RECORD 1992/84

PETROLEUM PROSPECTIVITY EVALUATION REPORT ARAFURA BASIN

by

Vidas Labutis, Aidan Moore and John Bradshaw

Australian Geological Survey Organisation
Canberra, ACT, Australia
1992

Bibliographic reference
Labutis, V., Moore, A., Bradshaw, J. 1992 - Petroleum Prospectivity Evaluation - Arafura Basin. Australian Geological Survey Organisation Record 1992/84.

ISSN: 1039-0073
ISBN: 0 642 18600 6

Inquiries should be directed to the Principal Information Officer, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601

CONTENTS

Figure Captions

Table 1.

Enclosures

1. Seismic base map showing AGSO seismic, wells, boundaries and structural elements of the Arafura Sea.

2. Stratigraphy of Arafura Sea basins

3. Structural cross-section - Tuatara 1 to Goulburn 1.

4. Stratigraphic cross-section - Tuatara 1 to Torres 1

5. Interpreted seismic sections - line drawings of selected AGSO profiles

6. Structure contour map of the base Mesozoic.

7. Structure contour map of the base Arafura Basin.

8. Total sediment thickness map for the Arafura Basin.

SUMMARY

The eastern Arafura Sea is a poorly known and little explored area of over 180,000 km^2 in water depths of less than 200m beneath the northern continental shelf of Australia. In 1990 AGSO (then BMR) began a program of investigating the region to establish the extent and nature of a suspected depocenter to the north of the Goulburn Graben. The investigation of the region was undertaken through the acquisition of over 5000 km of multichannel seismic data in the Arafura Basin Reconnaissance (ABR) seismic program. This report summarises the results of this work and presents preliminary subsurface structure maps of the basins that lie beneath the Arafura Sea, cross-sections of interpreted seismic profiles at the same scale as the maps (1:1 million), a well sequence stratigraphic correlation of all the wells in the Arafura Basin, and a review of the petroleum prospectivity of the area with description of several new plays from the northern sub-basin.

The eight wells drilled so far have only given an indication of the basin configuration and its hydrocarbon potential in a small part of the basin - the Goulburn Graben. No wells have yet encountered late Permian or Triassic sediments. The recent AGSO seismic data has revealed the structuring to the northwest of the Goulburn Graben that was not detectable earlier, as well as identifying seismic reflectors outside the Goulburn Graben area that were postulated to exist from the limited coverage of the older seismic lines (Bradshaw et al 1990). The age of these sediments can not be accurately ascertained with the current data set. The area to the east of Goulburn 1 has not been tested and should contain the thickest section of rich source rocks. Well correlation within the Arafura Basin has been plagued by misleading dates, both absolute and palaeontological. Absolute dates from both onshore and offshore sediments have indicated a Proterozoic age for rocks that have subsequently yielded middle Cambrian faunas (Bradshaw et al., 1990). A well log correlation and sequence stratigraphic study has been undertaken to establish a reliable well correlation for the basin. Spore/pollen

dates, from the Palaeozoic in particular, should be treated with caution because of the pervasive reworking and caving that affects sidewall cores and even cores from many of the wells. The same problems apply to geochemical data processed from sediments caved and unrepresentative of the section under examination.

The study has identified an extensive sub-basin to the north of the Goulburn Graben with more than 7 km of section. The first maps of the complete Arafura Basin are presented and several untested plays, including faulted anticlines adjacent to the graben and tilted fault blocks in the northwestern sector, described .

INTRODUCTION

The eastern Arafura Sea is a poorly known and little explored area of over 180,000 km ^{2} in water depths of less than 200m beneath the northern continental shelf of Australia. In 1990 AGSO (then BMR) began a program of investigating the region to establish the extent and nature of a suspected depocenter to the north of the Goulburn Graben. The investigation of the region was undertaken through the acquisition of over 5000 km of multichannel seismic data in the Arafura Basin Reconnaissance (ABR) seismic program. This report summarises the results of this work and presents preliminary subsurface structure maps of the basins that lie beneath the Arafura Sea, cross-sections of interpreted seismic profiles at the same scale as the maps (1:1 million), a well sequence stratigraphic correlation of all the wells in the Arafura Basin, and a review of the petroleum prospectivity of the area with description of several new plays from the northern sub-basin.

The well log and sequence correlation was carried out by Vidas Labutis (Visulab Pty. Ltd.) Age dating for the wells examined was revised and upgraded from the Open File data by Clinton Foster and Robin Helby, and supplemented with zonations contained in the AGSO Oracle-based biostratigraphic database (STRATDAT). The seismic mapping was done by Aidan Moore of AGSO, and John Bradshaw (AGSO) developed the plays for the northern subbasin.

Location

The area covered by this study is located in the Arafura Sea north of Arnhem Land in the Northern Territory of Australia, in water depths ranging from 30 to 200m, but mostly less than 100m (Figure 1). It extends from longitude 132° 30' East to 137° East, and from the border of the territorial waters of Australia and Indonesia at around latitude 9° South to 11° 30' South.

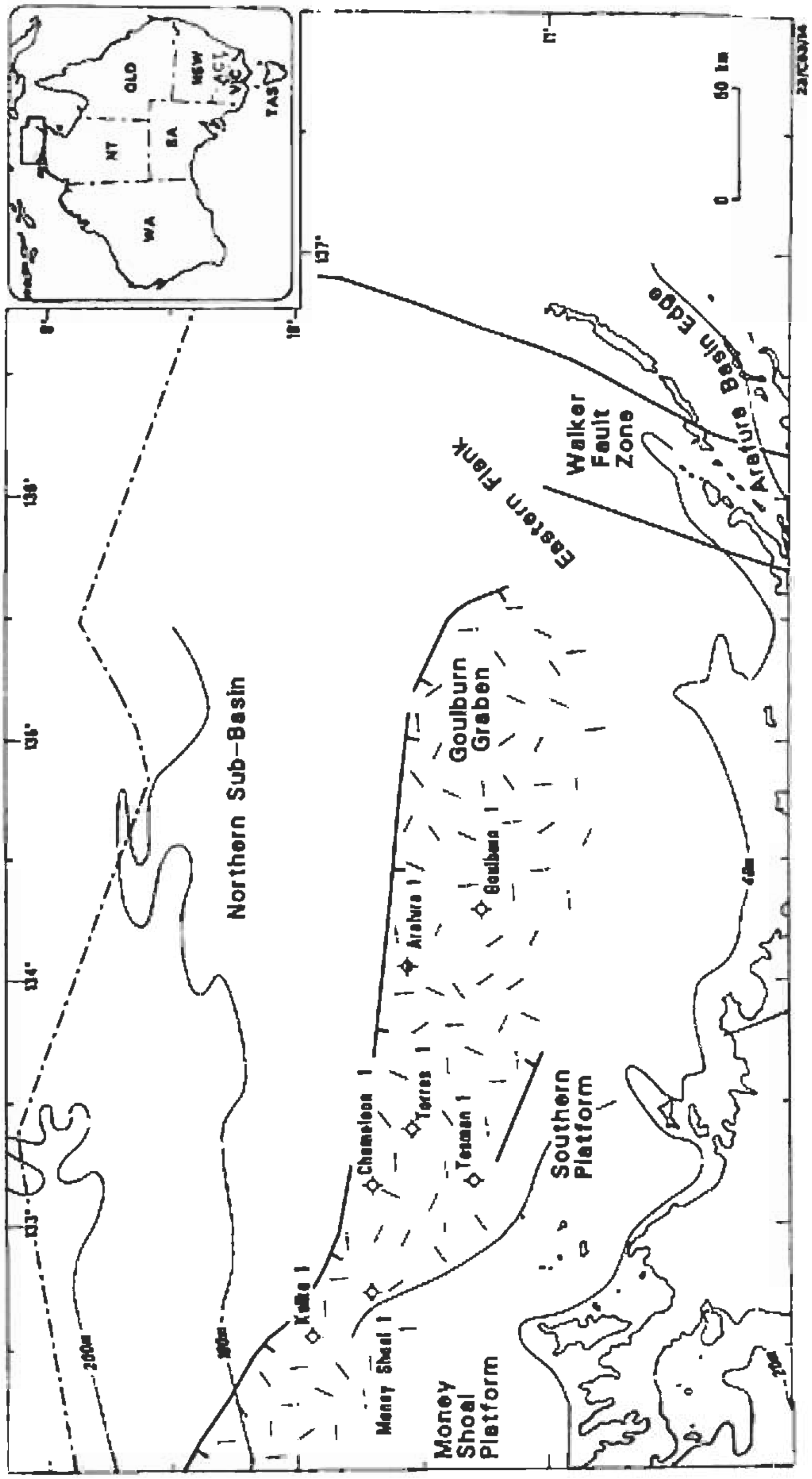


Figure 1. Locality map showing the major structural elements of the Arafura Basin and bathymetry.

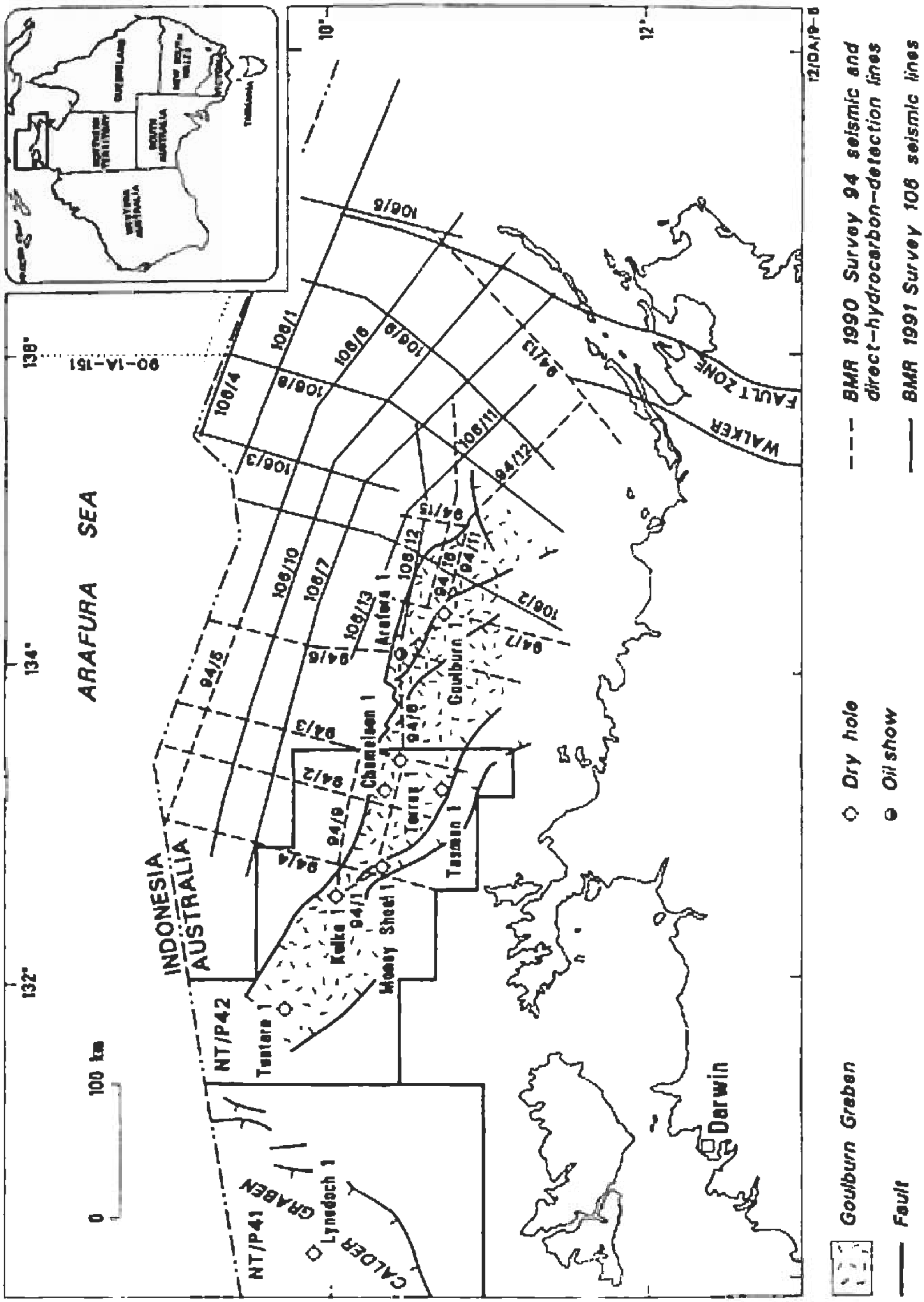


Figure 2. Locality map showing the seismic lines of the BMR's Arafura Basin Reconnaissance (ABR).

It contains the existing permit NT\P42, held by BHP Petroleum and BP. Areas NT92-3 to 6, gazetted for exploration in November 1992, cover a combined area of 94,000km^2 in the eastern and northern parts of the area, covering most of the remaining, non permited area of the eastern Arafura Sea.

Geological Setting

The margin of Australia beneath the Arafura Sea is little known and poorly understood. It contains the Money Shoal, Arafura and McArthur Basins of Cainozoic-Mesozoic, Palaeozoic and Proterozoic age respectively, which are stacked vertically, one above the other to form a sedimentary pile well over 10 kilometres thick. Over most of the area the basinal succession has not been severely tectonised, and geothermal gradients are low. The only oil exploration wells are restricted to the Goulburn Graben, near the southern rim of the Arafura Basin (Figure 1).

Money Shoal Basin

The Money Shoal Basin occupies the western parts of the Arafura Sea. It is mainly of Cretaceous age in the gazetted areas. The Tertiary succession is thin or absent in the eastern parts of the basin, and has not been sampled in the wells drilled in the study area. There are up to 400m of Jurassic marine clastics at the base in the western part. The basin onlaps the angular unconformity at the top of the underlying Arafura Basin, and the shales above the 'base Cenomanian' maximum flooding surface (*D. multispinum* dinoflagellate zone (Helby, Morgan and Partridge, 1987)) overly the basal unconformity over part of the gazetted areas.

Arafura Basin

The Arafura Basin extends from onshore outcrops of Cambrian rocks in Arnhem Land to the

Australian-Indonesian border and beyond, possibly as far as the mainland of Irian Jaya. In Australian waters it covers an area of more than 130,000 km^2. Its simple synclinal shape is interrupted by the Goulburn Graben which lies on its southern flank and trends west-northwest. In the Goulburn Graben the basin fill consists of up to 10 km of marine and marginal marine clastics and carbonates ranging in age from the Lower Cambrian to Permian, with possibly some Triassic in a few restricted locations. The greater part of the basin, east and north of the graben, is undrilled. It is probably composed of Lower Palaeozoic marine clastics and carbonates. It overlies and overlaps the McArthur Basin.

McArthur Basin

The McArthur Basin is widely exposed and drilled onshore. It has not been reached offshore. It is a thick and complex basin with (?Upper and) Mid Proterozoic marine and marginal-marine sediments, and it contains at least one major internal angular unconformity, together with five oil source rocks (Crick, 1992; Crick et al., 1988) and a thick dolerite sill. In the central area, the McArthur Basin is likely to be youngest Proterozoic (Roper Group), but toward the Wessel Islands in the east, an angular unconformity separates older Middle Proterozoic, McArthur or Nathan Group sediments from the mildly onlapping Cambrian.

EXPLORATION HISTORY

Although Shell and others conducted aeromagnetic and seismic exploration during the 1960s and 1970s, the modern work dates from 1981, when Esso, Diamond Shamrock, Sion Resources and Petrofina began acquiring seismic data, followed by BHPP with seismic in the late 1980s and early 1990s. The work was mainly confined to the Goulburn Graben, with some reconnaissance lines extending into the northern sub-basin. Seismic surveys of regional significance and with good subsurface penetration include:

SURVEY	OPERATOR	CONTRACTOR	YEAR	LINE ID
Wessel Marine	Beaver	Western Geophys.	1972	WM & W
M81A	Esso	GSI	1981	M81
Arafura Sea	Sion	GSI	1981	S81
AM81	Mincorp	GSI	1981	AM81
DS81	Diamond Shamrock	Western Geophys.	1981	DS-81
DS84	Diamond Shamrock	Western Geophys.	1984	DS-84
HA88A & B	BHPP	Halliburton	1988	HA88A & HA88B
HA89A & B	BHPP	Halliburton	1989	HA89A & HA89B
HA90A	BHPP	GECO	1990	HA90A
ABR	BMR		1990	94/
ABR	BMR		1991	106/

A complete listing of geophysical work undertaken in the basin and surrounding areas up until 1989 is contained in Petroconsultants (1989).

The BMR data set of approximately 5320 km of stacked seismic profile, shown in Figure 2, forms a basin-wide grid of seismic lines that is largely complementary to the industry surveys and is the only modern multichannel seismic (MCS) grid covering most of the basin including the northern sub-basin.

BHPP conducted an aeromagnetic survey in 1989 over the whole of its permit areas (NT/P41 and NT/P42) between 130° and 132° 30' East, and BP flew airborne laser fluorosensing 'ALF' surveys over parts of the Arafura Sea in 1989 (Martin & Cawley, 1991).

Drilling

Over a twenty year history since 1971, eight wells have been drilled in the Arafura Basin, all but one of them within the Goulburn Graben confines (Enclosure 1). No wells have been drilled in the large sub-basin that lies to the north of the Goulburn Graben.

Money Shoal 1 was drilled during an early phase of exploration by Shell in 1971 to test a Cretaceous anticlinal closure. The well encountered a basement high along the margin of the Goulburn Graben, but had no hydrocarbon indications.

The remaining wells were drilled in a later phase of exploration during the decade beginning in 1983. Arafura 1 was drilled by Petrofina in 1983 to test a fault related closure of the section underlying the Mesozoic sediments within the Goulburn Graben. Oil shows were encountered in the Devonian clastic section and the Tremadoc-Cambrian carbonate section. Traces of bitumen also occurred in early Permian clastics underlying the Cenomanian.

Tasman 1 was drilled by ESSO, also in 1983, to test a fault related closure near the southern bounding fault of the Goulburn Graben. Oil shows were encountered in a carbonate section of supposedly Carboniferous age, interpreted here as Devonian (Enclosures 2 & 3).

