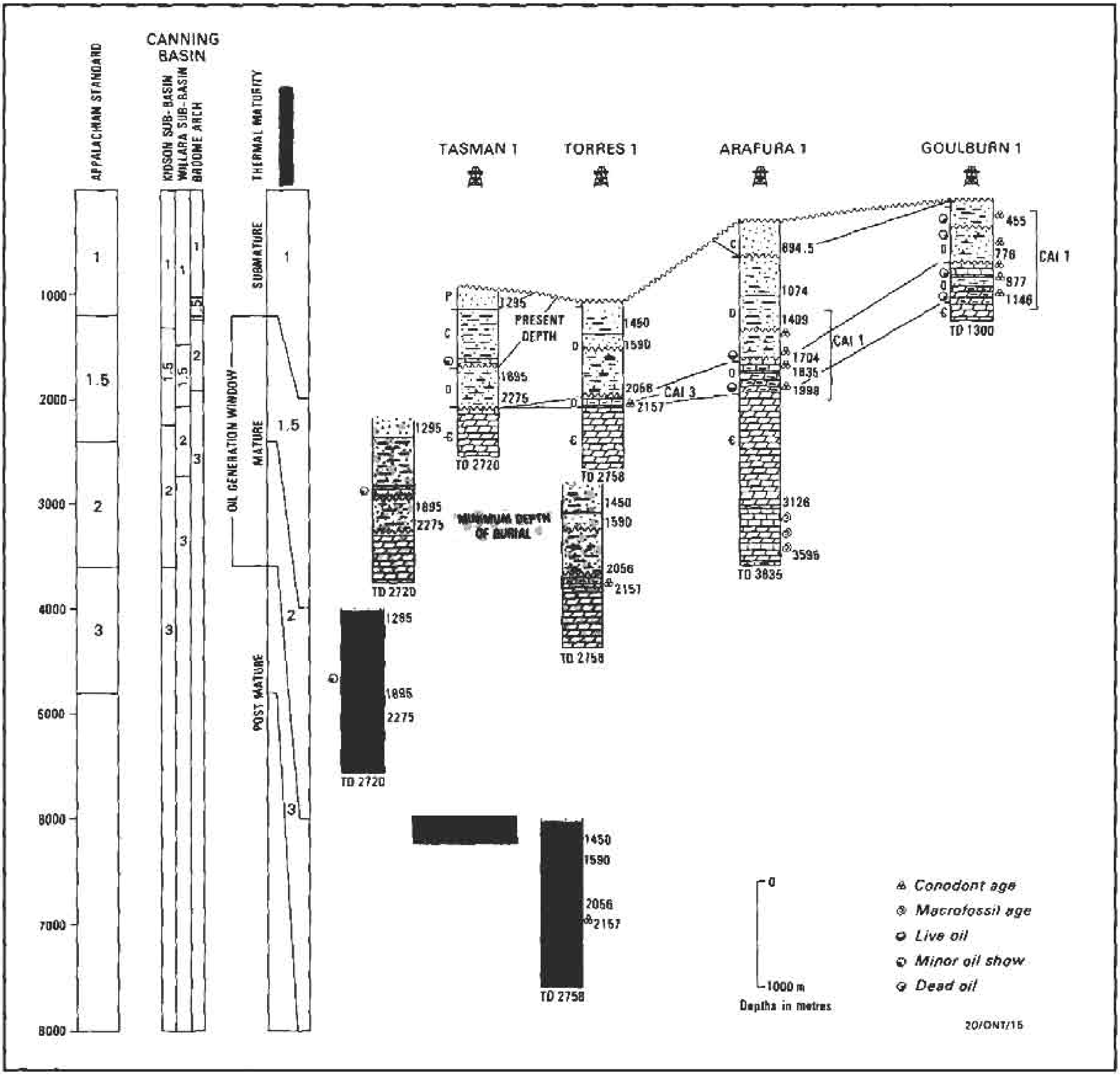


Figure 14 — Arafura Basin thermal maturation ranges from conodont alteration indices (CAI) and vitrinite reflectance. Upper columns plot wells at present depths, middle columns in light shading, show Tasman-1 and Torres-1 at the minimum depths indicated by thermal maturation indices, and lower columns in heavy shading, plot Tasman-1 and Torres-1 at the maximum depths indicated. Arafura-1 and Goulburn-1 are currently at their maximum depths of burial. Comparison with the Appalachian Standard and Canning Basin CAIs (Nicoll & Gorter, 1984) suggests lower geothermal gradients in the Arafura Basin.

