RECORD 1992/24

PETROLEUM PROSPECTIVITY OF THE EAST MALITA GRABEN AREA, BONAPARTE BASIN

by

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Authorship of individual sections in the text is labelled throughout. Elements of style, grammar and scientific content are the responsibility of individual authors. The compiler takes responsibility for formatting and grammatical inconsistencies, and has attempted to resolve scientific inconsistencies in the text and conflicting interpretations on Plates and Figures.

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GLOSSARY

API	American Petroleum Institute
CMC	Sodium carboxymethylcellulose
"d"	Drilling exponent
"dcs"	Corrected drilling exponent
DST	Drill stem test
FIT	Formation interval test
g/cc	Grams per cubic centimetre
i-	iso-
Jb	Callovian 'Breakup' Unconformity seismic event
K	Near top Cretaceous seismic event
Ka	Aptian/Albian Unconformity seismic event
KCl	Potassium chloride
Kt	Turonian marker
lbs	Pounds
LCM	Lost circulation material
m	Metres
Ma	Million years
MSL	Mean sea level
n-	Normal
ppm	Parts per million
psi	Pounds per square inch
PVT	Pressure, volume and temperature
RFT	Repeat formation test
RKB	Relative to kelly bushing
secs	Seconds
s.g.	Specific gravity
SP	Spontaneous potential
TD	Total depth
TOC	Total organic carbon
TWT	Two-way time

SUMMARY

Release Areas NT92-1 and NT92-2 comprise 138 blocks and 133 blocks respectively, located in the northeastern part of the Bonaparte Basin, approximately 300 kilometres northwest of Darwin. Water depths generally range from less than 100 metres over more than half of the two areas, to greater than 400 metres in the northeastern corner of Area NT92-2.

The release areas overlie the eastern part of the Malita Graben, a northeast-southwest trending Mesozoic trough and depocentre which contains a thick Late Mesozoic to Recent section. The release areas also cover the flanks of the graben, the Sahul Platform to the north, and the margin of the Darwin Shelf to the south.

The Malita Graben is probably underlain by a thick Palaeozoic section, which has only been intersected on the Sahul Platform to the northwest by Troubadour 1. Total sediment thickness may exceed 10 kilometres. The graben is characterised by northeast-southwest trending tilted fault blocks of Mesozoic age.

The Sahul Platform on the northern flank of the Malita Graben is a region of elevated Mesozoic and Palaeozoic sediments which exhibit fault displacements parallel with the Malita Graben. The Darwin Shelf is an offshore extension of the Proterozoic Sturt Block. It has been subjected to numerous episodes of peneplanation, and is covered by a thin veneer of Mesozoic and Cainozoic sediments which thicken northwards towards the Malita Graben.

Two wells (Heron 1 and Shearwater 1) have been drilled in NT92-1. Evans Shoal 1 (a gas discovery) is located in NT/P40 which separates NT92-1 and NT92-2. Other wells have been drilled in the Malita Graben (Lynedoch 1, Jacaranda 1 and Darwinia 1) and the Sahul Platform (Troubadour 1 and Sunrise 1) adjacent to the release areas. Troubadour 1 and Sunrise 1 were gas/condensate discoveries.

Exploration in the region commenced in the mid 1960s and can be divided into two phases.

The initial phase of exploration, from the mid 1960s to the mid 1970s, focussed on a regional approach, with aeromagnetic and seismic acquisition. Approximately 7100 kilometres of seismic data covers Areas NT92-1 and NT92-2. Two wells were drilled, Heron 1 in 1971-72 and Shearwater 1 in 1974. Heron 1 was located on a seismically defined high within the Malita Graben,

with major objectives in the Jurassic Plover Formation sands. Numerous gas shows were recorded in the Cretaceous and Jurassic sections, however, no testing was carried out. Shearwater 1 was located on the northern flank of the Malita Graben, again with Plover Formation objectives. Residual oil staining was encountered in the Plover Formation.