Torres 1 was drilled by ESSO in 1983 to test the Palaeozoic section in the large central anticline of the Goulburn Graben. There were no hydrocarbon shows.

Kulka 1 was drilled by Diamond Shamrock in 1984 to test an anticlinal closure within the western portion of the Goulburn Graben. Oil shows were present throughout the Permian with minor shows in the middle Jurassic section. There were no shows in the late Carboniferous section.

Goulburn 1 was the second and final well drilled by Petrofina in 1986 to test a fault related structure following up the oil shows of Arafura 1. Oil shows were recorded from the Devonian clastics and the Cambrian to Tremadoc carbonates.

Tuatara 1 was drilled by BHP Petroleum in 1990 to test a faulted anticline in the western portion of the Goulburn Graben. No significant oil shows were encountered. Chameleon 1 was drilled by BHP Petroleum in 1991 to test a structure within the Goulburn Graben.

GEOLOGICAL HISTORY

The Arafura Basin is a Palaeozoic intracratonic basin with up to 10 km of section. The oldest dates known from the basin are early middle Cambrian from Arafura 1 and crop out on Elcho Island (Plumb et al., 1976), but seismic data and regional correlations suggest that there is a potential of earliest Cambrian and latest Proterozoic sediments to be present as well.

The Cambrian to Ordovician sequences pre-date Goulburn Graben development, and were deposited on a low lying shelf with open sea to the north and northeast. No late Ordovician, Silurian or early Devonian sediments have been encountered in any of the wells. The Torres, Tasman and Money Shoal areas appear to have been highs early in the history of the Arafura Basin. In the case of Money Shoal, there is only a thin section of possible Devonian sediments, overlying volcanics that could be considered to be the equivalents of the Antrim Plateau volcanics.

The Middle Cambrian onlaps towards Torres 1 from Arafura 1 and pinches out before reaching it. The Arenigian sequence also onlaps towards Torres 1 and pinches out, but may be eroded from the Torres area. The Arenigian sequence is thickest in Goulburn 1 and the upper part of the sequence is eroded in Arafura 1. The absence of the Arenigian sequence in Torres 1 and Tasman 1 is partly a result of thinning by onlap and partly by erosion of the thinned sequence from the high. On the other hand, the dolomitic late Cambrian and Tremadocian sequences are more extensive, and are represented by a thick section in both Torres 1 and Tasman 1. Middle Cambrian to Ordovician sedimentation did not reach Money Shoal 1 to the west because it was exposed throughout the early Palaeozoic.

There appears to have been a marine embayment to the east of the Torres, Tasman and Money Shoal areas in the Middle Cambrian to early Ordovician, with an open shelf to the north and northeast. It is also expected that any early to middle Cambrian and middle to late Ordovician sediments would have their thickest distribution and be preserved in this area. Nicoll et al., (1988) have suggested a sea level fall in Late Arenigian time was responsible for a widespread unconformity that is found in the Canning, Georgina and Amadeus Basins. This event may also explain the lack of post early Arenigian to middle Devonian sediments in the Arafura Basin.

The early to middle Devonian is the most likely time of the initiation of the precursors of the Goulburn Graben. The oldest Devonian sediments penetrated so far are ?Givetian to Frasnian clastics in Tasman 1, Torres 1, Arafura 1 and Goulburn 1 dated as *A. parva - G. lemurata* from spore/pollen. The sediments are near shore and tidal red beds which thin, with younger deposits to the east, indicating that an east-west tilt to the graben had been established by the middle Devonian (Enclosure 3). Unlike the Canning Basin, Middle Devonian sediments have not been recorded from the Goulburn Graben, but are likely to be present and deeply buried in the western portion of the graben.

There was carbonate deposition among the shallow marine to coastal plain and shoreline sediments during the *P. crepida* sequence in the Tasman and Torres areas. The sediments within the western part of the graben, whether carbonates or shales, represent the basinal, marine facies equivalents of the near shore clastics to the east. There is thus a possibility of reefal growth within this and other Frasnian and Famennian sequences along the margins of the western part of the graben.

Deposition within the graben continued through the Strunian to Visean through several sequences, all of which were deposited in similar environments of near shore marine to tidal and coastal plain. In this stage of basin fill, sedimentation proceeded within the Goulburn

Graben and the northern platform, as well as covering the Money Shoal area during one of the Devonian or early Carboniferous sequences. Visean spore/pollen forms are a common reworked constituent of late Carboniferous and Permian sediments indicating that Visean sediments, although not identified in any wells, were deposited and extensively eroded. Wells that could have preserved a section of Visean, such as Tasman 1 and Arafura 1, are faulted with late Carboniferous and Permian superposed on the Devonian or early Carboniferous.

Tectonic movement in the late Visean resulted in exposure of much of the area to extensive erosion as a prelude to reactivation of the faulting in a rifting event that led to the late Carboniferous to early Permian sedimentation. Late Carboniferous sediments contain a high proportion of labile minerals that are probably volcanic in origin, suggesting that igneous activity accompanied or preceded the Visean tectonism. The early Permian in the Arafura Basin was accompanied by igneous activity, exemplified by the dolerite intrusion in Kulka 1, and the resetting of the fission track dates. This activity was a prelude to middle Permian tectonic episodes.

Late Permian and Triassic sediments have not been penetrated in the Arafura Basin but a well from offshore Irian Jaya (ASM-1X) records earliest Permian sediments overlain by late Permian and early Triassic sediments. A similar section, that has not been intersected by drilling, is expected in the Goulburn Graben, preserved on the flanks of the central anticline.

An episode of convergent wrenching resulted in the folding of the Goulburn Graben sediments into a large northwest-southeast trending anticline. Subsequent deep erosion has stripped the top of the Palaeozoic and Triassic section, leaving the younger section preserved only on the flanks of the fold (Enclosure 5). The early phases of rifting on the northwest shelf were probably contemporaneous with wrench movement in the Arafura Basin. These movements could have initiated as early as the Permo-Triassic and continued through until around the time of the Triassic to Jurassic boundary. The early phases coincide with northward drift of the Shan Thai Malaya block from a region near the present day position of Timor (McKerrow & Scotese, 1990). The later movements also established northeast-southwest trending troughs on the NW Shelf. Such structuring of similar age is apparent in the Bonaparte Basin in the Petrel area where several thousand metres of Carboniferous to Triassic (predominantly Carboniferous) sediments have been folded (G. O'Brien pers. comm., 1992).

Early Jurassic, Hettangian to Bajocian, sedimentation was confined to the western part of the Goulburn Graben around Tuatara 1, while the eastern part was exposed and undergoing erosion (Enclosures 3, 4). There are signs of northeast-southwest and east-west fault trends in the western part of the basin around Tuatara 1, which may be situated in a different depositional system to the Goulburn Graben. The Jurassic sediments are considered to be filling troughs predominantly along these trends as well as extending into the Goulburn Graben.

Bathonian deposition extended to the Tasman area but did not reach the Torres or eastern areas. The greatest erosion was along the flanks of the anticline and in the vicinity of the graben bounding faults, where these areas were filled with the thickest late Jurassic and early Cretaceous sediments as in Money Shoal 1 and Tasman 1 (Enclosure 3). Kulka 1 and Torres 1 are located more towards the centre of the anticline and have a thinner section of Jurassic. The main sedimentary troughs extended along the margins of the Goulburn Graben as two prongs extending eastwards, straddling the anticline to the north and south of Torres 1 and pinching out towards the Arafura 1 area.

Late Callovian to Kimmeridgian sediments are represented by sandstones in the late Callovian and early Oxfordian sequence followed by a shale prone, condensed section of several marine sequences through the late Oxfordian to Kimmeridgian. The shoreward direction is indicated by the sandy sections in Tasman 1 and Torres 1. Much of this section has been eroded from Kulka 1 and Tuatara 1 where only a thin, older part of the section is preserved. Money Shoal 1 has the thickest section of these sequences and was located near the centre of a depositional trough at this time (Enclosure 8, a1, a2 and b).

A sea level fall in the early Tithonian resulted in deposition of a thick section of shallow marine to non marine sandstones of the *D. jurassicum* sequence. Similar conditions continued through the *P. iehiense* sequence with widespread sedimentation around the time of the maximum flooding surface. Shallowing occurred through the progradational highstand that is preserved in Kulka 1 and wells to the west. The *P. iehiense* sequence also has an extensive distribution in the Timor Sea and Browse Basin

The *C. delicata* sequence follows a sea level fall which resulted in erosion of the highstand sediments of the *P. iehiense* sequence and deposition of predominantly marine, shaly sediments. The sequence is confined to the Tuatara area where there is a thin sand at the base followed by a thick section of marine shale. Tuatara 1 is located in a more basinal setting and shallower equivalents should occur eastwards in the Goulburn Graben. *C. delicata* has been recorded from the lowstand of the overlying sequence, indicating that the sequence had a wider distribution and has been eroded.

A major sea level fall and erosion of the *C. delicata* sequence was followed by inundation of large areas of the basin during the *D. lobispinosum* sequence which together with the *P. iehiense* sequence experienced an extensive maximum flooding interval and is one of the few sequences to preserve a progradational highstand. The depositional pattern and thickness of this sequence is similar to that in the Barrow Sub-basin (Barrow Group) and unlike the Timor Sea and Browse Basins where the sequence is usually absent.

The *E. torynum* sequence is confined to the Tuatara and Kulka areas reflecting the withdrawal of the sea westwards to the deepest parts of the graben.

Deposition of sequences after the Valanginian is restricted to the western part of the graben, leaving at least from Kulka 1 eastwards exposed to erosion. The distribution of these sequences follows the northeast-southwest trends initiated in the early Jurassic with the younger sequences cropping out on Bathurst Island. Subsequently, the first sign of sedimentation in the Goulburn Graben is in the Aptian-Albian in Torres 1. Further erosion was terminated by the flooding during the Cenomanian *D. multispinum* sequence which has a regional distribution over the Arafura Basin, extending to the Carpentaria Basin.
The eastern part of the basin received very little sediment after this time with more and thicker late Cretaceous and Tertiary sequences deposited towards the west.
The stratigraphy of the basin is summarized in Enclosure 2.

SEQUENCE STRATIGRAPHY

The concepts of sequence stratigraphy applied in this report follow the definitions of Van Wagoner *et al.* (1988). Each sequence has been distinguished on palaeontological data and the sequence boundaries identified on well logs. The palaeontology used for the definition and correlation of sequences includes palynomorphs, conodonts and trilobites.
The Jurassic and Cretaceous sequences are based on the analysis of over 200 wells from the Timor Sea, Bonaparte, Browse and Carnarvon Basins, some of which have been documented by Labutis (1991, 1992). The identification of sequences from the Jurassic and Cretaceous is now at a stage where a cycle chart could be drawn up, based on an Australian palaeontological zonation. The absolute dating remains a problem and significant discrepancies will not be resolved until more SHRIMP dates are available to tie the Australian, American and European zonations. The sequence boundaries identified in this report are tied to the palaeontological zonation without applying absolute dates.
The identification of sequences in the Palaeozoic is at an early stage and has been initiated in

the Canning Basin by Jackson *et al.* (1992). The identification of the faunal and floral zones that characterise each sequence is necessary before Palaeozoic sequences can be correlated into other Australian basins. The Palaeozoic sequences identified in the Arafura Basin are preliminary and require confirmation from areas with a better palaeontological base. Sequences in a predominantly shoreline to non marine environment present difficulties in distinguishing sequence boundaries as well as having sparse and poor palaeontology with long ranging forms. Much of the Palaeozoic and early Mesozoic falls into this category. Detailed palaeontology can help in resolving this problem in some cases but requires many samples to find any forms that could be used as a marker Reworking the spore/pollen and fish faunas would be the most appropriate for the Palaeozoic.

There have been no signs of deep water deposits, such as submarine fans or turbidites, in any of the sequences from the Arafura Basin. There is also no indication of a shelf-slope break developed in the pre-Tertiary of the basin. The model most applicable to deposition within shallow water troughs, such as the Goulburn Graben, is the ramp margin, Type 2 unconformity of Van Wagoner et al., (1988, 1990). From the Devonian to the Berriasian, the environments in the Goulburn Graben have ranged from marine to fluvial-estuarine. Sequences correlated with the lithostratigraphic subdivisions of Bradshaw *et al.*, (1990) for the Arafura Basin are shown on the stratigraphic chart (Enclosure 2). Lithostratigraphic equivalents of formations named in the Bonaparte Basin have been avoided because of the poor and long ranging dates of the Carboniferous and Permian sections. The tops, bottoms and thicknesses of each sequence for all the wells examined are listed in Table 1.

Well correlation within the Arafura Basin has been plagued by misleading dates, both absolute and palaeontological. Absolute dates from both onshore and offshore sediments

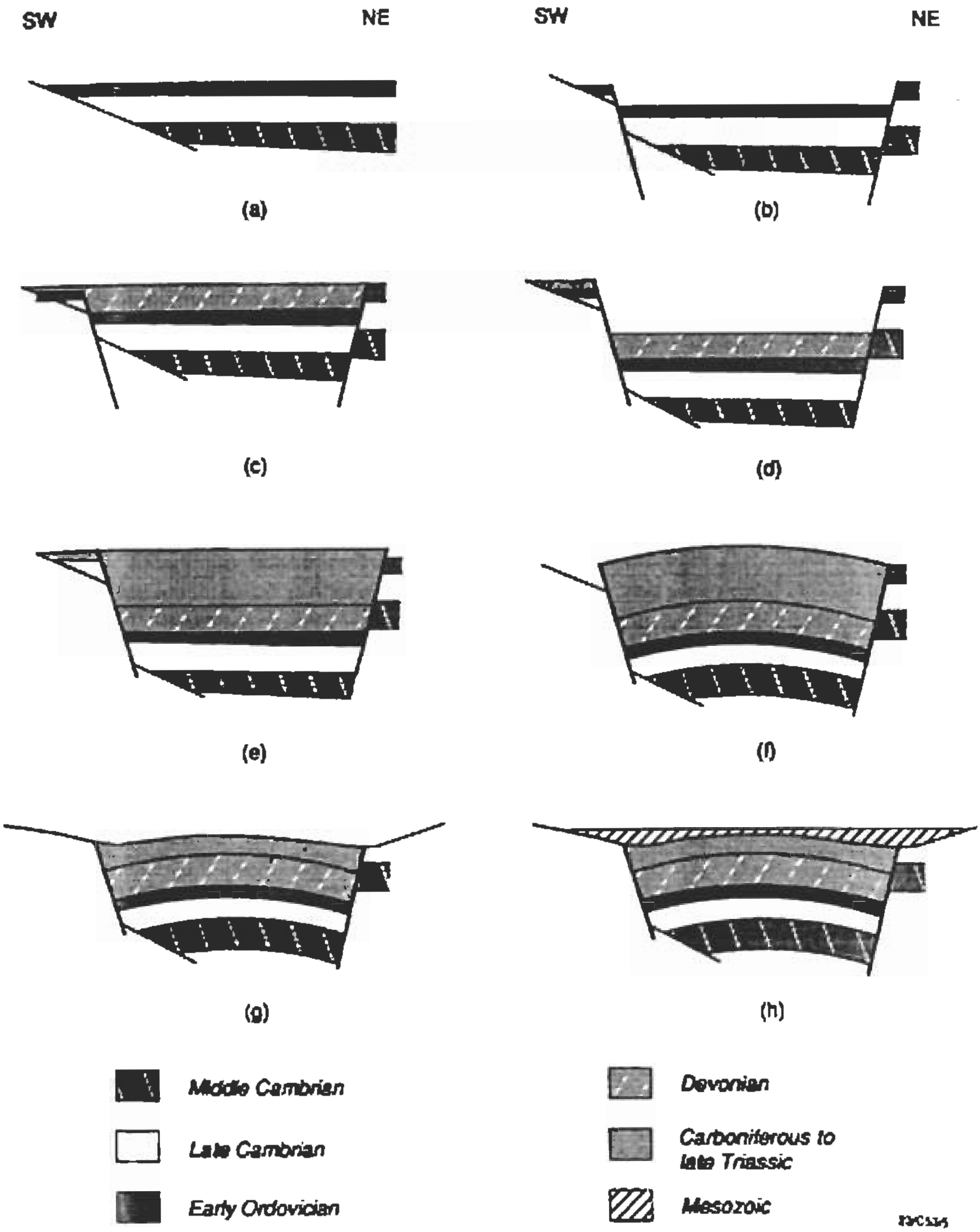


Figure 3. Schematic diagram of the Goulburn Graben showing its geological history.

have indicated a Proterozoic age for rocks that have subsequently yielded middle Cambrian faunas (Bradshaw et al., 1990). Fission track dating seems to have been reset by an early Permian heating event (Petroconsultants, 1989), which is commonly seen as a major event on the entire Australian continent (Bradshaw & Vizy, 1991). Spore/pollen dates, from the Palaeozoic in particular, should be treated with caution because of the pervasive reworking and caving that affects sidewall cores and even cores from many of the wells. The same problems apply to geochemical data processed from sediments caved and unrepresentative of the section under examination.

PROTEROZOIC

Proterozoic sediments crop out onshore but have only been penetrated in the Money Shoal 1 well in the Arafura Basin where they occur below the equivalents of the Antrim Plateau volcanics. The section consists of shales and indurated sandstones. No other wells have penetrated the Proterozoic and the section at the bottom of Arafura 1, previously considered Proterozoic in age, has been dated as early middle Cambrian from trilobite faunas (J. Shergold pers. comm. 1992; Bradshaw et al, 1990).

CAMBRIAN

Cambrian sediments overlie Proterozoic Macarthur Basin sediments cropping out on Arnhem Land and the Wessel Islands, marking the southern and eastern boundaries of the Arafura Basin. J. Shergold (pers. comm. 1992) has identified early Middle Cambrian agnostid trilobite faunas from Arafura 1, the oldest of which correlate with the trilobite faunas from the Elcho Island Formation cropping out on Elcho Island. Plumb et al. (1976) have compiled a composite stratigraphic section for the onshore Cambrian outcrops. The Marchinbar Sandstone near the top of the section is considered here to represent the lowstand of the *X. templetonensis* Sequence, although there could be another intervening sequence that has not been penetrated. The lowermost section of Arafura 1, dated as *T. gibbus* or older, is considered to be part of the *X. templetonensis* sequence. The thick Raiwalla Shale and the Buckingham Bay Sandstone are older and part of an underlying, and as yet undated, series of sequences that have not been penetrated by any wells in the Arafura Basin, but have well documented equivalents in the Amadeus Basin.