GRABEN DEVELOPMENT

Timing

The Arafura Basin sequence comprises pre-rift sediments that were deposited on a broad platform during the Palaeozoic, and preserved within the Goulburn Graben when it developed in the Permo-Triassic. This is indicated by:

1 the lateral continuity of at least the Cambrian to Carboniferous (± Permian) sequence on seismic data outside the graben, north to the Australia–Indonesia border,

2 the absence of angular unconformities on seismic data despite major time breaks between both the Early Ordovician to Late Devonian and Late Devonian to Late Carboniferous (Fig. 13),

3 the lack of thickening of Cambrian to Carboniferous sediments into the major bounding faults,

4 the eastward thickening along the current graben of both the Cambrian and Ordovician sequences, opposite to both the present regional dip and the Permo-Triassic thickening trends, and

5 minimal extension (3 per cent) on the Devonian horizon along line M81A-132 (section B, Fig. 6).

Petroconsultants (1989) suggest that in the Devonian to Carboniferous there was local thickening into intra-graben fault blocks, but no evidence is available of thickening into the major graben bounding faults during that time. The fission track data and the age of the dolerite dyke in Kulka-1 indicates a brief period of thermal heating and intrusion of dykes in the Early Permian, but these events can precede structural deformation, or coincide with it (Rosendahl, 1987). Plate reconstructions of the northern margins of Australia show that gradual separation of the Australian and the Shan Thai–Malayan palaeocontinents began in the Early Permian, with rapid acceleration in separation during the Middle Triassic (Gahagan & Ross, 1987; McKerrow & Scotese, 1990).

Regional tilting and uplift may have triggered or accentuated extension within the Goulburn Graben during the early part of the Permo-Triassic, producing regional westward thickening. The precise order and timing of extension, faulting, folding and uplift of the Goulburn Graben will never be clear because of the erosion of the Permian and Triassic sequences. Thus the age of the major movement on the northern and southern bounding faults of the Goulburn Graben is loosely confined between the Permo-Triassic and the development of the Mesozoic unconformity, which is presumed to be Late Triassic to Early Jurassic.

Tectonic Style

The Goulburn Graben formed by oblique extension in the Permo-Triassic as the Australian and Shan Thai–Malayan palaeocontinents diverged. The graben was initiated by regional tilting to the west as the plates separated in a northwest direction (Gahagan & Ross, 1987; McKerrow & Scotese, 1990). The steepness on the graben bounding faults (65–85°) may indicate that although they have a net normal displacement (8 km – south bounding fault and 5 km north bounding fault), they also could have strike-slip displacement. If they formed during the tilting to the west in the Permo-Triassic, then significant amounts of lateral movement would have occurred along them. A negative flower structure occurs in the centre of the graben suggesting oblique extension (transtension) (Fig. 6 – M81-105/S81-105).

Folding is most abundant in the central and western parts of the Goulburn Graben where thick Permo-Triassic sediments were deposited, whereas in the east, only middle and lower Palaeozoic sediments were deposited, and block faulting predominates. This suggests that the structural elements that controlled tilting to the west and thick Permo-Triassic sedimentation were also critical in determining the location of the later folding. If the compressive forces responsible for the folding originated from outside the Arafura Basin, then they must have been transmitted through the stable platforms without deforming them, and selectively shortened the graben which had previously been weakened by extension and tilting. However, regional plate reconstructions suggest that no major compressive events occurred on the flanks of the Arafura Basin during the Permian to Jurassic (Gahagan & Ross, 1987)

The Torres-1 anticline is asymmetrical across strike, as the northern side is deformed and faulted whereas the southern side comprises continuous beds dipping uniformly at 10–15° without major faulting for 25 km (Figs 11, 12 & 6). Along strike (Fig. 6 – M81A-105) the anticline has the appearance of an inverted 'keystone block'. The asymmetrical shape and deformation of the anticline, and regional plate configurations indicate that the uplift and folding was not produced by pure compression but may have had significant oblique components (transpression), with rotation on the bounding faults contributing to uplift of the centre of the graben (Torres-1).

NORTHERN PLATFORM

Deformation of the platform to the north during development of the graben was comparatively minor. The regional seismic lines which continue northeast to the Australian–Indonesia border show only minor fault block development, although there are regional highs adjacent to the graben which dip northeast. There is at least a middle and lower Palaeozoic section all the way from the Goulburn Graben to the Australia–Indonesia border which is comparable in thickness and character to that within the graben. To the north and northeast of the Wessel Islands, the regional dip is to the northeast with perhaps upper and definitely lower Palaeozoic sequences beneath the Mesozoic unconformity (Figs 7 & 8).