The second phase of exploration commenced in the mid 1980s with Western Mining Corporation (WMC) and joint venturers being granted exploration permit NT/P40 (which now makes up the bulk of Areas NT92-1 and NT92-2). WMC obtained approximately 2500 kilometres of new seismic data from three surveys (1985, 1986 and 1987) which led to the drilling of Evans Shoal 1 by BHP Petroleum in 1988. The well was drilled to test a low relief anticline overlying an earlier faulted structure. The primary objectives of the well were Jurassic Plover Formation sandstones, and gas was recovered from the Jurassic section. WMC has applied to renew part of NT/P40 over the Evans Shoal structure.

In this study, most of the lines from WMC's 1985 Marie Seismic Survey were used to provide a grid of about 20 x 30 kilometres over most of the two release areas. Three lines from WMC's 1987 Connie Seismic survey and two lines from ARCO Australia Limited (ARCO)'s 1972 Baldwin Bank Seismic Survey were also used to infill some detail. Twenty interpreted lines are included in the prospectivity package.

Four key horizons were eventually mapped: top Cretaceous, Turonian marker, Albian/Aptian Unconformity and the Callovian ('Breakup') Unconformity. On some lines, the probable top Permian or Triassic is mapped in part, but this horizon is unreliable as there is no well control. Control for the other horizons was provided by Shearwater 1, Heron 1 and Evans Shoal 1. The Albian/Aptian Unconformity provides a very strong regional marker at about 2 to 2.5 secs (TWT), resulting from a seismic contrast between the overlying basal Bathurst Island Group carbonates and underlying Flamingo Group sands/shales.

The Malita and Plover Formations, Flamingo Group and Bathurst Island Group all contain siltstones and shales with good to excellent source potential. However, geochemical sampling has been relatively sparse, with only a few wells to sample. The Malita and Plover Formations, Flamingo Group and the Maastrichtian sands at the top of the Bathurst Island Group all contain good reservoir quality rocks. Sediments in the Jurassic units tend to lack porosity at depth due to diagenetic alteration, but they may have retained some porosity at shallow depths near the margin of the Malita Graben. It is not known whether the interpreted Albian carbonate 'mounds' have any porosity, but similar features elsewhere in the world do provide good reservoirs. Intraformational shales within the Jurassic, marine shales of the Bathurst Island Group, and Tertiary carbonates and shales can all expect to provide good seal.

Lack of sufficient well control makes regional maturity trends difficult to establish. However, it appears that most potential source rocks have reached maturity for oil generation, although the Jurassic section within the Malita Graben is expected to be overmature. The Bathurst Island Group shales appear to have reached the optimum level of maturity for oil generation.

At least five play types have been identified in the release areas. Most are associated with fault-dependent anticlines or horst blocks within the Malita Graben and Sahul Platform.

Fault blocks along the margins of the Malita Graben are likely to contain Malita and Plover Formation sands at relatively shallow depths (2.4 secs TWT), sealed by intraformational shales and the overlying Flamingo Group or the Bathurst Island Group shales. A number of these structures have been mapped along the southern margin of the Malita Graben.

Low relief fault-dependent anticlines, or anticlines associated with underlying Permo-Triassic fault blocks were mapped mainly in the northeast, on the Sahul Platform. These are likely to contain Malita and Plover Formation and Flamingo Group sands, sealed by intraformational or Bathurst Island Group shales.

Mounded features, interpreted to be Early Jurassic turbidite sands were identified in the northeast of Area NT92-1 within the Malita Graben. However, they occur relatively deep in the section, at 3 seconds (TWT) or greater.

Several 'mounds' have been mapped immediately above the Albian/Aptian Unconformity. The 'mounds' are linearly distributed along the high side of the northern margin of the Malita Graben. The presence of basal limestones in nearby wells (Shearwater 1 and Heron 1) suggests these might be carbonate 'mounds' which could present a new play in this area.