Ordian/early Templetonian *X. templetonensis* Sequence.

Xystridura templetonensis/Redlichia chinensis trilobite zone.

The lowermost beds of Arafura 1 are included in this sequence which is poorly defined but the dates tend to indicate an age older than the *T. gibbus*. zone.

Floran/late Templetonian *T. gibbus* Sequence.

Triplagnostus gibbus trilobite zone.

T. gibbus is diagnostic of this sequence but its range may extend lower into the underlying *X. templetonensis* sequence.

Late Cambrian Sequences.

The Cambrian sequence boundaries in the dolomite section (Enclosure A), are tentative and based purely on log character, since none of this section has been dated.

ORDOVICIAN

Tremadocian Sequence

This sequence is represented by the upper part of the dolomitic section underlying the Devonian terrigenous section in Tasman 1 and Torres 1, and the Ordovician carbonate and terrigenous section in Arafura 1 and Goulburn 1. The sequence is dated as Tremadocian on conodonts (*Cordylodus* spp. from cuttings at 2150-2160 m) in Torres 1 and from core 5 in Arafura 1 (R. Nicoll, pers comm 1992)

Early Arenigian *P. elegans* Sequence

Prioniodus elegans-Bergstroemognathus extensus conodont zone.

This early Arenigian sequence is dated on conodonts from core 3 in Arafura 1 (R. Nicoll, pers comm. 1992). The sequence is thickest in Goulburn 1, the top of the sequence is somewhat more eroded in Arafura 1 and entirely absent from the Torres and Tasman areas (Enclosure A). The absence of this sequence from the Torres area may also be due partly to onlap relationships where the sediments pinch out onto a palaeohigh at Torres 1. The Upper Cambrian and Lower Ordovician dolomitic section shows only slight thinning towards Torres 1 whereas the Middle Cambrian and underlying sediments thin markedly and are absent in the Torres area (Enclosure A).

DEVONIAN

Sediments overlying the volcanics near the bottom of Money Shoal 1 were reported as containing Chitinozoa and have been variously dated as Silurian and Devonian (Balke et al., 1973; Petroconsultants, 1989). Chitinozoa range from the Middle Ordovician to the Carboniferous, thus ruling out the possibility of a Proterozoic or Cambrian age for these sediments or an early Permian age for the volcanics and any relationship with the dolerite in Kulka 1. The lack of Middle Ordovician to Silurian age sediments in wells penetrating the Palaeozoic section in the Goulburn Graben suggests that these ages are also unlikely for the Money Shoal section. The most likely age is late Devonian to early Carboniferous, related to one of the sequences of this age penetrated in the Tasman 1 and Torres 1 wells.

Frasnian-?Givetian *A. parva* Sequence.

Ancyrospora. parva -Geminospora lemurata spore/pollen zones.

A. parva and *G. lemurata* characterise this sequence in Tasman 1 and Torres 1. A specimen of *Palmatolepis* was recorded from Arafura 1 and a *P. crepida* assemblage from cuttings (690 m) in Goulburn 1.

Early Famennian *P. crepida* (Fa1b) Sequence.

Palmatolepis crepida (Fa1b) conodont zone.

Age control for this sequence is derived from cuttings (690m) in Goulburn 1 and cores 1 and 2 (1419 - 1437m) from Arafura 1 containing an Fa1b conodont assemblage. The Arafura cores were cut in the interpreted lowstand of the Fa2c sequence and the conodont assemblages are considered to be reworked from the underlying Fa1b sequence. The conodont assemblage is not definitive and is described as around the *P. crepida* zone. The age of the sequence could be as young as the *P. marginifera* conodont zone (R. Nicoll, pers. comm. 1992).

The carbonate in Tasman 1 was dated as the late Carboniferous (*S. ybertii* zone) from core. The date was taken from the very top of the core in a mud, rather than from the rest of the core which is dominantly limestone and is considered to represent caving from higher in the well. Permian and Visean forms are also commonly present in samples from the core and the Permian and Carboniferous section. Correlations with other wells suggest that this carbonate horizon falls within the *P. crepida* Sequence rather than the *S. ybertii* zone.

Late Famennian *P. expansa* (Fa2c) Sequence.

Palmatolepis expansa (Fa2c) conodont zone.

Age control for this sequence is limited to core 1 (426 - 433.5 m) from Goulburn 1. This core was cut within a flooding surface of the Fa2c sequence and is considered a reliable date for this sequence. Long ranging palynomorphs, such as *Diasphanospora*, have been recorded in cuttings from the upper part of the sequence in Arafura 1. The section in Tasman 1 is dated as *S. ybertii - D. birkheadensis* and is considered to be caved. The correlation is on log character alone and depends on where the fault intercepts the well. If the fault is as low as the interval above the carbonate section then all of this section would be late Carboniferous. If the fault is higher, then the underlying section would be Devonian as in the present correlation.

Strunian 1

All of the Strunian sequences have been identified mainly on log character because of the long ranges of the spore/pollen zones and the general lack of flora or fauna. The sequences are near shore marine to non marine.

Retispora lepidophyta spore/pollen zone.
The *R. lepidophyta* flora first appears in this sequence, recorded in cuttings from Arafura 1.

Strunian 2

Retispora lepidophyta spore/pollen zone.

R. lepidophyta has been recorded in cuttings from this sequence.

Strunian 3

This sequence is not well characterised in the Arafura Basin and is picked on log character alone.

CARBONIFEROUS

?Tournaisian Sequence.

Early Carboniferous, probably Tournaisian, sequences have been penetrated in Arafura 1 and Visean palynomorphs are a common reworked component in sample residues from late Carboniferous and younger sections. The lower part of Kulka 1 that has been dated as *S. ybertii - D. birkheadensis* and the underlying undated section may actually be early Carboniferous in age. *S. ybertii* in particular tends to swamp indigenous forms either by reworking into younger sediments and caving into older sediments.

The section overlying the interpreted fault in Arafura 1 is considered to be early Carboniferous in age, with the fault intersecting the well higher in the section and down faulting late Carboniferous *S. ybertii* sequences onto early Carboniferous and Devonian sequences.

Late Carboniferous - *S. ybertii -D. birkheadensis* Sequences.

S? ybertii - D? birkheadensis spore/pollen zone

These sequences have been identified in Kulka 1, Tasman 1 and Arafura 1 wells but individual sequences have not been correlated.

PERMIAN

Sequences are tentatively correlated between Kulka 1 and Tasman 1, based mainly on log character because of the long ranges of *G. confluens* and *M. tentula*.

Asselian 1 Sequence.

Granulatisporites confluens spore/pollen zone.

This sequence contains elements of the late Carboniferous *D. birkheadensis* zone as well as early Permian *G. confluens* zone.

Asselian 2 Sequence.

G. confluens spore/pollen zone.

M. tentula was recorded from this sequence in Tasman 1. *M. tentula* could represent the lower part of the *G. confluens* zone or it could be contemporaneous. Detailed work on the spore/pollen assemblages is necessary before a subdivision of these zones is possible.

Asselian 3 Sequence.

G. confluens spore/pollen zone.

Asselian 4 Sequence.

G. confluens spore/pollen zone.

This sequence includes the dolerite intrusion that has been dated at 293 Ma The *R. aemula* date reported from the section above the intrusion and below the Jurassic sandstones (Diamond Shamrock, 1984), is considered to be cavings. This sequence, which was recorded only in Kulka 1, is the youngest Palaeozoic sequence so far found in the Arafura Basin.

Younger Permian and Triassic sequences have not been penetrated by any wells in the Goulburn Graben Basin region.

JURASSIC

***C. turbatus* to *C. torosa* Sequences.**

Callialasporites turbatus to *Corollina torosa* spore/pollen zones.

Sediments of early Jurassic age have been penetrated only in Tuatara 1 in the western part of the basin and have not been subdivided into individual sequences. *Kekryphallospora distincta* is recorded at 3604?m. This distinctive form is a good correlation marker in the Timor Sea, occurring around the boundary of the *C. turbatus* and *C. torosa* zones. Tuatara 1 bottomed in sediments of *C. torosa* age and it is expected that sediments underlying this section would be of Triassic age. BHPP have suggested that the sediments in the bottom part of Tuatara 1 are possibly Devonian.

***D. caddaense* (7d) Sequence.**

Dissiliodinium caddaense dinoflagellate zone - Lower *Dictyotosporites. complex* spore/pollen zone.

Assemblages of this sequence have only been recorded from Tuatara 1. Sequence boundaries have not been distinguished in the sand prone section.

***C. halosa* (7cii) Sequence.**

Caddasphaera halosa dinoflagellate zone - Upper *Dictyotosporites. complex* spore/pollen zone.

This sequence is represented near the base of the Mesozoic in most wells. It is also possible that the sequence has been eroded and elements of the *C. kalosa* assemblage are reworked into the lowstands of the overlying sequences

***R. aemula* to *D. swanense* (*O. montgomeryi*) Sequences.**

Rigaudella aemula to *Dingodinium swanense (Omatia montgomeryi)* dinoflagellate zones

There are several sequences included within this group and the oldest, probably the *R aemula - W. spectabilis* sequence, is the only one with a sandy lowstand. The other sequences are condensed and several sequences are represented, spanning a time range from the *D. swanense* to *O. montgomeryi* zones. The thickest section is in Money Shoal 1 which is also the only well to record the *O. montgomeryi* assemblage.

TITHONIAN TO BERRIASIAN

Tithonian

***D. jurassicum* (5a/5b) Sequence.**

Dingodinium jurassicum (5a/5b) dinoflagellate zones.

The number of sequences within this zone are not yet resolved but there may be two sequences involved. The sequences in the Arafura Basin area are treated as a single sequence as in Labutis (1992)

Tithonian to Berriasian *P. iehiense* Sequence.

Kalyptea wisemaniae (4biii), *Pseudoceratium iehiense* (4ci/4cii) and upper *Dingodinium* *jurassicum* (5ai) dinoflagellate zones.

The maximum flooding surface of this sequence occurs within the *P. iehiense* zone and represents the Jurassic - Cretaceous (Tithonian -Berriasian) boundary. This horizon has also been used as the datum for the stratigraphic cross section (Enclosure 4). The *P. iehiense* sequence is the most widespread of the Jurassic to early Cretaceous sequences in the Money Shoal and other basins of the Northwest Shelf. It is the one sequence that extends onto highs in all basins where it has been observed. It is therefore likely to have the most extensive distribution of the Jurassic-Cretaceous sequences extending the furthest eastwards.

Berriasian *C. delicata* (4biia/b) Sequence.
Cassiculosphaeridea delicata (4biia/4biib) dinoflagellate zone.

Tuatara 1 is the only well where this sequence could be recognised. Elements of the *C. delicata* zone have been recorded from Kulka 1 and Money Shoal 1 but the sequence has been eroded from those areas.

Berriasian *D. lobispinosum* (4aiv - 4bi) Sequence.
Lower *Batioladinium reticulatum* (4aiv) to *Dissimulidinium lobispinosum* (4bi) dinoflagellate zones.

This sequence is particularly well developed in Kulka 1 with a thick, sandy lowstand, a well defined maximum flooding surface and a thick progradational highstand with coastal plain sands at the top of the progrades. The progrades in this and in the *P. iehiense* sequence are characterised by long, straight reflectors rather than sigmoidal. The *D. lobispinosum* sequence is absent or rarely represented in the Timor Sea and Browse Basins, but attains a similar thickness and pattern in the Barrow Sub-basin.

Berriasian to early Valanginian *E. torynum* Sequence.

Egmontodinium torynum (4ai) to upper *Batioladinium reticulatum* (4aiii) dinoflagellate zones.

This sequence has been identified in Tuatara 1 and may also be present in Kulka 1 in the upper part of the sands that have been dated as *B. eneabbaensis* and *D. multispinum*. The *D. multispinum* components are considered cavings.

CRETACEOUS

Valanginian to Aptian *S. areolata* to *O. operculata* Sequences.

Systematophora areolata to *Odontochitina operculata* dinoflagellate zones.

The sequence boundary of the *S. areolata* sequence represents the Intra Valanginian Unconformity. These sequences occur only in Tuatara 1 and none of them is found in any other wells in the Goulburn Graben.

Aptian to Albian *D. davidii* to *P. ludbrookiae* Sequences.

Diconodinium davidii to *P. ludbrookiae* dinoflagellate zones.

These sequences have only been identified in Torres 1, underlying the Cenomanian shales.

Cenomanian to Turonian *D. multispinum* to *P. infusorioides* Sequences.

The sequence boundary of the *D. multispinum* sequence is a strong reflector and extensive, covering all of the sediments of the Money Shoal Basin and most of the Arafura Basin.The *D. multispinum* sequence is predominantly shaley comprising a regional seal over underlying sediments.

Younger Cretaceous and Tertiary sequences have not been identified in this report. Some of these sequences, particularly the Maastrichtian, become sandy in the western part of the Goulburn Graben but are absent from the eastern portion.

STRUCTURE

The acquisition and interpretation of new seismic data, the interpretation of some existing company seismic, and the study of eight petroleum wells, have enabled a revision of the structural and stratigraphic framework for the Arafura and Money Shoal Basins. The basin-wide grid of seismic established by AGSO (the Arafura Basin Reconnaissance) in 1990 and 1991 and used as the primary seismic grid in this study is shown on Enclosure 1. The wells, the water depth contours at 200m, 100m and 40m, pre-existing permit boundaries and the limits of some major structural and stratigraphic elements, are also shown.
Time structure maps have been drawn on the Base of Arafura Basin and the Base of Money Shoal Basin as well as a total sediment thickness map of the Arafura Basin succession (Enclosures 6 to 8). The Base of Arafura Basin (horizon 3) is the unconformity or disconformity between the Proterozoic McArthur Basin sediments and the Cambrian to Triassic Arafura Basin. The Base of Money Shoal Basin (horizon 10) is the unconformity between the Palaeozoic Arafura Basin and the mainly-Mesozoic Money Shoal Basin (Enclosure 2). Line drawings have been made of the interpretation of key seismic lines.

These are presented in a montage (Enclosure 5). The base map, the contour maps and the line drawings on Enclosures 5 to 8 are at a common horizontal scale - 1:1 million.

The three basins that lie beneath the Arafura Sea are described below with reference to the time-structure maps (Enclosures 6 to 8) and the line drawings of key seismic section interpretations (Enclosure 5).

The Money Shoal Basin occupies the western parts of the Arafura Sea, shallowing rapidly eastward from a thickness of around 2500m west of longitude 133 degrees East, to a thickness of only a few hundred metres east of longitude 134 degrees East, and south of latitude 11 degrees South. The base of the succession (horizon 10) is strongly time-transgressive, ranging from Hettangian in the west, to Cenomanian or younger in the east. It is shown contoured in seismic two-way time on Enclosure 6. Approximately 1 second on this map is in the order of 1100 m depth, and 2 seconds is around 2500 m. Diagrams 5a, 5f and 5g show this structure in section. On these cross-sections, made from digitised seismic interpretations, horizon 13 is the major flooding surface at the base of the *D multispinum* dinoflagellate zone, overlying the mid-Cretaceous unconformity. Horizon 13 onlaps the top of the Palaeozoic Arafura Basin. The base of this onlap is shown on Enclosure 1. The shales associated with this flooding surface may seal the unconformity.

The Arafura Basin consists of three parts. In ascending order of area these are, the southern platform, the Goulburn Graben, and the northern sub-basin. These three elements in turn vary markedly from west to east. The base of the succession (horizon 3, the base of the Wessel Formation, nominal base of Cambrian) has been mapped, and is shown contoured in seismic two-way time on Enclosure 7. Approximately 2 seconds on this map is in the order of 3 kilometres depth, and 3 seconds is more than 5 kilometres. The time-thickness of the Arafura Basin succession has been mapped, and is shown contoured in seismic two-way time on Enclosure 8. On this map, 1 second is approximately 2 kilometres of thickness, and 2 seconds represents about 5 kilometres thickness.

The southern platform lies between the southern bounding fault of the Goulburn Graben and the edge of the basin which, onshore, is substantially erosional. In the west, a thin veneer of clastics of uncertain Lower Palaeozoic, possibly Devonian, age, overlies the indurated Lower Proterozoic basement near the Money Shoal 1 well. This is illustrated on the southern end of Enclosure 5b. The older marine sediments of the Arafura Basin, e.g. the Ordovician and the Cambrian, may never have been deposited south of the graben in the Money Shoal area. The McArthur Basin is absent in this area also, and the Money Shoal high appears to be an ancient basement high visible on aeromagnetics maps. Further to the west and south it merges with the Darwin Shelf.

Eastward from Money Shoal 1, the Cambrian is present on the southern platform, and it crops out onshore. The McArthur Basin underlies the Arafura Basin in this area.

The Goulburn Graben is a very heterogeneous feature. At Money Shoal 1 it is less than 20 kilometres in width. Eastward, it becomes broader, opening out southward into a series of fault terraces, and the Cambrian succession thickens eastward. The difference between the graben and the southern platform lessens. Enclosure 5e illustrates the structure in the central area, and the lack of distinction between the graben and the southern platform in this region. On this cross-section the horizons designated by letters, A and B, are Palaeozoic horizons that have been intersected in wells, and whose age is known. The Cambrian succession lies between horizons 3 and A, where A is the top of the Wessel Group, intersected near the base of the Arafura 1 well (Petrofina's horizon F, now redated as Lower

Cambrian). The Ordovician dolomites between horizons A and B(top of dolomites in Arafura 1 and Goulburn 1, Petrofina's horizon E), and the overlying Devonian are not faulted out but rise to the south and are truncated at the base of the Money Shoal Basin (horizon 10). The relative role of erosion and of thinning is not clear on the existing seismic. The base of the Cambrian Wessel Group (horizon 3) continues rising to the south off-section until it crops out onshore. At some stage, therefore, the Lower Cambrian, containing a proposed regional seal and source rock, is both accessible and conceivably within the oil generation window on the southern platform.