PETROLEUM PROSPECTIVITY

Oil shows in offshore wells at five different stratigraphic levels and reported in situ occurrences of bitumen (Table 1) attest to the Arafura Basin being petroliferous. Beach strandings (Fig. 2 & Table 1) are more ambiguous pieces of evidence. Preliminary geochemical findings (R. Summons, BMR, personal communication, December 1989) indicate a

Elcho Island	Bitumen in outcropping Wessel Group sandstones (Wade, 1924) and beach strandings (Plumb, 1965).
Cobourg Peninsula, Bathurst &Melville Islands	Bitumen strandings along beaches and headlands (McKirdy & Horvarth, 1976).
Mountnorris Bay, Cobourg Peninsula	Bitumen adhering to rocks, outcropping Cretaceous? (Hughes &Senior, 1973).
Arafura 1	Oil bleeding from cores in Devonian (1419-1437m) and Ordovician (1842-1846m) sequences, oil stained cuttings in Devonian (1437?-1704m), oil in the mud and cuttings from Ordovician (1835-1855m). DST in Ordovician (1837-1855m) recovered salty water.
Tasman 1	Oil shows, fluorescence and cut in Carboniferous (1830-1850m). RFTs (1829-1853m) and DSTs (1803-1877m) mechanically unsuccessful and inconclusive.
Kulka 1	Oil shows, intermittent fluorescence and cut in Jurassic (2318-2450m) and Permian(?) (2618-3147m). No tests.
Goulburn 1	Dead oil/bitumen shows in Devonian (420-532m) and Ordovician and Cambrain (808-909m & 970-1300m). No tests.

Table 1 — Hydrocarbon occurrences in the Arafura Basin.

Cretaceous or younger source for one sample from the Cobourg Peninsula, as suggested by McKirdy & Horvath (1976). Samples from Elcho Island, which is located in the eastern part of the basin where the Mesozoic is thin and Palaeozoic and Proterozoic sediments dominate the section, have not been examined geochemically. Exploration to date has been disappointing and any analysis of the petroleum prospectivity of the Arafura Basin must consider the earlier tests.

WELL RESULTS

Table 2 lists information concerning the six wells drilled to date into the Arafura Basin sequence. Money Shoal-1 was a Mesozoic test and Torres-1 was overmature and tight due to excessive burial. All the other wells had oil indications of varying degree (Table 1), but the lack of discoveries highlights the major risks of porosity and trap integrity. Primary porosity in sandstones is commonly occluded by silica cements and the carbonates are usually tight. Porosity was encountered in some sands and in vugs and fractures in dolomitised carbonates. Factors inhibiting fault seal include the brittle character of the section, the lack of a thick shale in the Ordovician to Carboniferous sequence, and later reactivation of faults.

PLAY ANALYSIS

Source

The well results indicate four viable source rock intervals (Table 2) and regional correlations suggest at least two others. The Arafura Basin is underlain by the Proterozoic McArthur Basin sequence which onshore has recorded recovery of live oil and TOC contents up to 7.2 per cent in the Velkerri Formation of the Middle Proterozoic Roper Group (Jackson et al., 1988). The Velkerri Formation is interpreted as a marine shale and so should have a predictable and widespread occurrence with the likelihood of an equivalent unit being present in the offshore. Plays in the Proterozoic and Cambrian sequence as described by Jackson et al. (1988) have the potential to occur in the eastern, shallower parts of the Arafura Basin (Table 3). Apart from directly sourcing into overlying Cambrian or younger sands across the Proterozoic unconformity, McArthur Basin hydrocarbons could migrate up faults into younger section in the more deformed western segment of the basin. The Roper Group is not overmature throughout much of the McArthur Basin (Jackson et al., 1988) and geothermal gradients have apparently been low in the Arafura Basin as indicated by CAI data (Fig. 14). It is notable that in the late Proterozoic, northern Australia and Oman were located along the northern margin of Gondwana facing onto the Tethyan ocean, and that the late Proterozoic in Oman has sourced 12 thousand million barrels of reserves (Al-Marjeby & Nash, 1986; Fritz, 1989).