Widespread Maastrichtian sands at the top of the Bathurst Island Group have been mapped in the central Malita Graben and to the northeast of Heron 1. These sands show distinct mounding and channelling with intraformational shale drapes. Examination of well cuttings shows these sands to be clean, well sorted and reworked, indicating they could be submarine fan sands that have been deposited in the Malita Graben during the Late Cretaceous low-stand. They appear similar in style to the Frigg Field in the North Sea. Late Tertiary reactivation of pre-existing faults may have provided suitable pathways for the migration of hydrocarbons generated in the deeper Bathurst Island Group shales. Although these sands have been recognised previously, they remain untested.

A possible lead occurs in the southeast part of Area NT92-1 with draped sediments associated with probable salt diapirism.

This study demonstrates that in this area of nearly 23 000 square kilometres, which, by modern standards, has generally inadequate seismic coverage with relatively poor quality data, there are numerous targets remaining to the evaluated, many of which require only minimal work to be brought up to prospect status. As the region has known hydrocarbon occurrences, the results of this study indicate that Areas NT92-1 and NT92-2 should be considered to be highly prospective.

1. INTRODUCTION (B.G. West)

Release Areas NT92-1 and NT92-2 are located in the northeastern part of the Bonaparte Basin, approximately 300 kilometres northwest of Darwin, and immediately to the east of the Timor Gap Zone of Co-operation areas that were awarded in January 1992. Water depths range from less than 100 metres to greater than 400 metres (Figure 1). The major portion of the two release areas was previously held as exploration permit NT/P40.

The release areas overlie the eastern part of the Malita Graben, a northeast-southwest trending Mesozoic depocentre, as well as part of the Sahul Platform and Darwin Shelf. Mature source rocks are known to occur in the graben, and potential petroleum targets have been identified in at least four Mesozoic age sequences.

The Petroleum Resource Assessment Branch (PRAB) of the Bureau of Mineral Resources (BMR) has carried out this study of the petroleum potential of the areas to complement a regional review of the Bonaparte Basin undertaken by the Northern Territory Geological Survey (NTGS, 1990). The NTGS report is included in the package as Appendix 1.

Aspects that were examined for this package include a review of previous exploration and drilling results, regional geology, geophysics, hydrocarbon potential, and baseline environmental conditions and the likely impact of petroleum exploration.

Enclosures include: a shotpoint location map (Plate 1); composite well logs and velocity surveys for Shearwater 1, Heron 1 and Evans Shoal 1 wells drilled within the two release areas (Plates 2-10); composite well logs for Lynedoch 1, Troubadour 1, Jacaranda 1 and Darwinia 1 wells, located adjacent to the release areas (Plates 11-14); twenty full-scale uninterpreted seismic lines and corresponding interpreted seismic lines (Plates 15-34a), showing major stratigraphic units, structure and potential leads. Two time structure maps, one at Near Top Cretaceous (Plate 35) and one at Near Albian/Aptian Unconformity showing potential leads (Plate 36) are also included.

While the two release areas have been previously explored, well and seismic data are still relatively sparse. Previous exploration has been focussed mainly on the pre-breakup Plover Formation sands. However this study has identified a number of potential leads in the Late Jurassic and Cretaceous sections, and we believe the areas have significant hydrocarbon prospectivity and warrant further exploration.