The northern bounding fault is prominent from west of Kulka 1 to about 135° E. There is no recognisable correlation of the graben sequences across this fault into the northern basin, hence the throw is unknown. It must be large, in the order of kilometres, but the relative proportions of horizontal and vertical movement remain unknown. The fault trace shows some offsets east of longitude 135° on Enclosure 7. Further to the east, the throw on the northern bounding fault becomes small near longitude 135°, and the graben gives way to the eastern flank of the basin.

The undrilled northern sub-basin of the Arafura Basin extends from the northern bounding fault of the Goulburn Graben to the limit of Australian territorial waters, and beyond into Indonesian waters. The age of the succession is unknown, but is presumed to be Palaeozoic. This opinion is based on its seismic signature, which is stratified, though of high velocity, and does not resemble the signature of the indurated sediments drilled on the southern platform at Money Shoal 1. These latter also appear on aeromagnetics maps as shallow basement. The thickness of the Arafura Basin succession in the northern sub-basin varies from a minimum of between one and two kilometres in the west, where it is truncated by an angular unconformity at the base of the Money Shoal Basin, to greater than seven kilometres in the central area, where it overlies the disconformable McArthur Basin. The structure of the basin in the west is illustrated in cross-section on Enclosure 5b. Here the base, horizon 3, is also the top of basement (or top of intrusions\indurated sediments) and the succession is older than elsewhere in the study area. The basinal succession is younger on the next line to the east, illustrated on Enclosure 8c, and it is younger still near the central area, on Enclosure 5d. Enclosure 5g illustrates how the Arafura Basin succession becomes younger to the east. The nature of the lithological changes producing reflectors 5, 7 and 8 is not known. Some have claimed to recognise the high-amplitude reflector 5 as the signature of the Jurassic Plover Formation of the Timor Sea, others the Permian Hyland Bay Formation of the Bonaparte Basin. It is referred to here simply as Palaeozoic. On the eastern flank of the basin, near the Wessel Islands, the basin shows signs of thinning, and mild onlap of the McArthur Basin at an almost peneplaned surface. The Cambrian succession is partially exposed in the Wessel Islands, and the estimated thickness of the Wessel Group, added to the intersection of its top in Arafura 1, was used to define seismic horizon 3, the base of the Arafura Basin succession. Horizon 3, the predicted base of the Wessel Group and base of Cambrian, thus represents the top of the McArthur Basin where that basin is present, or the top of basement elsewhere.

The McArthur Basin has not been intersected offshore, hence its presence is inferred from seismic. The top of the succession where it exists is horizon 3, mapped and contoured in seismic time on Enclosure 7. The bottom of the succession is horizon 1, defined only on seismic lines in the northern sub-basin and shown in cross-section on Enclosure 5f and 5g. In the west of the study area, the basin is probably absent both north and south of the Money Shoal 1 well. The east-west fault trends in the western part of the northern sub-basin may represent structuring in the Mid or Lower Proterozoic, but are also typical of areas bordering highs where northwest-southeast and northeast-southwest trending troughs intersect. The same fault trends are present to the north of the Londonderry High near the intersection of the Sahul Syncline and the Cartier Trough as well as in the northern Browse Basin. In the gazetted area the McArthur Basin thickens rapidly from the west, east and south to form a sequence several kilometres thick under the center of the Arafura Basin and disconformable with it. In that area, the McArthur Basin is likely to be uppermost Proterozoic (Roper Group), but toward the Wessel Islands in the east an angular unconformity at an almost peneplaned surface separates older, probably Middle Proterozoic, McArthur Basin sediments from the mildly onlapping Cambrian. Signs of a north-south trending rift (the Walker Trough) are visible underneath the peneplaned base of Cambrian near the Wessel Islands, but the interpretation of this feature has not been resolved at this date.

HYDROCARBON DISCOVERIES AND POTENTIAL

RESERVOIRS

Palaeozoic clastic reservoirs penetrated have proven to be of generally poor quality with low porosity and permeability. Carbonate cementation, the breakdown of volcanic and lithic fragments and silica overgrowths have occluded the primary porosity in many of the Palaeozoic sandstones Jurassic sandstones have also suffered diagenetic effects that have reduced porosity.

Log analysis of sandstones based on sonic and neutron calculations in Kulka 1 and other wells penetrating the Palaeozoic clastics, have shown minimal porosity (less than 7%) in the Carboniferous and Permian section. Kulka 1 shows several zones of washouts and bad hole conditions where the porosity measurements are unreliable. These zones, generally those representing the lowstand systems tracts, are considered to represent sandstone sections with reasonable porosity. Porosity estimations are based on visual observation of cuttings and log derived determinations Visual determinations usually record cemented aggregates of grains and may not be representative of the sandstone as a whole since loose grains can pass through the shakers and not be detected in that part of the section. This does not mean that all of the washed out zones are porous sandstone reservoirs, but that at least some of them are likely to contain sands of reasonable reservoir quality, particularly in the Permian section.

Core measurements in the Famennian clastic section of Arafura 1 and Goulburn 1, that are interpreted to represent the lowstand and transgressive systems tracts, have shown some sands to be of fair quality with up to 19% porosity. Better quality sands are usually found in the lowstand system tract but this also depends on the location of the well, whether in an incised valley, towards the edges or downdip from the shoreline. The Devonian sequences were deposited in a tidal to sabkha environment conducive to the deposition of a large proportion of mud with the sands as well as the formation of dolomite and carbonate cements. The Devonian and younger Palaeozoic depositional systems were generally confined to the Goulburn Graben area and not an extensive, shallow shelfal environment as in the Cambrian and Ordovician. This type of confined estuarine environment should still produce areas with sands of good porosity, particularly within the main depositional channels.

Cambrian, Ordovician and Devonian limestones and dolomites show negligible primary porosity and permeability. The Cambrian dolomites are vuggy and fractured, so the development of porosity and permeability in these sediments depends on their location near faults and folds where fracturing could be enhanced. Goulburn 1 had several zones of lost circulation in the dolomites that were also associated with oxidised oil and bitumen. These zones may represent karstic porosity developed during exposure of the carbonates as a consequence of major relative falls in sea level. They should therefore occur around sequence boundaries and lowstand system tracts. Karstic reservoirs still require fracturing of the carbonates to provide a conduit for the migration of oil.

The late Jurassic (Tithonian to Berriasian) sandstones, in particular, generally show good porosity ranging up to 33%

SEALS

Seals are plentiful in the Palaeozoic sequences where every flooding surface (marine incursion) has the capacity to act as a source and a seal. Both Arafura 1 and Goulburn 1 recorded live oil, bitumen and dead oil shows throughout the Cambrian to Devonian section. Oil shows in both wells extend up to the flooding surface of the late Famennian *P. expansa* sequence and are absent in sands above that surface. The flooding surface therefore, acts as an effective seal preventing migration of oil into reservoirs higher in the section.

The shows of bitumen in the Permo-Carboniferous sediments below the *D. multispinum* unconformity in Arafura 1 are likely to be a result of fault migration from the deeper Cambrian since there are no shows in the intervening Devonian and Carboniferous section. There are no shows in the *D. multispinum* section and it is acting as an effective seal, where any migrating oil is trapped beneath this unconformity, as suggested by Arafura 1.

Reservoirs are often tight in the Carboniferous section and Vitrinite Reflectance and Conodont Alteration Indices suggest that these sediments have been buried a few thousand metres deeper than the present day. This section would act as a sealing rather than a reservoir interval.

The maximum flooding surfaces, that are well displayed by the *P. iehiense*, *D. lobispinosum* and the Oxfordian sequences (Enclosures 3, 4), form effective seals as well as comprising good sources where mature. These surfaces are confined to the western part of the basin and are unlikely to exert any influence in the gazetted area Equivalent surfaces within the Palaeozoic sequences, as in Arafura 1 and Goulburn 1, will act as seals in the eastern part of the basin.

SOURCE AND MATURATION

Bitumen strandings have been a common occurrence in the Arafura Basin and these have been considered to possibly represent Palaeozoic or Proterozoic oil seepages (Wade, 1924). Analysis of this bitumen by McKirdy & Horvath (1976) and recently (J. Bradshaw, pers. comm., 1992) has revealed that all have a Cretaceous to Tertiary origin.

The richest source rocks (up to 8.65% Total Organic Carbon) in the Arafura Basin occur in the early Middle Cambrian *T. gibbus* Sequence in Arafura 1. The Raiwalla Shale section, immediately underlying this interval, is potentially also a rich oil source but has not been sampled geochemically.

Proterozoic sediments of the McArthur Basin underlying the Arafura Basin also have TOC contents up to 10 % (Summons et al., 1988). If latest Proterozoic sediments are present within the basin, as they are suspected in the north-western region, then excellent source potential is likely in these sequences. During this period, Oman was located on the northern margin of Gondwana facing northward onto the Tethyan ocean in a similar setting to the Arafura region. This late Proterozoic sequence in Oman has sourced 12 thousand million barrels of oil.

Arafura Basin samples from Ordovician rocks have revealed low TOC values, although equivalent aged sediments from other basins are good source rocks (Bradshaw et al, 1990). The distribution of the Arenigian and early to middle Cambrian has a bearing on the oil shows since these sequences contain the richest source rocks. Arafura 1 and Goulburn 1 are both located in the area of thick Arenigian and middle Cambrian and display hydrocarbon shows up to the Devonian, even in the dolomitic section. All of these shows are considered to be sourced from the middle Cambrian. The middle Cambrian and Ordovician pinch out to the east of Tasman 1 and Torres 1, neither of which have shows in the dolomitic section. Tasman 1 had shows in the Famennian limestones that may have been sourced locally or also from the Cambrian. The presence of the source rocks, the middle Cambrian in this case, determines the distribution of oil shows and accumulations. The source rock section is expected to thicken to the north and east of the Goulburn Graben in the gazetted area.

The Devonian sediments also show high TOC values, ranging up to 0.69% in the *A. parva* sequence, 0.9% in the *P. crepida* sequence and 4.88% in the *P. expansa* sequence. All of these values however, are derived from oil stained sections and may not represent the true source potential. High values have not been reported from the Strunian section which does not have any oil shows.

Carboniferous samples are mainly from Kulka 1 which shows values up to 1% TOC, with many of the samples over 0.5%. The sediments are good, but gas prone sources.

The Permian sediments are sampled from Kulka 1 and Tasman 1 reaching 1.09% TOC values with much of the shale section over 0.5%. Geochemical analysis by Diamond Shamrock (1985) suggest a gas prone source but with moderate oil potential. All of the shows in Kulka 1 occur in the Permian sediments with some migration into the overlying late Jurassic section.

Late Permian and Triassic sediments could also contain good source rocks, but sediments of this age have not yet been penetrated in the Arafura Basin.

Jurassic and younger sediments also show good source characteristics but are unlikely to provide any source potential in the gazetted area.

Maturation in the Arafura Basin is quite variable and depends on present depth of burial and past depth of burial before the wrenching episode. The difference is well shown by Kulka 1 where the Vitrinite Reflectance values show a marked increase below the Base Mesozoic Unconformity. Vitrinite Reflectanc values do not apply to sediments of pre Devonian age and in these sediments are applied to Vitrinite-like organic material, if available. The Conodont Alteration Index is a better measure when conodonts occur. Geochemical data suffers the same problems as palaeontological dating and is particularly prone to contamination. There is no method of determining whether geochemical samples are representative of the section or are caved or even a mixture of both. This has obviously occurred in cases where chromatograms are indicating immature source rocks where CAI and other indicators show overmaturity.

Bradshaw et al., (1990) have discussed the maturation profiles for wells within the Goulburn Graben. Goulburn 1 and Arafura 1 have not been buried much deeper than the present day. Therefore, the Middle Cambrian and Proterozoic source rocks in the Gazetted area should lie within the oil window. This area has not been deformed as much as the western part of the Goulburn Graben, so that oil accumulations may be intact and not as affected by structural movements.

Permo-Triassic sediments in the western part of the graben are well within the oil window to source hydrocarbons into the Jurassic sandstones, although Carboniferous sediments would be sourcing dry gas.

PLAYS

All of the plays previously documented have been largely restricted to the graben, due to the structuring that has occurred in this region and the subsequent concentration of the seismic data acquisition to this area. The existence of structuring north of the graben has only now become apparent with the acquisition of Surveys 94 and 106.

Goulburn Graben Plays

Structural Plays

The wells drilled in the Goulburn Graben have been located on a variety of structural closures. The eastern part of the basin includes the thickest section of Middle Cambrian and Proterozoic source rocks which have sourced the oil in Arafura 1 and Goulburn 1. Structures in this area have a proven source and seal but have a risk of poor reservoir quality in the Devonian clastics and are dependent on fracturing or karstic porosity in the dolomite units. Better quality reservoirs do exist and are related to estuarine or river systems within the graben.

Arafura 1 recorded live oil and oil bleeding from cores. This suggests that Arafura 1 may have been drilled near the edge of closure and in the vicinity of the oil-water contact, thus leaving updip potential for an oil accumulation on the same structure. The fault in Arafura 1 is interpreted to penetrate the well closer to the Mesozoic unconformity, downfaulting late Carboniferous/Permian onto early Carboniferous. There are traces of bitumen just below the Cenomanian shales which suggest that the faults are acting as conduits for oil migration. Fault related closures in the gazetted area are likely to be accumulations of Cambrian oil in clastic reservoirs as well as carbonate reservoirs since fracturing would be enhanced. There are a number of undrilled structural leads within the gazetted area including fault related closures, transpressional anticlines, trapdoor structures and flower structures. Hydrocarbon accumulations are likely to be oil rather than gas because of the Cambrian algal source.

Reef Plays

The carbonates in Tasman 1 and Torres 1 have been included with the Famennian *P. crepida* sequence rather than in the Carboniferous. The Canning Basin has reefal development of this age and it is likely that reefs were formed in the Arafura Basin since the area was located in an even more tropical setting during the late Devonian than the Canning Basin.

The Famennian carbonates recorded from the Arafura Basin are not reefal but basinal, reflecting a reduction of clastic sediment supply. These carbonates were deposited in the centre of the graben in its pre-transpressional configuration (Figure 3) and are unrelated to reefs. Reef development would have been restricted to high blocks along the graben bounding faults of the northern and southern margins of the Goulburn Graben as they are in the Canning Basin. The eastern part of the Goulburn Graben consists predominantly of clastic sediments during the Famennian. Carbonates appear around the Tasman and Torres areas. It is unlikely that reefs would be found further to the east and should be restricted to the western part of the gazetted area.

Stratigraphic Plays

The folding of the Palaeozoic and Triassic sediments of the Goulburn Graben (Figure 3) sets up a stratigraphic play involving the Jurassic sediments. The *P. iehiense* sequence has the most extensive distribution of the Jurassic sequences, as well as a thick, sand prone lowstand section with excellent reservoir quality. The distribution of the sequence is in two embayments along the graben bounding fault systems and bordering the Torres anticline. These embayments extend into the gazetted area and have been eroded, eventually covered by the shale prone Cenomanian *D. multispinum* sequence that acts as a regional seal (Figure 4). The source is likely to be the Permian and Carboniferous sediments truncated by the reservoir sands since these are the only sediments in direct, angular contact with the sands. Fault migration could also include the Cambrian as a source. Permian and Carboniferous sources are principally gas prone but also comprise a fair oil source in the Permian, so that hydrocarbon accumulations are likely to be gas with oil.

Bottom seal is the risk associated with this type of play, since it depends on some form of seal below the Cenomanian shales to enclose the pinchout. The Palaeozoic sediments that would form the bottom seal are predominantly fine grained, sealing sediments but also include reservoir sand intervals that could lead to leakage.

Plays in the Northern Sub-basin

Examination of plays outside the graben are speculative because of the lack of well data north of the bounding fault system, and the variety of differences in interpretation of the age of the sequences that are present. However taking this into account four areas can be briefly described. Examination of seismic data from surveys 94 and 106 reveals a regional syncline north of the graben, which could have a core of Devonian sediment. It forms a basinal shape in the sub-crop map beneath the Mesozoic unconformity (Figure 5). The regional structure of the northern sub-basin and relative thickness compared to the graben, can be appreciated in Figure 10, which shows the central and western parts of the basin, and on Enclosures 5 and 8.

Faulted anticlines - adjacent to graben

Adjacent to the northern bounding fault are a series of fault blocks which locally appear to form a region of arching (Figures 6 & 7). This structuring occurs in late Palaeozoic sediments probably of Devonian to Cambrian age and at TWT's of 1.5 seconds. The major risks are porosity and lateral fault seal. Migration of hydrocarbons could have occurred from the syncline to the north, and perhaps also out of the graben.

Tilted fault blocks - northwestern area

The north-western edge of the basin contains a series of tilted fault blocks overlain by a rift infill sequence (Figure 8). The tops of the fault blocks occur on Line 94-4 at TWTs of around 2 seconds (Figure 9 and Enclosure 7). Reactivation has occurred, producing folding in the overlying rift infill sequence with some downside roll-over. A variety of ages for this sequence are possible, however the fault blocks are most likely Middle Proterozoic in age from the McArthur Basin sequence. The overlying rift infill is probably also Proterozoic, but could potentially be latest Proterozoic and perhaps lower Palaeozoic in age. The obvious risk is porosity as these sequences are on the flanks of a thick sedimentary section that appears to have been buried and subsequently eroded at the uplifted edge of the basin. However, speculation that features such as the Money Shoal block have been emergent for a long period of time could imply that deep burial may not necessarily have occurred, and thus porosity may have been preserved, as occurs in many places in the onshore McArthur Basin.

If the fault blocks are of Mid Proterozoic age then they may be equivalents of the Kombolgie Sandstone which forms the Arnhem Land escarpment and crops out on Goulburn Island south of Line 4. On Goulburn Island, the Kombolgie Sandstone consists of coarse grained, fluvially deposited sandstone, which on visual inspection contained excellent porosity. The risk is that such porosity may have been enhanced by surface weathering effects, however the mono-mineralic nature of the outcrops (quartz) could suggest that no feldspathic or clay based matrix had originally been present. Reworking of the tops of the faults blocks and enhancement of the existing porosity prior to deposition of the rift infill sequence is also possible, as a very coarse grained lag of quartz occurs on Goulburn Island overlying the outcrops of Kombolgie Sandstone.