The highest TOC contents reported from the Arafura Basin are from the Elcho Island Formation of the Wessel Group (8.65% in Arafura-1). The phosphatic and organic rich Beetle Creek Formation from the Georgina Basin is an age equivalent of the Elcho Island Formation (Shergold et al., 1985). The Raiwalla Shale, known only from poor onshore outcrop (Rix, 1964, 1965; Plumb, 1965), has the potential to be another Cambrian source rock interval. It is a probable age equivalent of the petroliferous Chandler Formation in the Amadeus Basin which has produced numerous oil and gas shows (Bradshaw, in press). The Raiwalla Shale may be up to 1000 m thick (Rix, 1965) and has a higher proportion of fine grained lithologies than the overlying Elcho Island Formation and so may have a greater thickness of source rock facies. No high TOC

Table 2 — Well information from the Arafura Basin.

	COMPANY YEAR T.D.	RESERVOIRS	SOURCE % TOC	SEAL	SHOWS	TRAP/RISKS
MONEY SHOAL 1	SHELL 1971 2590 m	Pz SST Poor-good ø	——	POSSIBLE INTRA FM SEAL IN Pz	——	GRABEN MARGIN FAULT BLOCK, DRAPE ANTICLINE *IN Mz, NOT VALID Pz TEST*
TASMAN 1	ESSO 1983 2720 m	PERM. CARB. DEV.ORD. All poor ø	CARB. 1.8 PERM. 2.3	INTRA FM SEAL PERM-CARB TOP DEV. CLAYST.	CARB. LMST.	GRABEN MARGIN FAULT BLOCKS. RISKS- FAULT SEAL, POROSITY
ARAFURA 1	PETROFINA 1983 3635 m	DEV. 3-16% ø ORD. 0.3-4% ø	DEV. 4.9 CAM. 8.6	DEV. CLAYST. ORD. SHALE	DEV. ORD.	FAULT BLOCK RISKS. FAULT SEAL. POROSITY
TORRES 1	ESSO 1983 2734 m	DEV. ORD. Poor ø	——	DEV. CLAYST.	——	FAULTED ANTICLINE RISK-DEEP BURIAL- NO POROSITY
KULKA 1	DIAMOND SHAMROCK 1984 3998 m	PERM- CARB. 3.5% ø	PERM. 0.9	DOLERITE SILL JUR. SILTST.	JUR. PERM.	FAULTED ANTICLINE RISK- POROSITY DIAGENESIS+ FACIES
GOULBURN 1	PETROFINA 1986 1300 m	DEV. 19% ø ORD. No ø	ORD. ?	DEV. CLAYST. ORD. SHALE	DEV. ORD	FAULT BLOCK RISK- FAULT SEAL FLUSHED

values have been reported from the Ordovician sequence of the Arafura Basin, although equivalent age sediments in the Canning Basin (Goldwyer Formation, Foster et al., 1986) and Amadeus Basin (Horn Valley Siltstone, Gorter, 1984) are oil source rocks. Ordovician, Cambrian and older source rocks are frequently juxtaposed against Devonian and younger reservoir units across major faults, such as the southern bounding fault of the Goulburn Graben (Figs 11 & 12).

Other source rock intervals occur in the Upper Devonian, Upper Carboniferous and Permian as indicated by the well results (Table 2). The unpenetrated sections of the Permo-Triassic sequence may also have mature source rocks in the deeper parts of the basin. Correlations with other basins suggest that these may be gas prone with a high contribution from land plants, as opposed to the older marine source rocks.

Reservoir

The reservoir characteristics of the Arafura Basin (Table 2) are discouraging. Primary porosity in many of the sandstones has been destroyed by silica overgrowths. In some cases there was little primary porosity, as in the argillaceous sandstones in the predominantly fine grained Upper Carboniferous and Permian section in Kulka-1. Limited zones of fair to good porosities (Table 2) and reasonable permeabilities (up to 9.68 md) have been reported from the Devonian clastics in Arafura-1 and Goulburn-1 (Table 3). Sandy facies indicate a location close to the palaeo-shoreline, and the early migration of hydrocarbons may have enhanced reservoir quality in this part of the basin. Good porosities occur in the Jurassic sandstones of the Money Shoal Basin sequence and their potential as reservoirs for older oil depends on the timing of maturation and migration in the Arafura sequence (note the oil show in the Jurassic in Kulka-1, Table 1).

The carbonate sequences are generally non-porous, except for some vugular porosity and permeability (ranging from 0.01 to 1200 md) in Ordovician dolomites in Arafura-1 (Tables 2 & 3). Enhanced porosity in carbonates can occur due to dolomitisation, fracturing and karstic weathering, but currently there is insufficient information to predict secondary porosity trends.