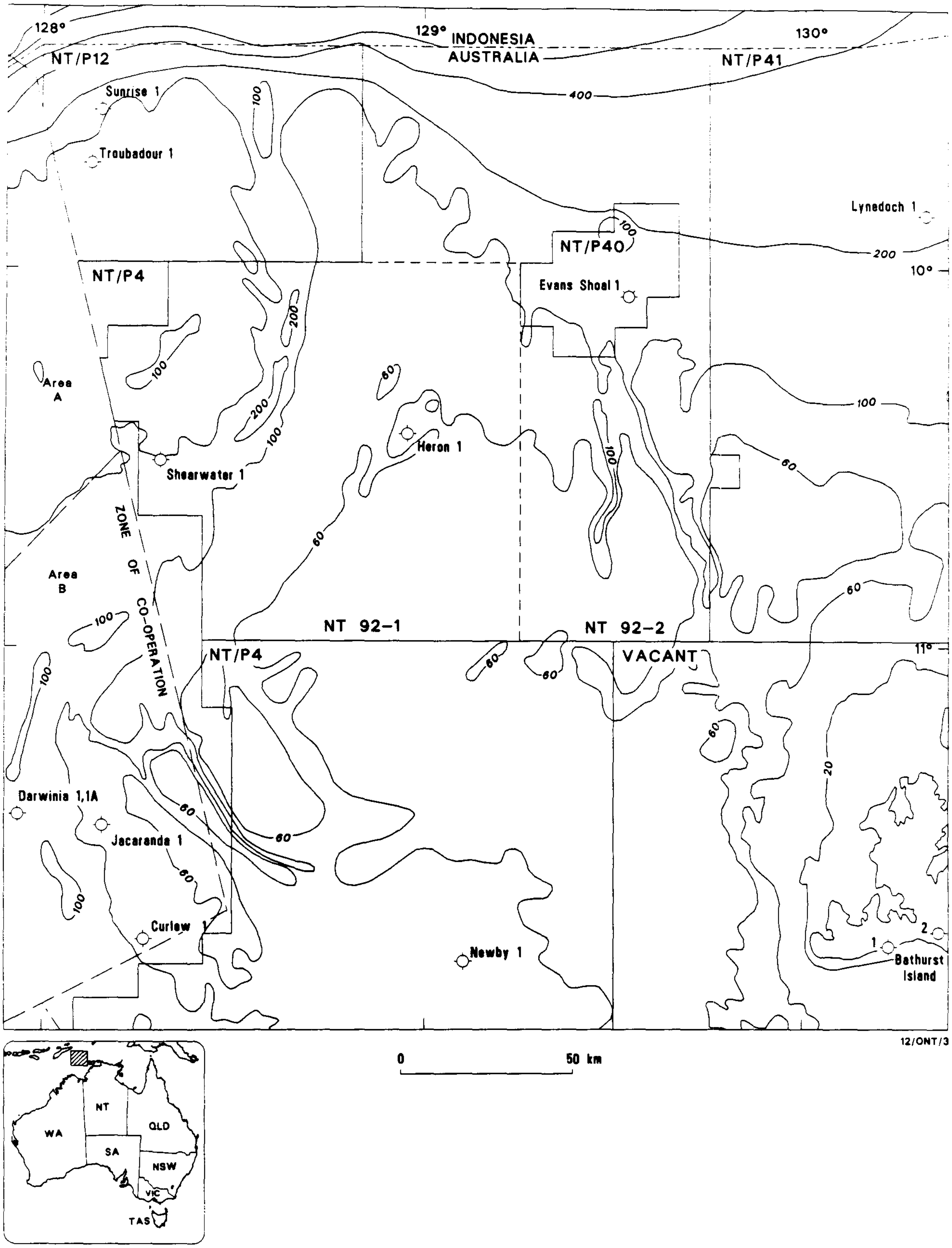

Figure 1. Locality map

2. REGIONAL GEOLOGY (B.G. West)

Areas NT92-1 and NT92-2 overlie the central and eastern part of the Malita Graben, a northeast-southwest trending depositional trough originating during Middle Jurassic time. They also cover the flanks of the graben, the Sahul Platform to the north and the Bathurst Terrace on the margin of the Darwin Shelf to the south.

2.1 STRUCTURAL ELEMENTS

The major structural elements of the east Malita Graben and surrounding region are shown in Figure 2 and described below.