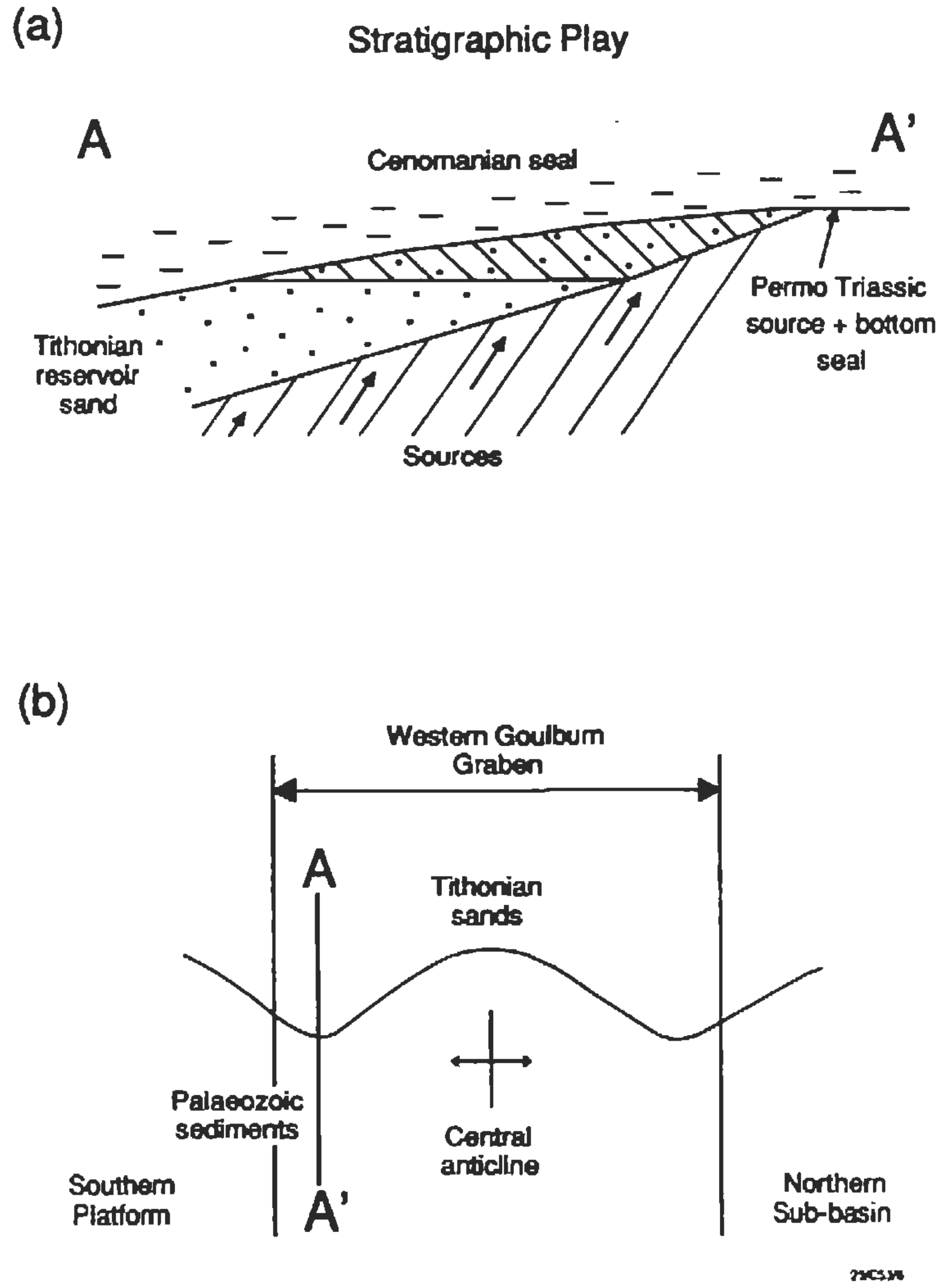


Figure 4 Schematic diagram showing the onlap of the sand prone Jurassic sediments at the western end of the Goulburn Graben.

The other risk in this play is east-west closure as the line spacing is very coarse. The Mesozoic sequence dips westward and the fault blocks strike approximately east-west but dip to the east, whilst the rift infill thins to the west. As such, premium well locations may exist where the fault blocks are at their shallowest structural positions, overlain by a minimum of Mesozoic sediment, and which coincide with the stratigraphic pinch out of the rift infill sequence. If such a position coincides with reactivation of the overlying Mesozoic sequence then a multiple target could exist. If the sequence contains latest Proterozoic sediments then excellent source potential is possible. Such a play can only be determined with a much closer seismic grid

Northern and north-eastern regions

In this region the structural dip is low in an overall synclinal setting, although a very thick sedimentary section is evident from seismic data (Figure 6 - northern end of line, and Enclosure 5). A tighter grid of seismic may define broad fault block structures in this region, although considered unlikely. The sediments sub-cropping the Mesozoic are most likely Cambrian to Devonian in age (Figure 5). As this area appears to not have been buried any more deeply than it is today, the risk of porosity is minimised, however finding viable structures may be the largest risk

In the northeast, the geology and structure is similar except immediately adjacent to Elcho Island, were a thick north south graben of undoubtedly Proterozoic sediment occurs, probably related to the Batten Walker fault zone. Structuring on the flanks of this graben in the overlying Palaeozoic sediments is a possible structural target with migration of hydrocarbons updip from the Palaeozoic depocentre to the west and out of the adjacent Proterozoic graben. Again this play depends on closer seismic control to properly define it.

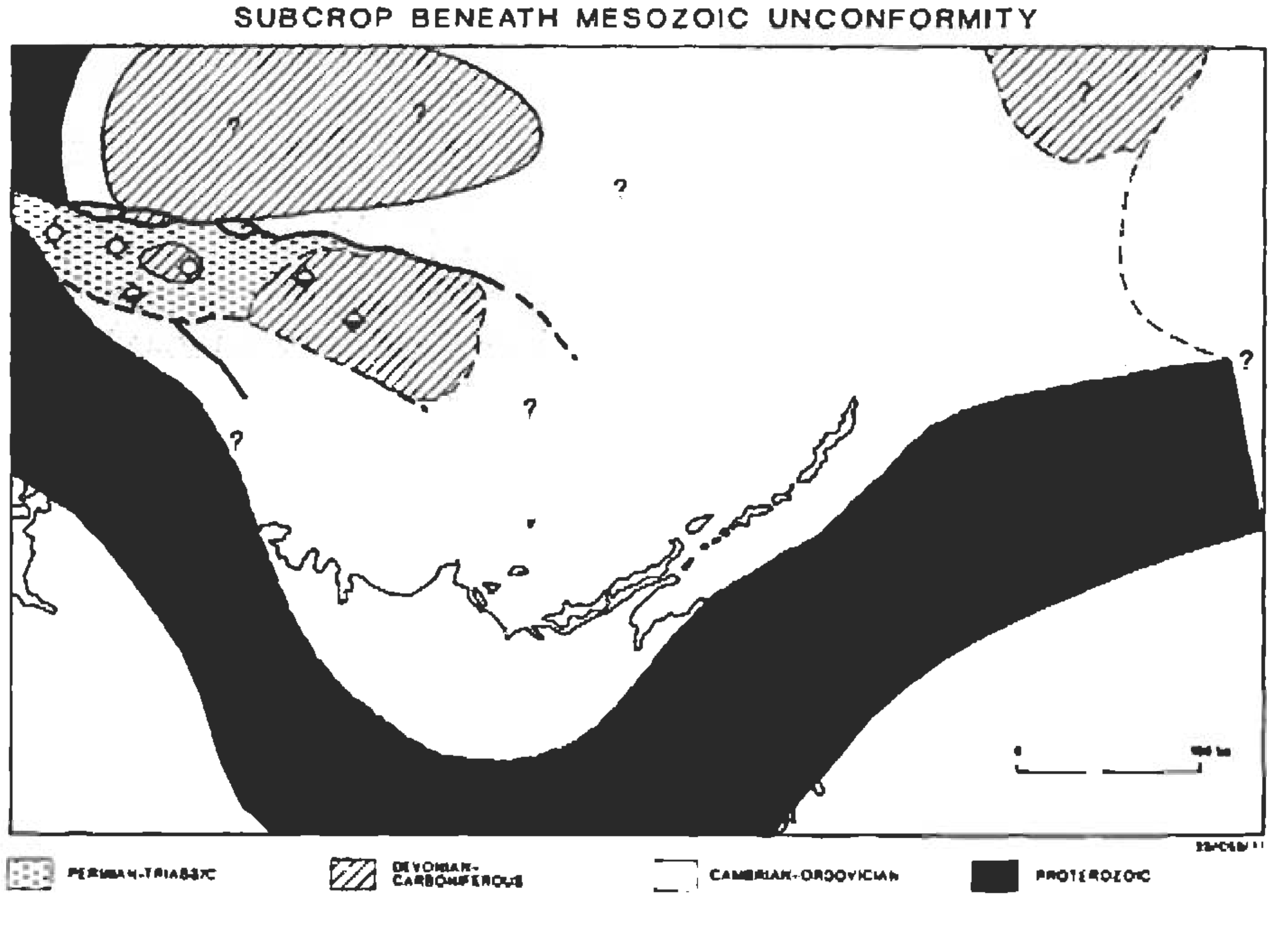


Figure 5. Arafura Basin subcrop map beneath the Mesozoic unconformity.

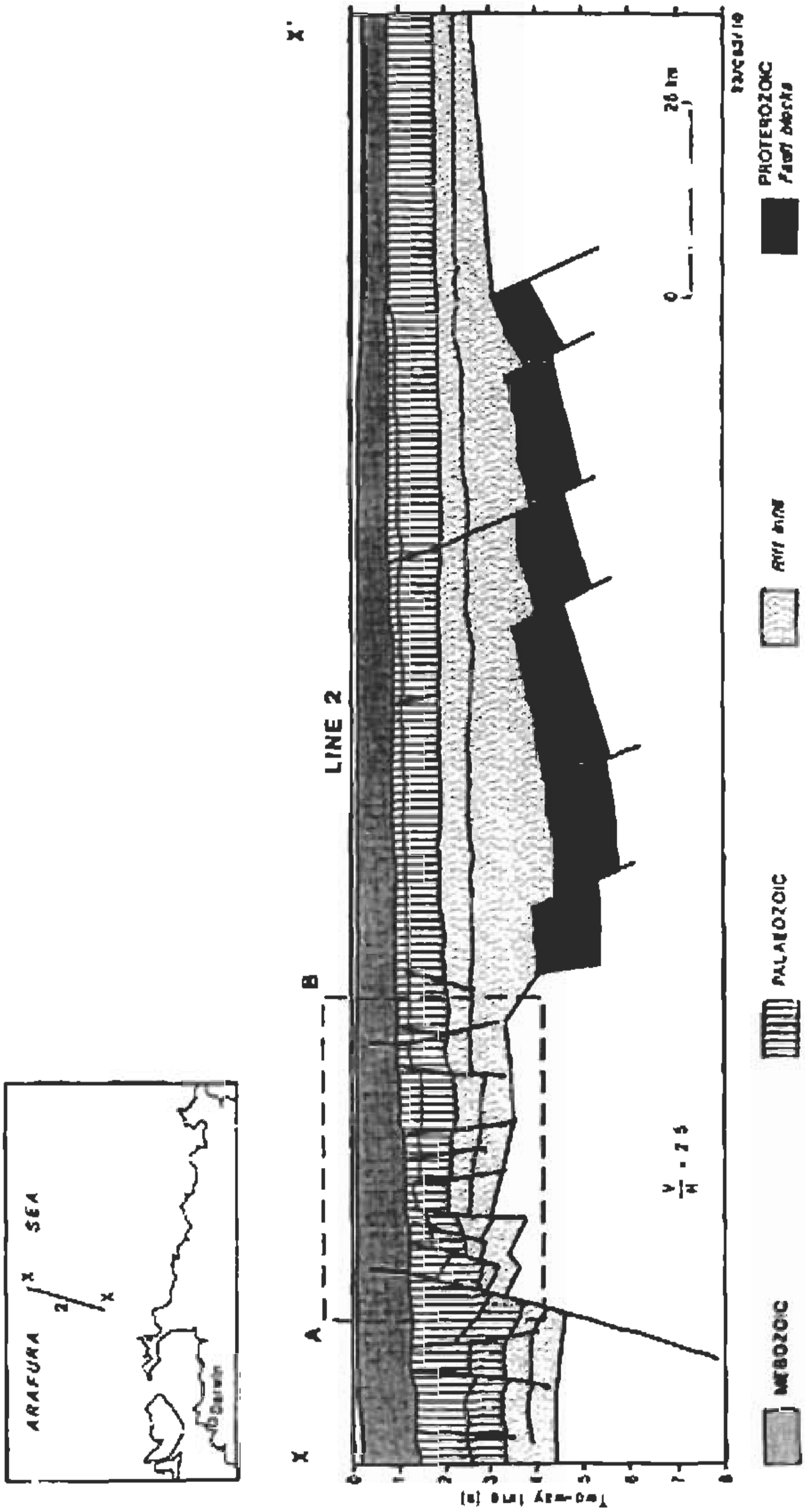


Figure 6. Line diagram of BMR seismic line 94/2 which extends from the Goulburn Graben to the Indonesian border. Inset AB refers to Figure 7.

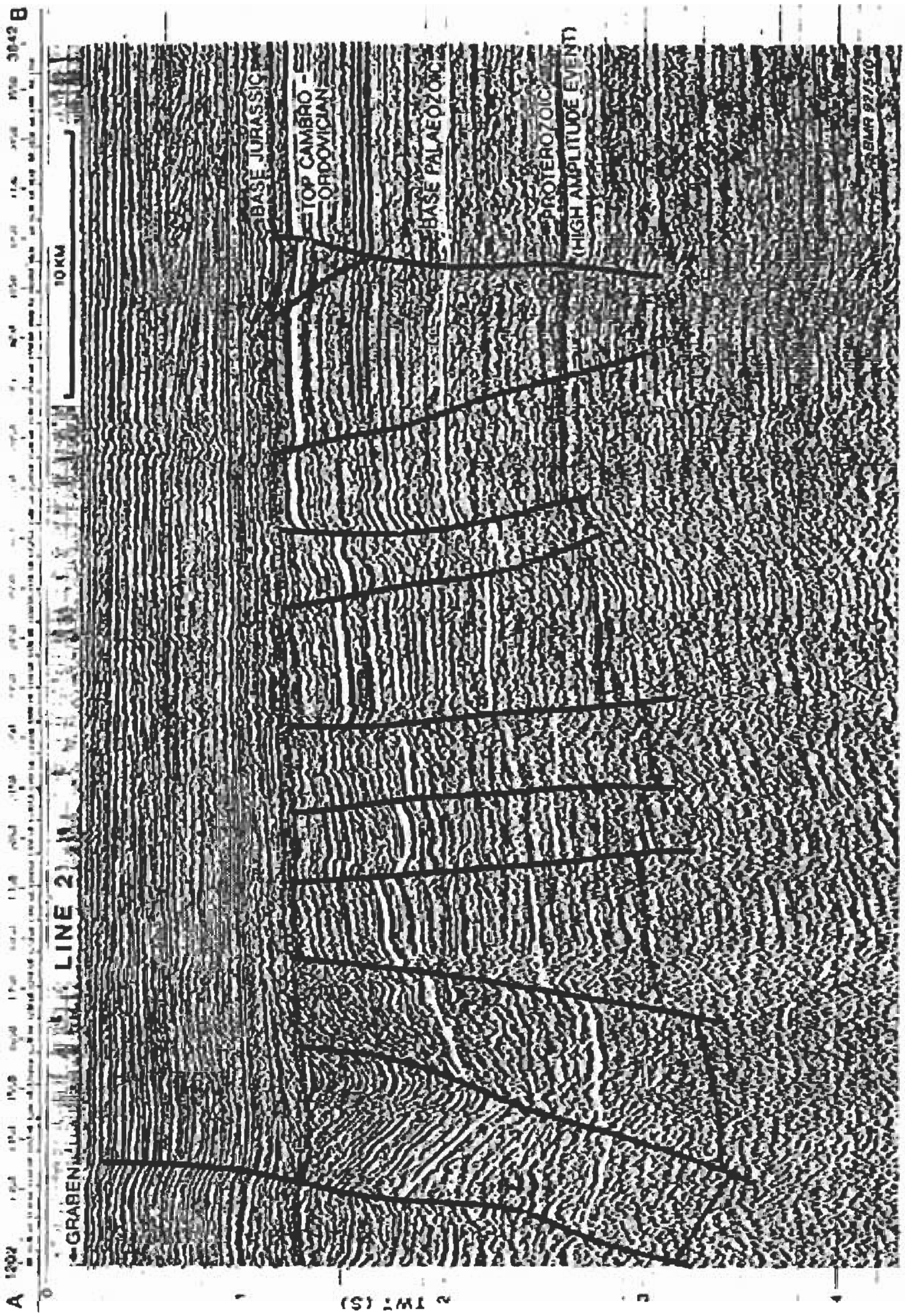


Figure 7. Seismic line 94/2 showing an area of local arching adjacent to the northern bounding fault of the Goulburn Graben See Figure 6 for location.