Potential reservoir units that have not been penetrated in the Arafura Basin include the Cambrian Buckingham Bay and Marchinbar Sandstones, respectively below and above the Raiwalla Shale. They are thick (270–500 m), quartz sandstones (Plumb, 1965) with good initial porosities but the subsurface character of the reservoirs is unknown. Correlations with other basins suggest that sands in the untested Permo-Triassic section could have good reservoir characteristics.

Seal

The Arafura Basin sequence intersected in wells is lacking in regional seal facies. Brittle carbonates and sandy clastics dominate except for the fine grained Upper Carboniferous to Permian sediments in the most westerly well, Kulka-1. The drilling results indicate that fault seal is a major risk (Table 2), however, the distribution of the oil shows points to a number of facies acting as local seals. These include calcareous shales in the Ordovician, Devonian claystones, and claystones and a dolerite sill (Kulka-1) in the Upper Carboniferous to Permian (Table 3). The basal Mesozoic section intersected in the wells is commonly a sand that has the potential to act as a thief zone. In the most westerly parts of the Arafura Basin where the overlying Money Shoal sequence is thickening, there is a chance of a Jurassic sealing shale over the unconformity, while in the eastern part of the basin Cretaceous transgressive shales may in some places rest directly on the unconformity.

The Raiwalla Shale, which has not been intersected in the wells, is a potential regional seal for the Lower Cambrian Buckingham Bay Sandstone. An equivalent of the widespread Lower Triassic shales on the western margin (Kockatea, Locker, Blina and Mt Goodwin formations, Bradshaw et al., 1988) is another possible regional

UNIT	RESERVOIR	SOURCE	SEAL	TRAP	TESTS, SHOWS	ANALOGUES
McARTHUR BASIN Middle Proterozoic 1400 - 1800 Ma	Roper Group-Malay Road Group qtz arenites ? McArthur Group Carbonates-Karst.	Roper Group-Velkerri Fm equivalent-Velkerri - 8.68% TOC	Overlying Cambrian Wessel Group	Fault	Live oil recovered onshore BMR Urapunga 4. Not intersected offshore. Duyken 1 not valid test - igneous not carbonate basement.	Proterozoic proven source in Oman.
WESSEL GROUP Lower Cambrian Clastics-ssts with middle shale unit	Buckingham Bay Sst - X stratified qtz sst with basal conglomerate. 500 m thick, *skolithos*. Marchinbar Sst 270 m qtz sst Elcho Island Fm. 270 m, gl. sst, shale dol., siltst. & chert.	McArthur Basin migration up faults? Raiwalla Shale? Elcho Is. Fm. 8.65% TOC in Arafura 1	Raiwalla Shale ~1000 m? Overlying Goulburn Gp carbonates	Drape Fault Anticline Strat. - pinch-out of Buckingham Bay under Raiwalla. salt?	Buckingham Bay & Marchinbar Ssts not intersected Elcho Island Fm. bitumen,fluorescence & cut,low ø in Arafura 1	Amadeus Basin - Dingo gas field in equivalent ssts. Cambrian production in Oman.
GOULBURN GROUP Ordovician & Cambrian carbonates.	1. Dolomite - fractures, vugs Arafura 1 dolomites more ø than limestones ø:4%, K 0.01 -1200 md (vugs)	McArthur Basin Raiwalla Shale Elcho Island Fm. Ordovician?	Overlying Devonian - Arafura 1 - 65 m of silty calcareous shale at base of Devonian	Drape Fault Anticline Strat. - salt?	Arafura 1 Live oil shows,DST recovered salty water. Goulburn 1 dead oil/ bitumen.	Canning Basin Nita Fm in Canning Pictor 1
ARAFURA GROUP Devonian	Sandstone ø decreased by diagenesis - pressure solution, qzt overgrowths, qzt replaced by dolomite Arafura 1 16 % ø K .02 - 9.8 md Tasman 1 0.06% ø Goulburn 1 19% ø,7.8 md	McArthur Basin Raiwalla Shale Elcho Is. Fm Devonian 4.86% TOC Arafura 1	Devonian claystone	Fault Anticline Strat.- salt?	Arafura 1 live oil in Devonian Goulburn 1 dead oil/bitumen.	Canning Basin Mirabelia 1 Mellinjerie Fm. Frasnian dolostones
POSSIBLE DEVONIAN facies not represented in wells	Reef reservoirs	Cambrian Devonian	Marine units at base of Carbonif-erous	Strat.	None	Canning Basin Blina Field
CARBONIFEROUS lower marine unit	Namurian lmsts. fractures filled with calcite Tasman 1 0.01% ø	Carboniferous Tasman 1 1.48% TOC	Interbedded shales	Fault Anticline Strat.	Tasman 1 fluoresence and cut	Canning Basin ? Lloyd 1
CARBONIFEROUS clastics	Sandstones Tasman 1 0.1% ø Kulka 1 3.5% ø	Devonian Carboniferous Tasman 1 1.81% TOC	Interbedded claystones	Fault Anticline Strat.		Canning Basin Kora 1 Sundown 1 West Terrace 1
PERMIAN & TRIASSIC	Sandstones Tasman 1 0.1% ø Kulka 1 3.5% ø	Proterozoic Lower Palaeozoic face-loaded. Devonian, Carboniferous Permian Tasman 1 2.3% TOC	Interbedded claystones, Lower Triassic regional seal? overlying Money Shoal sequence	Fault Anticline Strat.	Kulka 1 fluorescence and cut	Bonaparte Basin Petrel & Tern gas fields Barnett oil discovery