2.1.1 Sahul Platform

The Sahul Platform is a region of elevated Mesozoic and Palaeozoic sediments, which is thought to represent a partially rifted fragment whose present geometry resulted during the Jurassic breakup of Gondwana (NTGS, 1990). The flanks are dominated by northeast to east-northeast trending normal faults showing Mesozoic displacements. Many of the faults were reactivated during the Miocene collisional event (Mory, 1988; Veevers, 1984).

The Mesozoic and Tertiary structuring overprints older Palaeozoic structural trends which, across the crestal region of the platform, are manifest as a series of parallel, northwest-southeast trending fold axes plunging to the south.

2.1.2 Malita Graben

The Malita Graben forms a northeast-trending depositional trough between the Sahul Platform to the north and the Darwin Shelf to the south. It is bounded by intersecting east-northeast to northeast trending faults, with the largest displacements occurring adjacent to the Sahul Platform, giving it an asymmetric appearance in cross section. Major structural development probably commenced during the Callovian, coincident with the breakup of Gondwana (Veevers, 1984). At depth it is probably underlain by a thick Palaeozoic section, and total sediment thickness may exceed 10 kilometres (Mory, 1988).

Faulting within the graben parallels the major bounding faults, creating a series of prominent tilted blocks and terraces, the largest of which is the Heron Terrace, which represents a perched, down-faulted block covering an extensive area adjacent to the Sahul Platform.