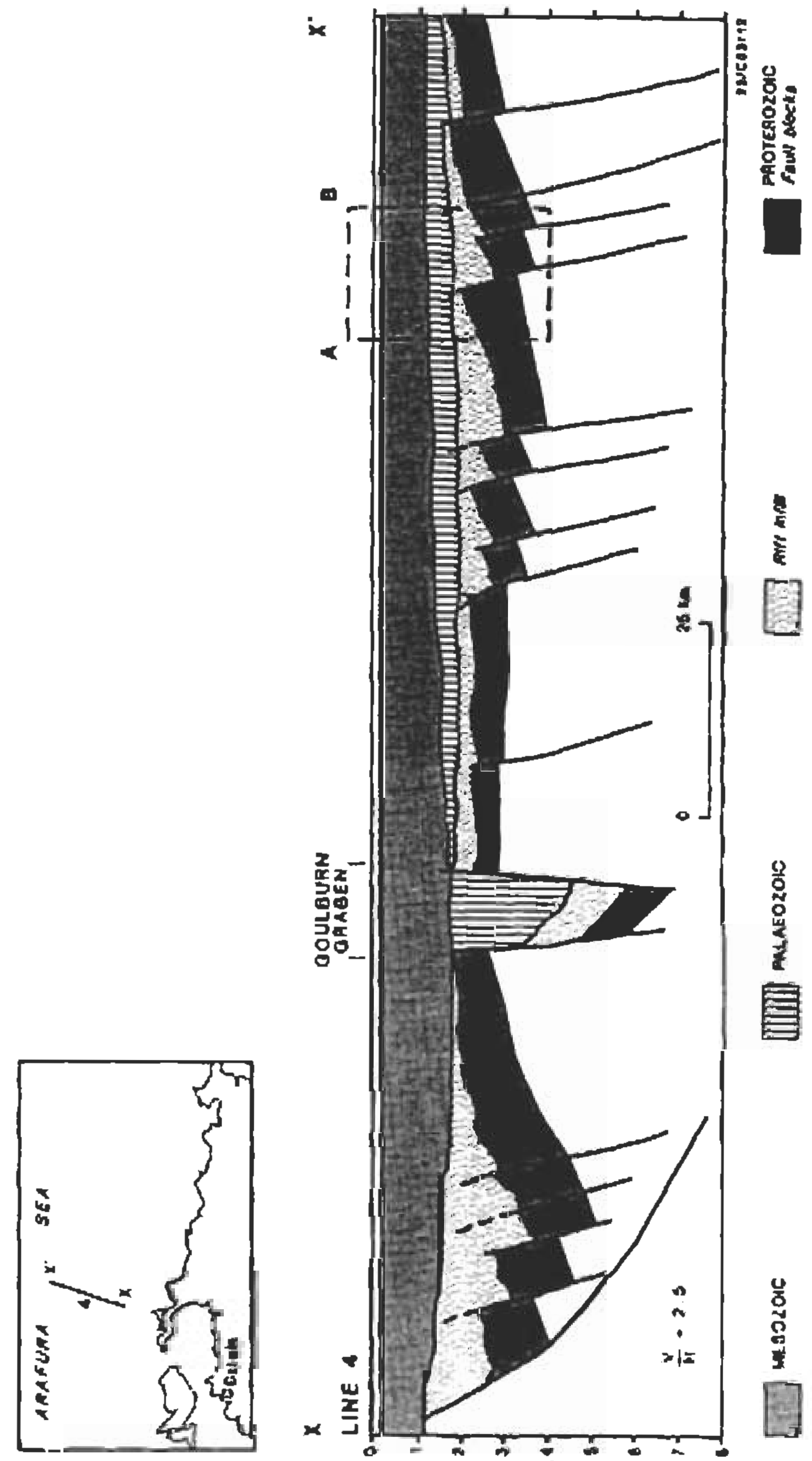


Figure 8. Line diagram of seismic line 94/4 which **extends from** the southern side of the **graben to the Indonesian border**. Inset AB refers **to Figure 9**.

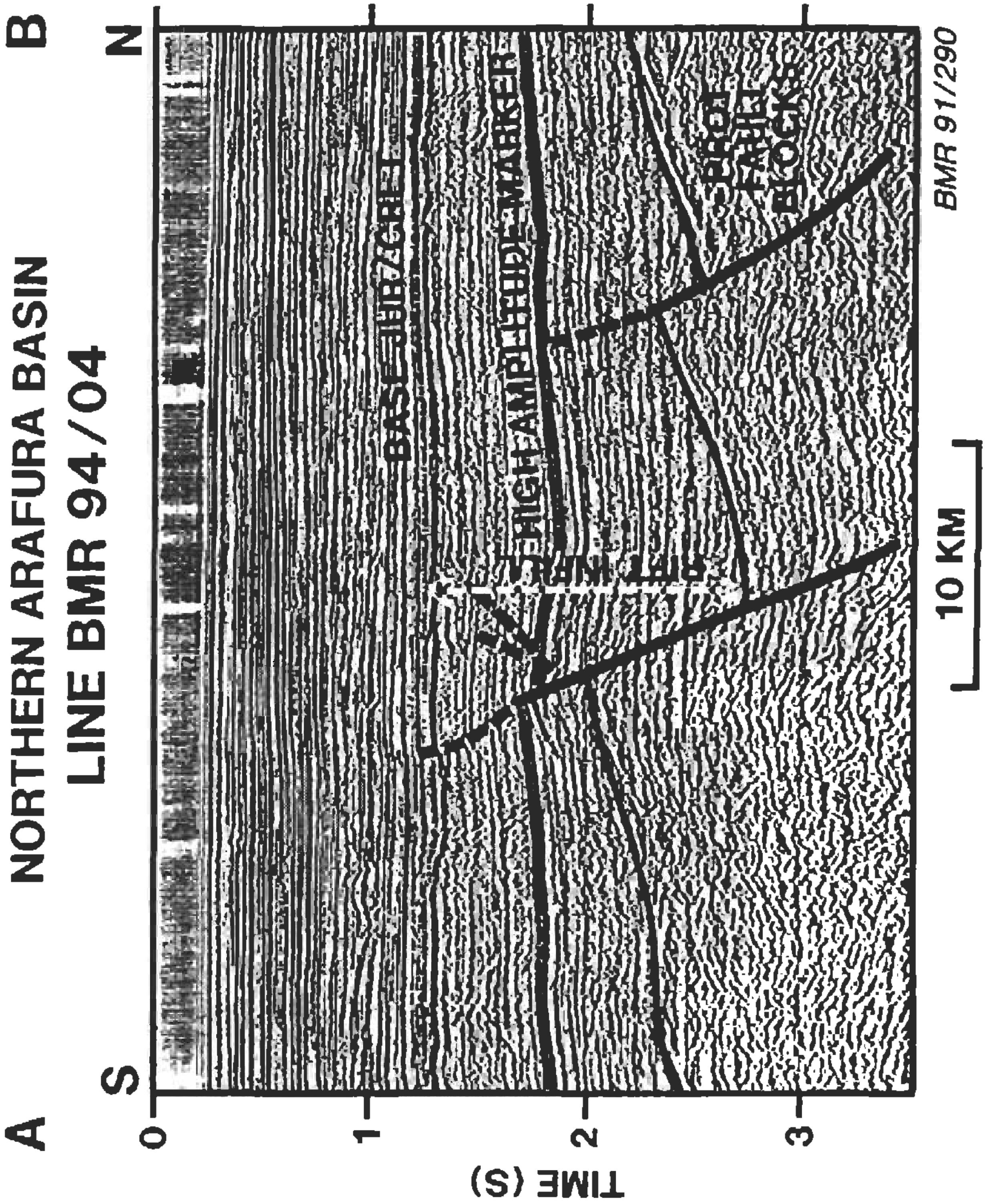


Figure 9. Seimic Line 94/4 showing fault blocks and rift infill sequence. See figure 8 for location.

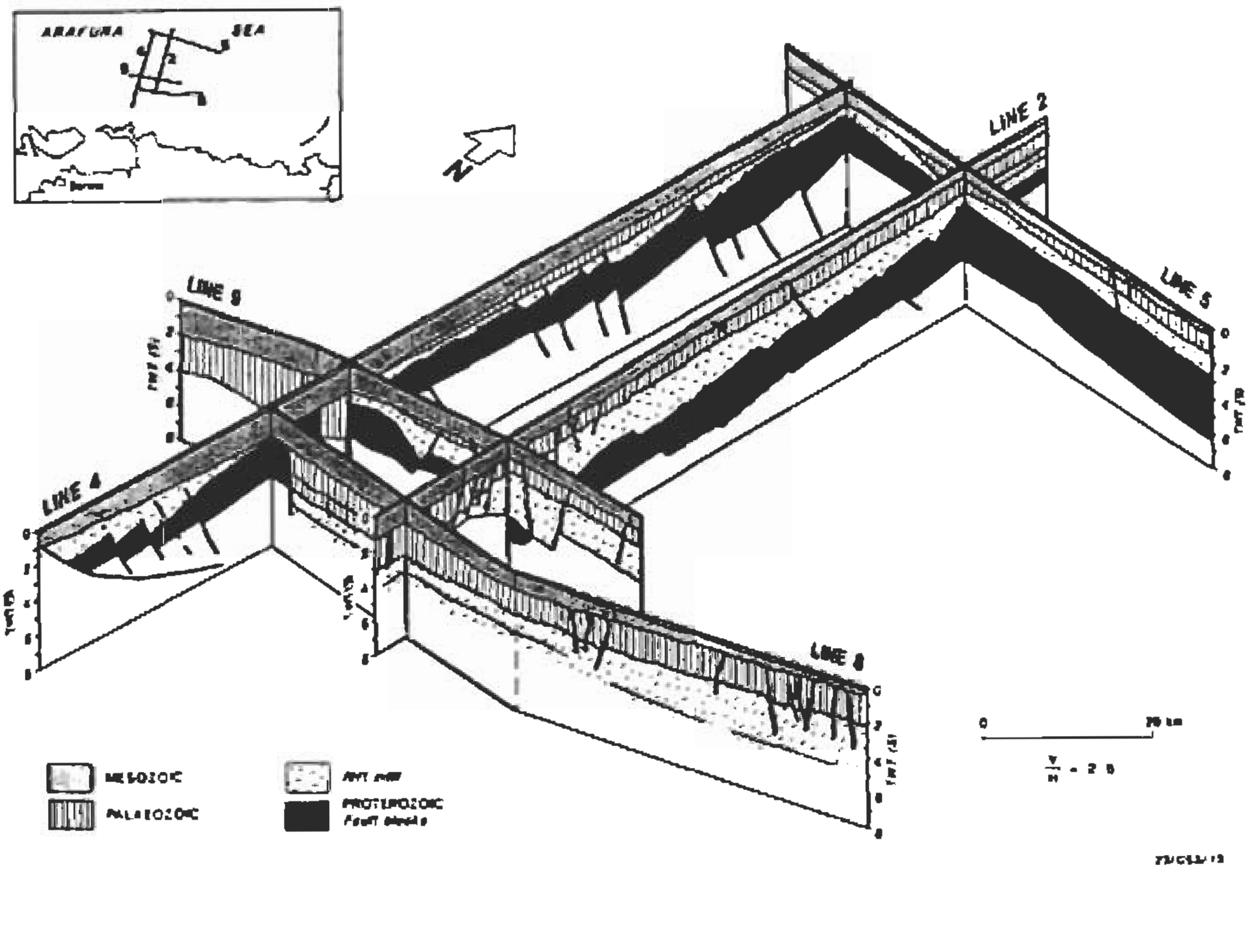


Figure 10. Line diagram of selected seismic lines from Survey 94 showing the relative scale of the Goulburn Graben to the sub-basin to the north.

WELLS		TUATARA	KULKA	MONEY SHOALS	TASMAN	TORRES	ARAFURA	GOULBURN
SEQUENCE								
D. multispinum	top							
	base	2597	1530	1152	653	762	398	172
	thickness							
S. areolata - O. operculata	top	2597						
	base	2935						
	thickness	338						
E. torynum	top	2935	1530					
	base	2968	1566					
	thickness	33	36					
D. lobispinosum	top	2968	1566	1152		783		
	base	3023	1900	1294		825		
	thickness	55	334	142		42		
C. delicata	top	3023						
	base	3146						
	thickness	123						
P. iehiense	top	3146	1900	1294	653	825		
	base	3254	2040	1791	798			
	thickness	108	140	497	145			
D. jurassicum	top	3254	2040	1791				
	base	3305	2198	2046				
	thickness	51	158	255				
R. aemula -O. montgomeryi	top	3305	2198	2046	798	1017		
	base	3333	2313	2322	1064	1188		
	thickness	28	115	276	266	171		
C. halosa	top	3333	2313	2322	1064			
	base	3437	2510	2472	1162			
	thickness	104	197	150	98			
Asselian 4	top		2510					
	base		2689					
	thickness		179					
Asselian 3	top		2689					
	base		2803					
	thickness		114					
Asselian 2	top		2803		1162			
	base		2965		1323			
	thickness		162		161			
Asselian 1	top		2965		1323			
	base		3115		1459			
	thickness		150		136			
?Tournaisian	top		3115		1459		600	
	base				1520		694	
	thickness				61		94	
Strunian 3	top						694	
	base						850	
	thickness						156	
Strunian 2	top						850	
	base						1077	
	thickness						227	
Strunian 1	top				1520	1188	1077	178
	base				1573	1295	1198	226
	thickness				53	107	121	48
P. expansa	top				1573	1295	1198	226
	base				1806	1553	1448	491
	thickness				233	258	250	265
P. crepida	top				1806	1553	1448	491
	base				1965	1759	1592	643
	thickness				159	206	144	152
A. parva	top				1965	1759	1592	643
	base				2275	2068	1704	776
	thickness				310	309	112	133
P. elegans	top						1704	776
	base						1904	1055
	thickness						200	279
Tremadocian	top				2275	2068	1904	1055
	base				2320	2298	2118	
	thickness				45	230	214	

Table 1. Tops, bottoms and thickness (meters) of the sequences for all the wells in the Arafura Basin

REFERENCES

BALKE, B., PAGE, C., HARRISON, R., & ROUSSOPOULES, G., 1973: Exploration in the Arafura Sea. APEA Journal 9(12), 9-12.

BHP PETROLEUM, 1991: Tuatara 1 well completion report (unpublished).

BRADSHAW, J., NICOLL, R.S., & BRADSHAW, M., 1990: The Cambrian to Permo-Triassic Arafura Basin, Northern Australia. APEA Journal, 30(1), 107-127.

BRADSHAW, J., & VIZY, J., 1991: Fission Track Database. BMR Record 1991/02.

DIAMOND SHAMROCK OIL COMPANY (AUSTRALIA) PTY. LTD., 1985: Kulka 1 well completion report (unpublished).

ESSO AUSTRALIA LIMITED, 1983: Tasman 1 well completion report (unpublished).

ESSO AUSTRALIA LIMITED, 1983: Torres 1 well completion report (unpublished).

FACER, R.A., 1984: Explanatory notes and discussion regarding fission track study of samples from Tasman-1 and Torres-1 (unpublished).

FOSTER, C.B., O'BRIEN, G.W., & WATSON, S.T., 1986: Hydrocarbon source potential of the Goldwyer Formation, Barbwire Terrace, Canning Basin, Western Australia. APEA Journal 26(1),142-155.

GLEADOW, A.J.W., DUDDY, I.R., 1982: Fission track dating of samples from Money Shoal-1, Arafura Sea, Dept. Geology, University of Melbourne report for Esso Aust. Ltd. (unpublished).

GLEADOW, A.J.W., DUDDY, I.R., & GREEN, P.F., 1983: Fission track analysis of samples RAF-1 to RAF-9, Dept. Geology, University of Melbourne for Esso Aust. Ltd. (unpublished).

HELBY, RJ., & PARTRIDGE, A D., 1982: A palynological review of the Money Shoal-1 well in the Arafura Sea off, Northern Australia (unpublished).

HELBY, R.J., MORGAN, R., & PARTRIDGE, A.D., 1987: A palynological zonation of the Australian Mesozoic. Association of Australasian Palaeontologists, Memoir 4.

JACKSON, M.J., DIEKMAN, L.J., KENNARD, J.M., SOUTHGATE, P.N., O'BRIEN, P.E., & SEXTON, M.J., 1992: Sequence Stratigraphy, Basin-floor Fans and Petroleum Plays in the Devonian-Carboniferous of the Northern Canning Basin. APEA Journal 32(1), 214-230.

LABUTIS, V.R., 1991: Sequence Stratigraphy of the Timor Sea Area. Report for Noreen International (unpublished).

LABUTIS, V.R., 1992: Sequence Stratigraphy of the Browse Basin, Northwest Shelf, Australia. Report for Petroconsultants Australasia Pty. Ltd. (unpublished).

LEE, R.J., & GUNN, P.J., 1988: The Bonaparte Basin in Petroleum in Australia, The First Century, APEA Publication, 252-269.

McKERROW, W.S., & SCOTESE, C.R., 1990: - Palaeozoic Palaeogeography and Biogeography : Revised world maps and symposium introduction. Geological Society Memoir 12..

Mc KIRDY, D.M., & HORVATH, A, 1976: Geochemistry and significance of coastal bitumen from southern and northern Australia, APEA Journal 16(1),123-136.

McLENNAN, J.M., RASIDI, J.S., HOLMES, R L., & SMITH, G.C., 1990: The Geology and Petroleum Potential of the Western Arafura Sea. APEA Journal 30(1), 91-106.

MARTIN, B.A., & CAWLEY, S J., 1991: Onshore and offshore Petroleum Seepage - Contrasting a conventional study in Papua New Guinea and airborne laser fluorosensing over the Arafura Sea. APEA Journal 31(1), 333-353.

MORY, A.J., 1988: Regional geology of the offshore Bonaparte Basin in Purcell, P.G., & R.R., (Eds.), The Northwest Shelf Australia: Proceedings of Petroleum Exploration Society of Australia Symposium, Perth 1988, 287-309.

NICOLL, R.S., & GORTER, J.D , 1984a, Condont colour alteration, thermal maturation and the geothermal history of the Canning Basin, Western Australia, APEA Journal, 24(1), 414-429.

NICOLL, R.S., & GORTER, J.D., 1984b. Interpretation of additional conodont colour alteration data and the thermal maturation and geothermal history of the Canning Basin, Western Australia. in PURCELL, P.G., (Ed.), The Canning Basin, WA.: Proceedings of Geological Society of Australia/ Petroleum Exploration Society of Australia Symposium, Perth,1984, 411-425.