Table 3 — Play types from the Arafura Basin.

seal facies. Correlations with neighbouring basins (Fig. 13) suggest there is some chance that evaporites could occur in the lower Palaeozoic and provide excellent seals.

Trap

The trap types tested have been faulted anticlines and fault blocks, all within the Goulburn Graben. Limited seismic coverage of the area outside the graben makes it difficult to speculate about the distribution of structural traps in the rest of the basin. The pervading northwest structural grain can be expected to be reflected in faulting outside the graben. Fault block traps may occur in the eastern part of the basin where the northwest trend intersects the older northerly trend of the Proterozoic Walker Trough/Fault Zone. Drape over this structure is another possible type of trap configuration outside the graben. Late Devonian bioherms and salt structures provide hydrocarbon traps in neighbouring basins and may also occur in the Arafura Basin, in areas lacking detailed seismic coverage.

Maturation and Timing

The maturation profile for several wells in the Arafura Basin as indicated by CAI and other organic petrology and geochemical data is shown in Fig. 14. The section penetrated by the shallowest well, Goulburn-1, is immature, and there is mature section in all other wells except for Torres-1 which is overmature. Figure 14 also shows a widening and deepening of CAI zones in comparison to other basins suggesting a low geothermal gradient.

The empirical evidence of the wells indicates that in various locations the Cambrian, Ordovician, Devonian, Carboniferous and Permian sequences are currently mature. In the graben the major episode of structural trap formation was in the Permo-Triassic, although there may have been some earlier movements on faults and growth on structures from Devonian times. The Permo-Triassic is also the critical time for maturation and migration of hydrocarbons due to increased rates of burial and the possible establishment of fault conduits.

During the Permo-Triassic deformation there was also some limited potential for the destruction of earlier formed accumulations in stratigraphic traps and drape features over the Wessel Rise. Early formed traps have the advantage of having had a longer time to fill and may have trapped oil from the Cambrian and even Proterozoic, and have the chance of preserving primary porosity. The Mesozoic unconformity truncates structures and up to 5 km of sediment was stripped off at this time. Destruction of previous accumulations by breaching of traps and intrusion of fresh water into reservoirs was likely during this period of severe erosion and uplift. Later events that may have affected trap viability in the Arafura Basin are reactivation of some faults and flushing of shallow reservoirs, especially during the Oligocene regression (Bradshaw et al., 1988).

Plays

Many plays can be developed from the combination of these multiple sources, seals, reservoirs and traps as are shown in Table 3. Most are inherently high risk, but of the untested plays those in the Cambrian beneath the Raiwalla Shale have the potential to overcome the seal problem, and the Permo-Triassic has enhanced potential for good reservoirs. The viability of some of the more speculative plays involving salt and reef facies requires more seismic data.

CONCLUSIONS

The Arafura Basin contains a Cambrian to Permo-Triassic sedimentary sequence that includes several source rock intervals. Most of the Cambrian and Permo-Triassic sections remain untested. The majority of the basin, extending far beyond the confines of the Goulburn Graben, is essentially unexplored. Drilling results to date have shown that the basin has a low geothermal gradient and is petroliferous, but that reservoir quality and the scarcity of regional seals are significant risks to exploration success. Some of these deficiencies may be overcome in the untested parts of the sedimentary sequence. The Arafura Basin is a high risk exploration venture but its potential is such that it warrants further investigation, principally by the acquisition of more and improved quality seismic data over areas outside the graben.

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