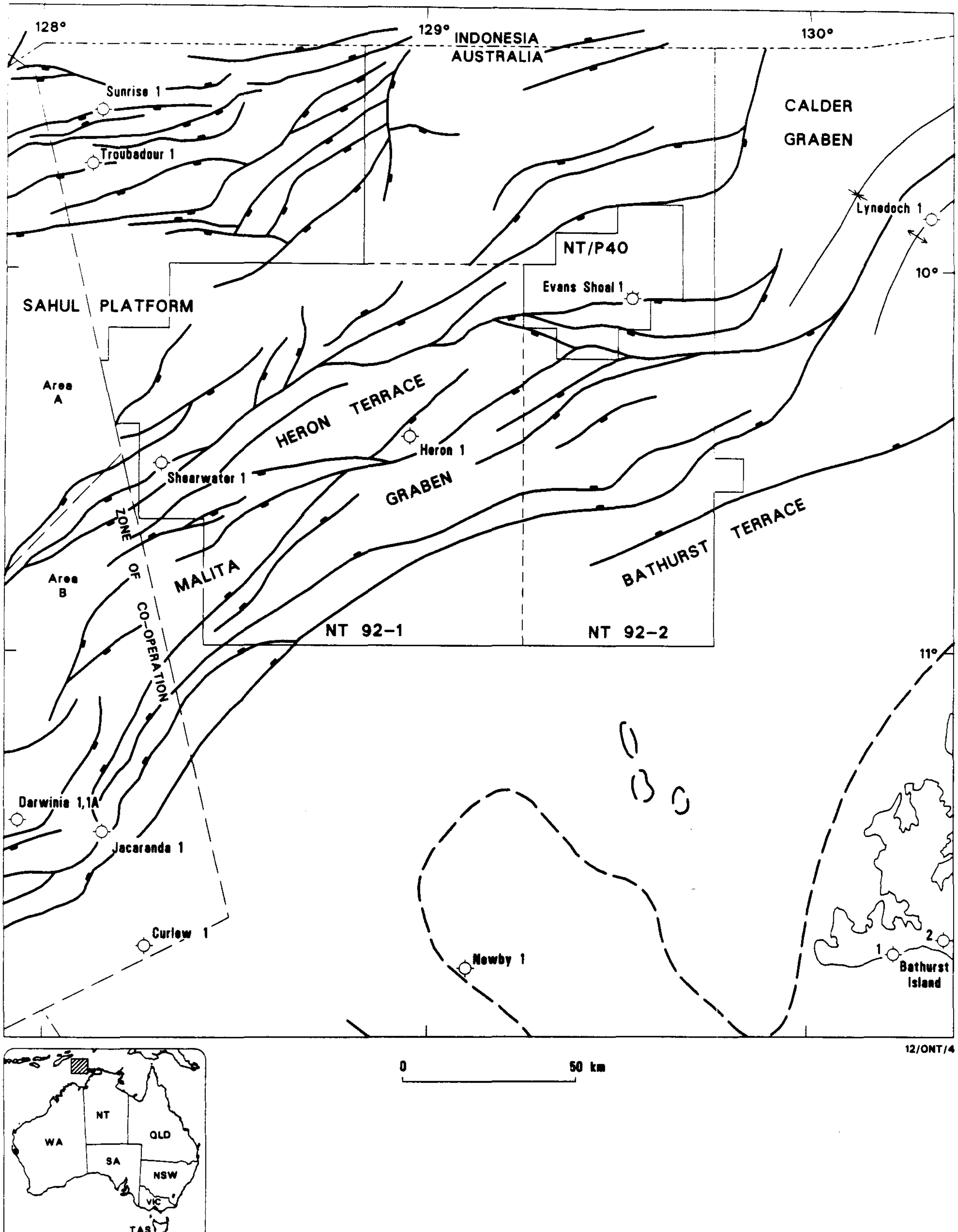

Figure 2. Regional structural elements

2.1.3 Darwin Shelf

The Darwin Shelf is an offshore extension of the Proterozoic Sturt Block (Mory, 1991). It is a prominent, structurally positive feature which has been subjected to numerous episodes of peneplanation (NTGS, 1990). A zone of shallowing basement between the Darwin Shelf and the Malita Graben, where Palaeozoic and Mesozoic sediments are progressively truncated, has been referred to as the Bathurst Terrace (NTGS, 1990).

2.2 STRUCTURAL EVOLUTION

The oldest rocks penetrated by drilling in the east Malita Graben area are pre-Permian granitic basement overlain by Late Permian sediments in Troubadour 1 on the Sahul Platform. The Latest Permian to Middle Jurassic represents a period of tectonism associated with the early breakup of Gondwana (NTGS, 1990). MacDaniel (1988) envisaged this initially as broad regional sags which became major depocentres in the Late Triassic. As rifting progressed, rift basins developed along northeasterly trends.

Basin subsidence associated with this tectonism resulted in transgression during the Early Triassic, and deposition of the Mt Goodwin Formation shales unconformably on the Permian Hyland Bay Formation. Marine conditions continued in the Middle Triassic with deposition of the Cape Londonderry Formation in the Malita Graben, and shallow water carbonates across the Sahul Platform.

In the latter part of the Triassic, regressive siliciclastics were deposited over the Sahul Platform, culminating in the deposition of continental redbeds of the Malita Formation during the Late Triassic to Early Jurassic. Subsequent transgression in the Middle Jurassic resulted in the deposition of a thick sequence of fluvial to deltaic sediments of the Plover Formation. Uplift associated with a major Gondwana breakup event of occurred during the Callovian, resulting in the erosion of at least the top of the Plover Formation, and much of the underlying units on the Sahul Platform (Mory, 1988).

During the Late Jurassic, the region tilted to the northwest and the Malita Graben subsided with local uplift and erosion taking place along the margin fault blocks. The Flamingo group represents a prominent Late Jurassic marine transgression during which the Frigate Shale was deposited in the Malita Graben. The upper part of the Flamingo Group represents a fluvial to deltaic siliciclastic cycle transgressing the basin margins. Turbidites may have developed in the Malita Graben at this time.

Final breakup of Gondwana occurred during Early Cretaceous Valanginian time, resulting in a regional hiatus and fault rejuvenation on horst trends (Botten & Wulff, 1990). Rapid basin subsidence followed the Valanginian event, resulting in submergence of the Sahul Platform, and enhancement of the Malita Graben as a major depocentre. Continued tilting to the west resulted in a regional transgression with the deposition of the Bathurst Island Group.