NICOLL, R.S., OWEN, M., SHERGOLD, J.H., LAURIE, J.R., & GORTER, J.D., 1988: Ordovician event stratigraphy and the development of a Larapintine Seaway, Central Australia. Extended Abstracts -Palaeogeography, sea level & climate implications for resource exploration. 17th BMR Aust. Research Symposium Canberra, 8-10 November 1988. Record 1988/42, 72-77.

PETROCONSULTANTS AUSTRALASIA PTY. LTD., 1989. Arafura Basin, Northern Territory Geological Survey Petroleum Basin Study.

PETROFINA EXPLORATION AUSTRALIA S.A., 1983: Arafura 1 well completion report (unpublished).

PETROFINA EXPLORATION AUSTRALIA S.A., 1986: Goulburn 1 well completion report (unpublished).

PLUMB, K.A., SHERGOLD, J.H., & STEFANSKI, Z., 1976: Significance of Middle Cambrian Trilobites from Elcho Island, Northern Territory, BMR Aust. Geology and Geophysics Bulletin 1 (1), 51-55.

SHELL DEVELOPMENT (AUSTRALIA) Pty. Ltd., 1971: Money Shoal 1 well completion report (unpublished).

SUMMONS, R.E., POWELL, T.G., & BOREHAM, C.J., 1988: Studies on petroleum geology and geochemistry of the middle Proterozoic McArthur Basin, northern Australia III : Composition of extractable hydrocarbons. Geochim. Cosmochim Acta, 52, 1747-1763.

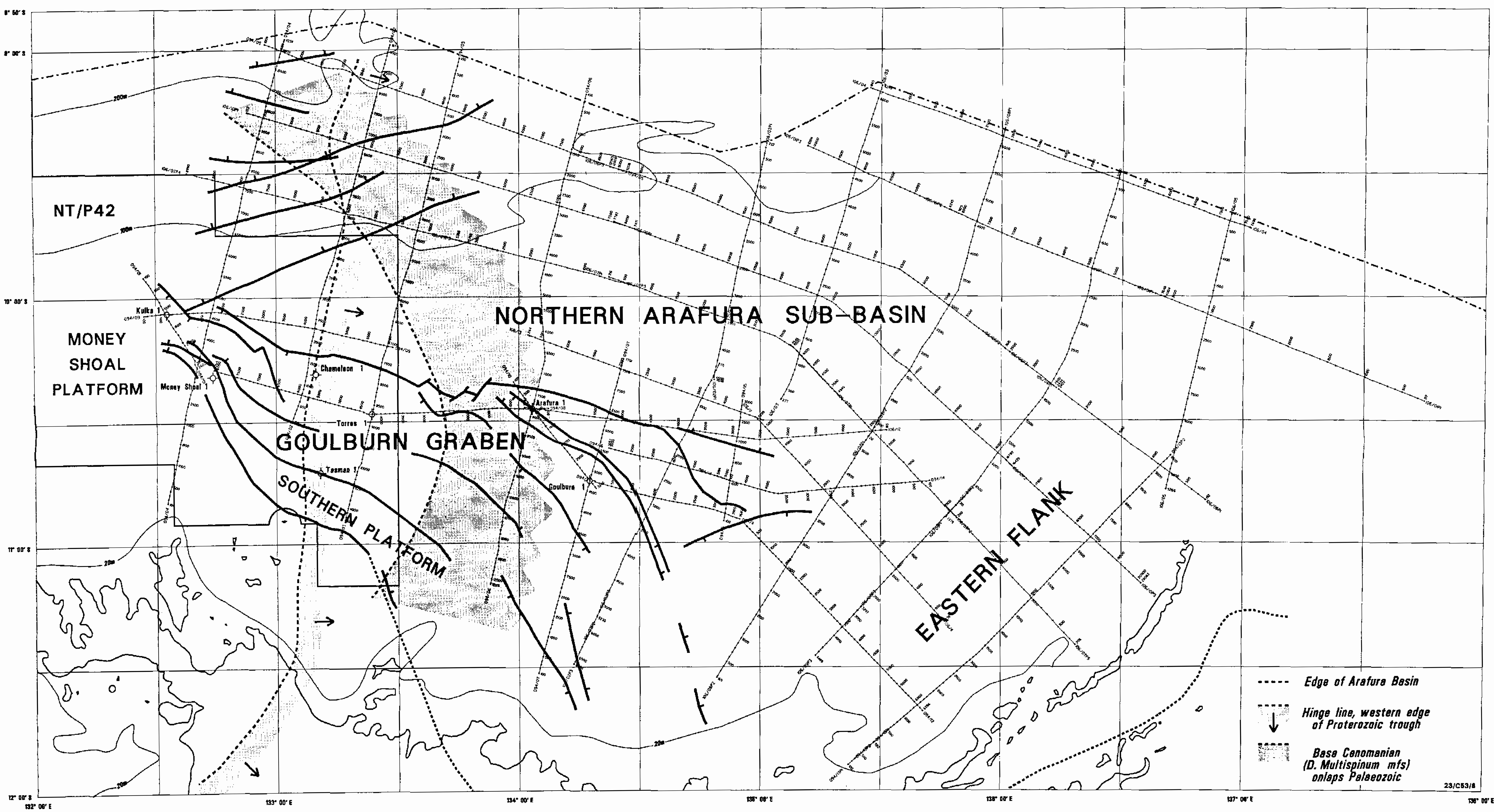
URBAN, L. & ALLEN, M.L., 1977: Vitrinite Reflectance as an indicator of thermal alteration within Paleozoic and Mesozoic sediments from the Phillips Petroleum Company ASM-1X well, Arafura Sea. Palynology 1, 19-26.

VAN WAGONER, G.C., POSAMENTIER, H.W., MITCHUM, R.M., VAIL, P.R., SARG, J.F., LOUTIT, T.S., & HARDENBOL, J., 1988. An overview of the fundamentals of Sequence Stratigraphy and key definitions. *In* WILGUS, C.K., *et al.*, (Eds) Sea Level changes: An integrated approach. S.E.P.M. Special Publication 42, 39-45.

VAN WAGONER, G.C., MITCHUM, R.M., CAMPION, K.M., RAHMANIAN, V.D., 1990: Siliciclastic Sequence Stratigraphy in Well Logs, Cores and Outcrops. AAPG Methods in Exploration Series, No. 7, 55 p.

VEEVERS, J.J., (Ed.),: 1984: Phanerozoic Earth History of Australia. Clarendon Press Oxford, 418 p.

WADE, A., 1924 - Petroleum prospects, Kimberley District of Western Australia and Northern Territory. Parliament of the Commonwealth of Australia Report 142.



STRUCTURAL ELEMENTS OF THE ARAFURA SEA ENCLOSURE 1

AGSO

PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN

Marine Geoscience & Petroleum Geology

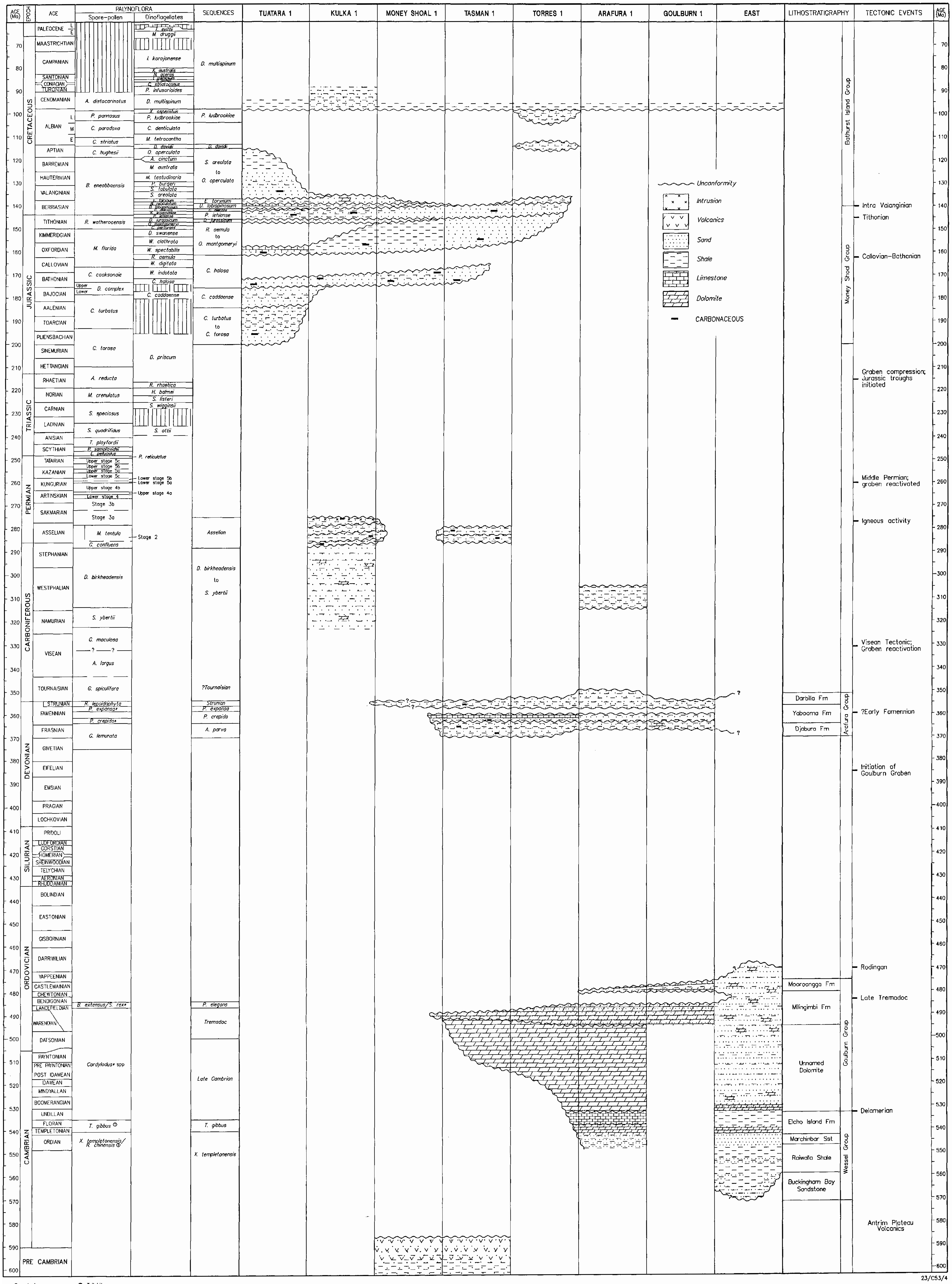
AGSO Seismic, Wells, Boundaries and

STRUCTURAL ELEMENTS OF THE ARAFURA SEA

AGSO Record 1992/84
November 1992

ENCLOSURE 1

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation



+ Conodont zones ⊕ Trilobite zones

23/C53/4

PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN

Marine Geoscience & Petroleum Geology

AGSO

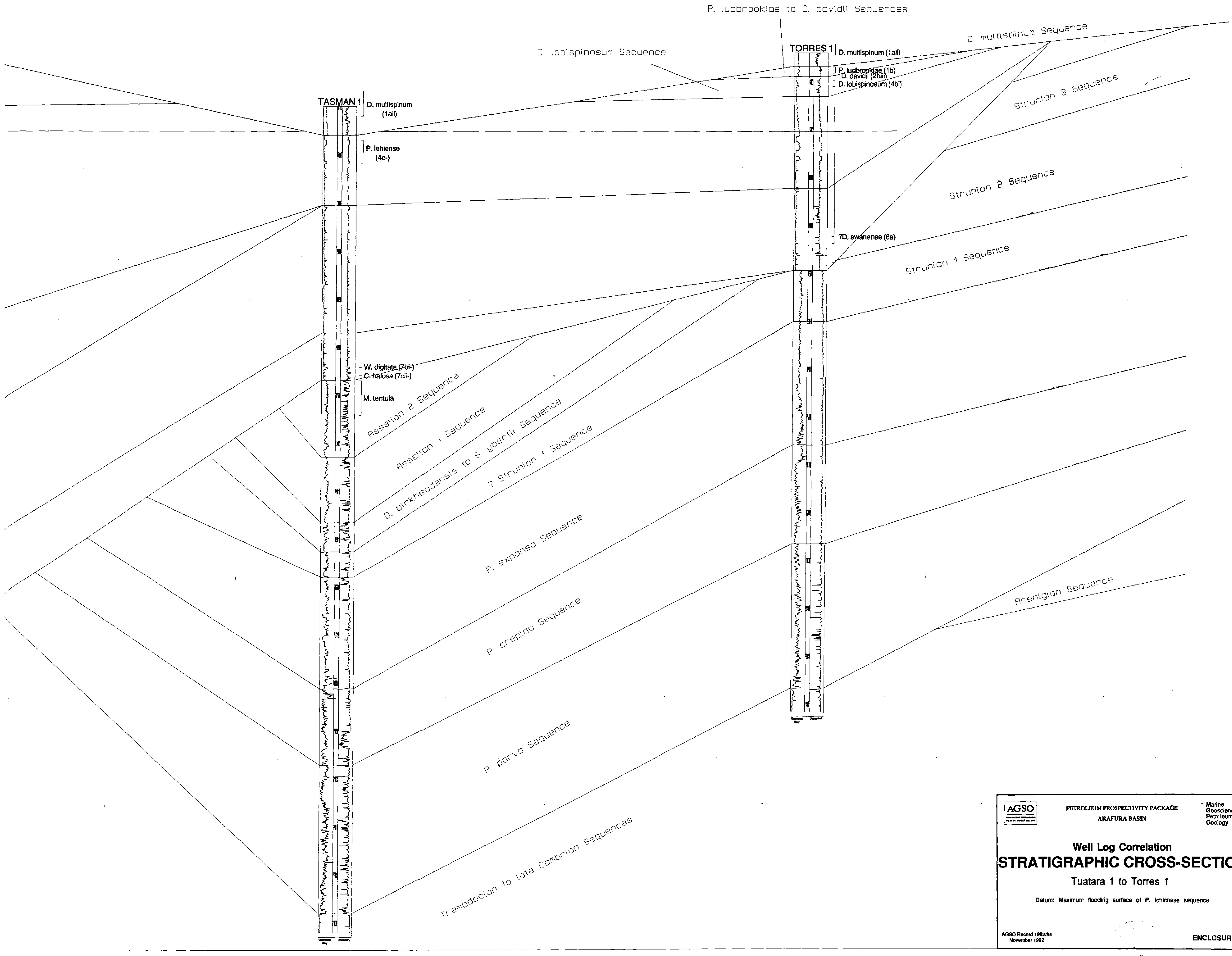
STRATIGRAPHY OF THE ARAFURA SEA BASINS

ENCLOSURE 2

AGSO Record 1992/64
November 1992

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation


TUATARA 1
KULKA 1
MONEY SHOAL 1
TASMAN 1
TORRES 1
ARAFURA 1
GOULBURN 1
200m
500m
1000m
1500m
2000m
2500m
3000m
3500m
4000m
D. multispinum Sequence
D. lobispinosum Sequence
MAXIMUM FLOODING SURFACE
P. lenlense Sequence
D. jurassicum Sequence
D. montgomeryi to R. aemula Sequence
C. halosa Sequence
S. areolata Sequence
E. torynum Sequence
M. australis to M. testudinaria Sequences
S. tabulata Sequence
C. delicata Sequence
D. caddaense to C. torosa Sequences
Asselian 4 Sequence
Asselian 3 Sequence
Asselian 2 Sequence
Asselian 1 Sequence
D. birkheadensis Sequence
D. birkheadensis to S. ybertii Sequences
G. confluens
D. birkheadensis to S. ybertii
CORE 1
D. lobispinosum Sequence
P. ludbrookiae to D. davidii Sequence
S. ybertii Sequences
? Tournaisian Sequence
Strunian 3 Sequence
Strunian 2 Sequence
Strunian 1 Sequence
P. expansa Sequence
P. crepida Sequence
A. parva Sequence
P. elegans Sequence
Tremadocian Sequence
Late Cambrian Sequences
T. gibbus Sequence
X. templetonensis Sequence
D. multispinum Sequence
Asselian 2 Sequence
Asselian 1 Sequence
D. birkheadensis/S. ybertii Sequences
? Strunian 1 Sequence
G. confluens
P. novicus
D. birkheadensis
S. ybertii
G. lemurata
A. parva
CORE 2
CORE 3
A. parva
Tremadocian
S. ybertii
R. lepidophyta
Diaphanospora
P. crepida (Fa1b)
A. parva
Arenigian
Tremadocian
T. gibbus
Middle Cambrian
T. gibbus or older
CORE 1, 2
CORE 3
CORE 4
CORE 5
P. expansa (Fa2c)
P. crepida (Fa1b)
LEGEND
SEQUENCE BOUNDARY
MAXIMUM FLOODING SURFACE
HYDROCARBON SHOWS
LIVE OIL
BITUMEN
FLUORESCENCE
AGSO
PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN
Marine Geoscience & Petroleum Geology
Well Log Correlation
STRUCTURAL CROSS-SECTION
Tuatara 1 to Goulburn 1
Datum: Sea Level
AGSO Record 1992/64
November 1992
ENCLOSURE 3



AGSO

PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN

Marine Geoscience & Petroleum Geology

Well Log Correlation
STRATIGRAPHIC CROSS-SECTION
Tuatara 1 to Torres 1

Datum: Maximum flooding surface of P. ichienese sequence

AGSO Record 1992/84
November 1992

ENCLOSURE 4

AGSO

PETROLEUM PROSPECTIVITY PACKAGE

ARAFURA BASIN

Marine Geoscience & Petroleum Geology

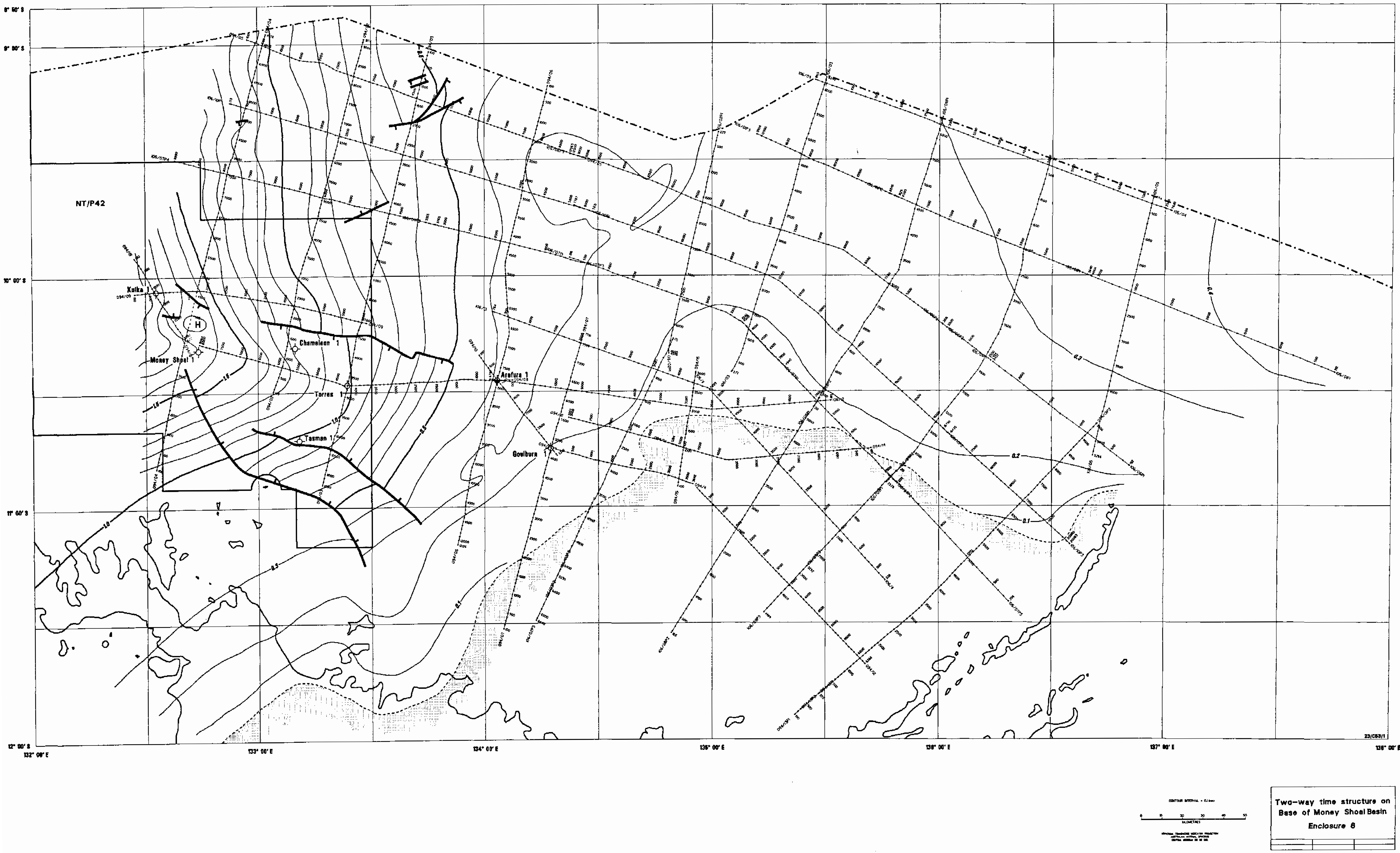
INTERPRETED SEISMIC SECTION

Line drawings of horizons picked on AGSO seismic profiles

AGSO Record 1992/84
November 1992

ENCLOSURE 5

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation



Two-way time structure on Base of Money Shoal Basin

Enclosure 6

AGSO

PETROLEUM PROSPECTIVITY PACKAGE

ARAFURA BASIN

Marine Geoscience & Petroleum Geology

Two-way time structure of

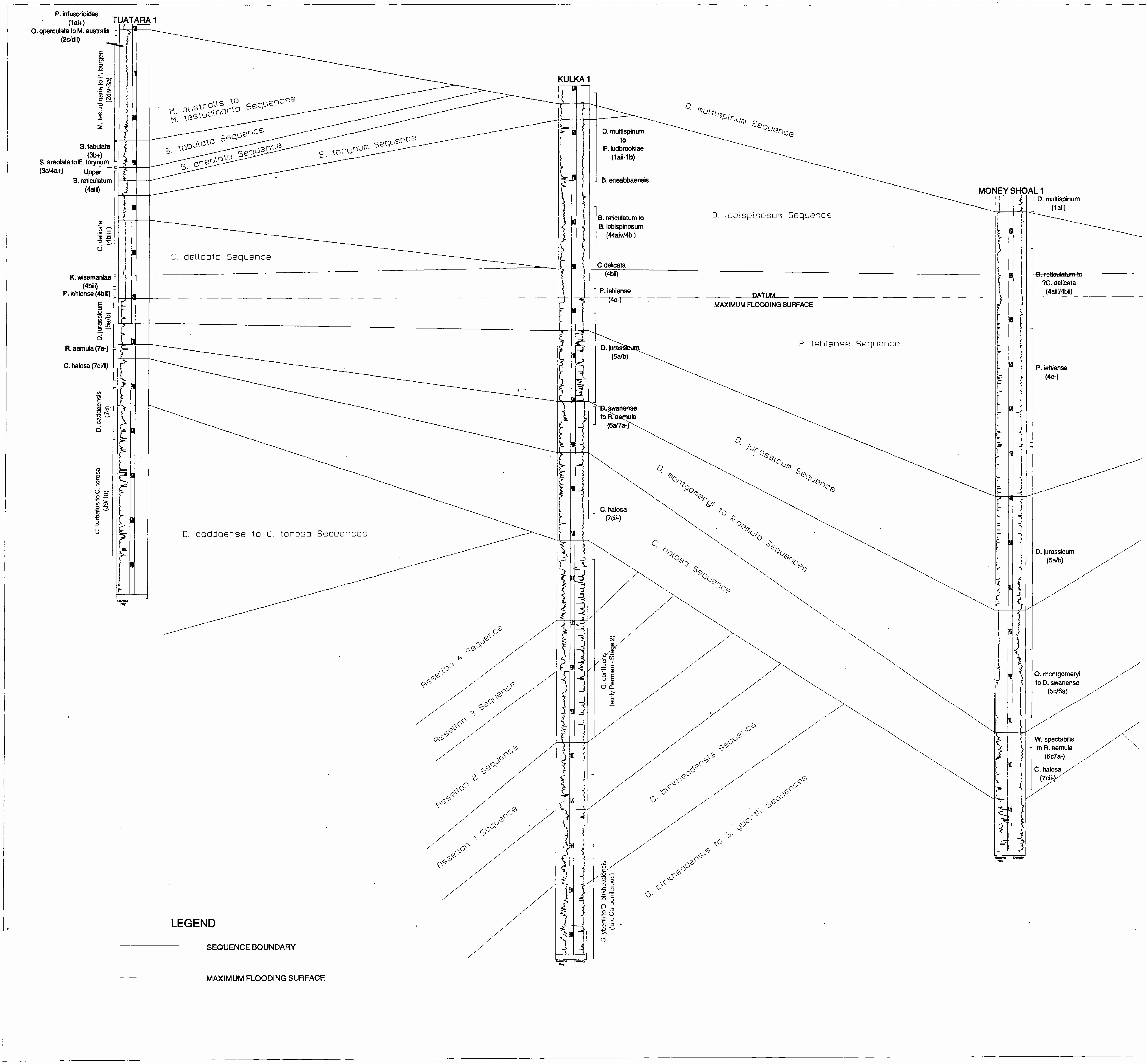
BASE OF MONEY SHOAL BASIN

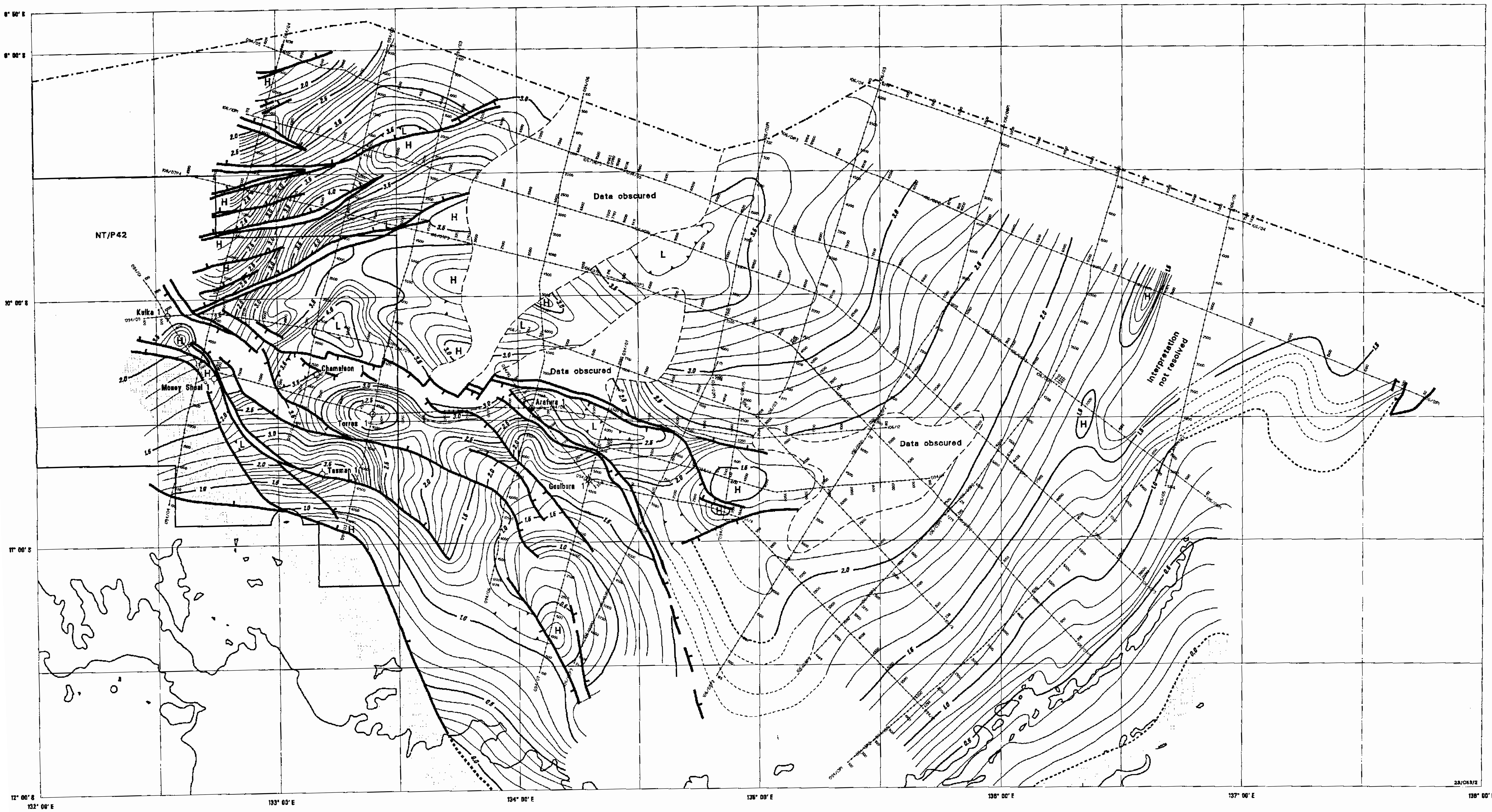
Approximately: 0.5 Second=450m; 1 Second=1100m; 1.5 Seconds=1900m

AGSO Record 1992/84
November 1992

ENCLOSURE 6

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation


TUATARA 1
KULKA 1
MONEY SHOAL 1
P. infusorioides (1ai+)
O. operculata to M. australis (2c/dii)
M. testudinaria to P. burgeri (2div-3a)
S. tabulata (3b+)
S. areolata to E. torynum (3c/4a+)
Upper B. reticulatum (4aiii)
C. delicata (4bii+)
K. wisemaniae (4biii)
P. iehiense (4biii)
D. jurassicum (5a/b)
R. aemula (7a-)
C. halosa (7ci/ii)
D. caddaensis (7d)
C. turbatus to C. torosa (J9/10)
M. australis to M. testudinaria Sequences
S. tabulata Sequence
S. areolata Sequence
E. torynum Sequence
C. delicata Sequence
D. caddaense to C. torosa Sequences
D. multispinum to P. ludbrookiae (1aii-1b)
B. eneabbaensis
B. reticulatum to B. lobispinosum (44aiv/4bi)
C.delicata (4bii)
P. iehiense (4c-)
D. jurassicum (5a/b)
D. swanense to R. aemula (6a/7a-)
C. halosa (7cii-)
G. confluens (early Permian - Stage 2)
S. ybertii to D. birkheadensis (late Carboniferous)
D. multispinum Sequence
D. lobispinosum Sequence
DATUM
MAXIMUM FLOODING SURFACE
P. iehiense Sequence
D. jurassicum Sequence
D. montgomeryi to R.aemula Sequences
C. halosa Sequence
Asselian 4 Sequence
Asselian 3 Sequence
Asselian 2 Sequence
Asselian 1 Sequence
D. birkheadensis Sequence
D. birkheadensis to S. ybertii Sequences
D. multispinum (1aii)
B. reticulatum to ?C. delicata (4aiii/4bii)
P. iehiense (4c-)
D. jurassicum (5a/b)
O. montgomeryi to D. swanense (5c/6a)
W. spectabilis to R. aemula (6c7a-)
C. halosa (7cii-)
Gamma Ray
Density
LEGEND
SEQUENCE BOUNDARY
MAXIMUM FLOODING SURFACE



Two-way time structure on Base of Wessel Group
Enclosure 7

AGSO

PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN

Marine Geoscience & Petroleum Geology

Two-way time structure of

BASE OF ARAFURA BASIN

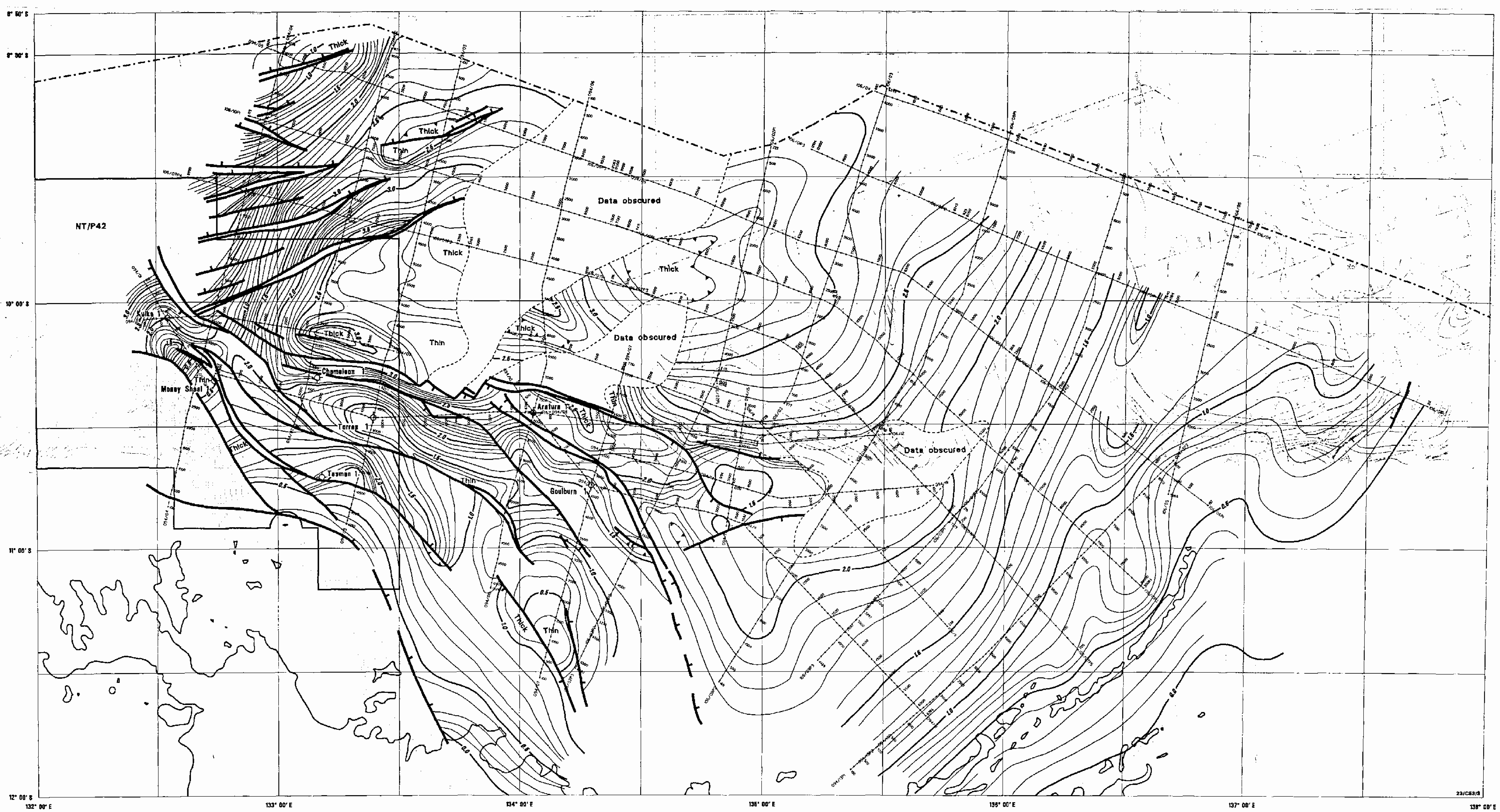
BASE OF CAMBRIAN WESSEL GROUP

(very roughly, 2 seconds is around 4000m deep, and 3 seconds is around 6000m)

AGSO Record 1992/84
November 1992

ENCLOSURE 7

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation



Arafura Basin Thickness
(3–10)
Enclosure 8

AGSO

PETROLEUM PROSPECTIVITY PACKAGE
ARAFURA BASIN

Marine Geoscience & Petroleum Geology

Two-way time
THICKNESS OF ARAFURA BASIN

Approximately: 1 Second=2100m; 2 Seconds=5000m

AGSO Record 1992/84
November 1992

ENCLOSURE 8

Cartography by the Cartographic Services Unit, Australian Geological Survey Organisation