Rapid eustatic fluctuations resulted in poor preservation of the post-Valanginian to Aptian marine sequences. In the Late Albian, carbonates were deposited over much of the region, with possible mound-like features being formed on the northern platform marginal to the Malita Graben. Sediments became progressively more open marine towards the Turonian sea level maximum, prior to a series of sea level falls during the Late Cretaceous. Falls in sea level resulted in beach and shoreline sequences being deposited around the margins of the Darwin Shelf, and submarine fans being deposited in the Malita Graben. Parts of the Darwin Shelf were emergent as this time, whereas on the Sahul Platform deposition was more distal.

The open shelf marine conditions in the Malita Graben continued throughout the Cainozoic, with onshore areas to the south the site of non-deposition and erosion. The Early Tertiary section is sandy in part, grading upwards to shelfal carbonates. Structuring, involving reactivated down-faulting across the flanks of the Sahul Platform, and tilting of the Malita Graben westwards appear to have continued during the Tertiary, some faults having present day bathymetric expression. Bathymetric deeps adjacent to the fault escarpments of the Heron Terrace suggest that sedimentation has not kept pace with recent down-faulting.

Reactivation of some faults in the Middle Miocene may reflect the collision of the outer Australian continental margin with the Southeast Asian Plate (Mory, 1988; Veevers, 1984). Except for some minor reverse faulting, however, structuring on the Sahul Platform does not appear to be characterised by compressional tectonics.

3. STRATIGRAPHY AND PALAEOGEOGRAPHY (B.G. West)

The stratigraphy (Figure 3) and palaeogeography (Figures 4 to 6) of the east Malita Graben study area have been prepared from a review of published literature, well completion reports and other information in the public domain. The stratigraphic nomenclature is a simplified version of that of Mory (1991) and NTGS (1990).

3.1 PERMIAN TO MIDDLE JURASSIC

Major uplift, associated with reactivation of northwest trending tectonism and isostatic readjustment due to extensive glaciation, took place during the Late Carboniferous to Early Permian (Mory, 1988). Wells in the Malita Graben have not drilled below the Middle Jurassic, and data on the sedimentary sequences deposited during this time are restricted to the periphery of the study area, and described in more detail by Mory (1991) and NTGS (1990).

3.2 MIDDLE JURASSIC TO VALANGINIAN

Within the study area, no wells have reached total depth below the Middle Jurassic Plover Formation, which is more or less conformable on the Malita Formation (Mory, 1988). Sediments of the Plover Formation generally consist of very fine to coarse quartz rich sandstones, interbedded with varying amounts of argillaceous siltstone and claystone. The sandstones tend to be well cemented, with quartz overgrowths, and pyrite and carbonaceous material are often present in the finer fractions. The depositional environment is interpreted as ranging from restricted marine to delta plain. The distribution of pre-breakup Jurassic sediments is shown in Figure 4.

A period of strong extensional tectonism in the Callovian as a result of breakup, gave rise to the major northeast-trending structural elements (Mory, 1988), and major erosion of Jurassic and Triassic sediments took place at this time on the Sahul Platform. These sediments may have been redeposited as basin floor sheet sands in the Malita Graben (Botten & Wulff, 1990). This sequence (Flamingo Group) onlaps the 'Breakup' Unconformity, where it overlies the Plover Formation and has been dated as Early Oxfordian to Berriasian, indicating that the sedimentation recommenced immediately after the Callovian breakup event (Mory, 1988).

In the Malita Graben, the Flamingo Group varies from 867 metres of mainly grey, silty, pyritic claystone in Heron 1, to 25 metres of mainly siltstone in Evans Shoal 1. The Flamingo Group pinches out laterally on the Bathurst Terrace to

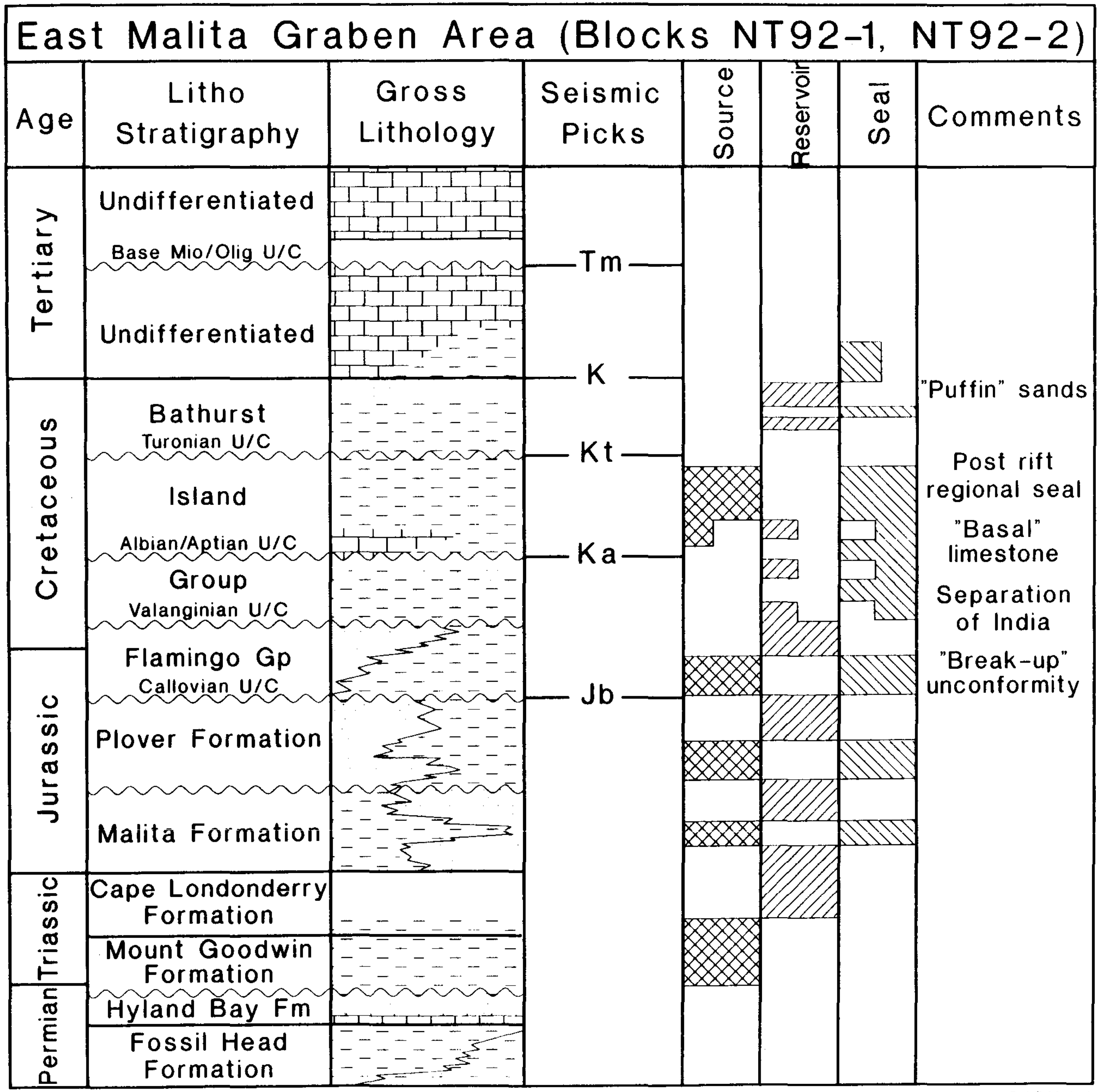

Figure 3 Generalised Stratigraphy

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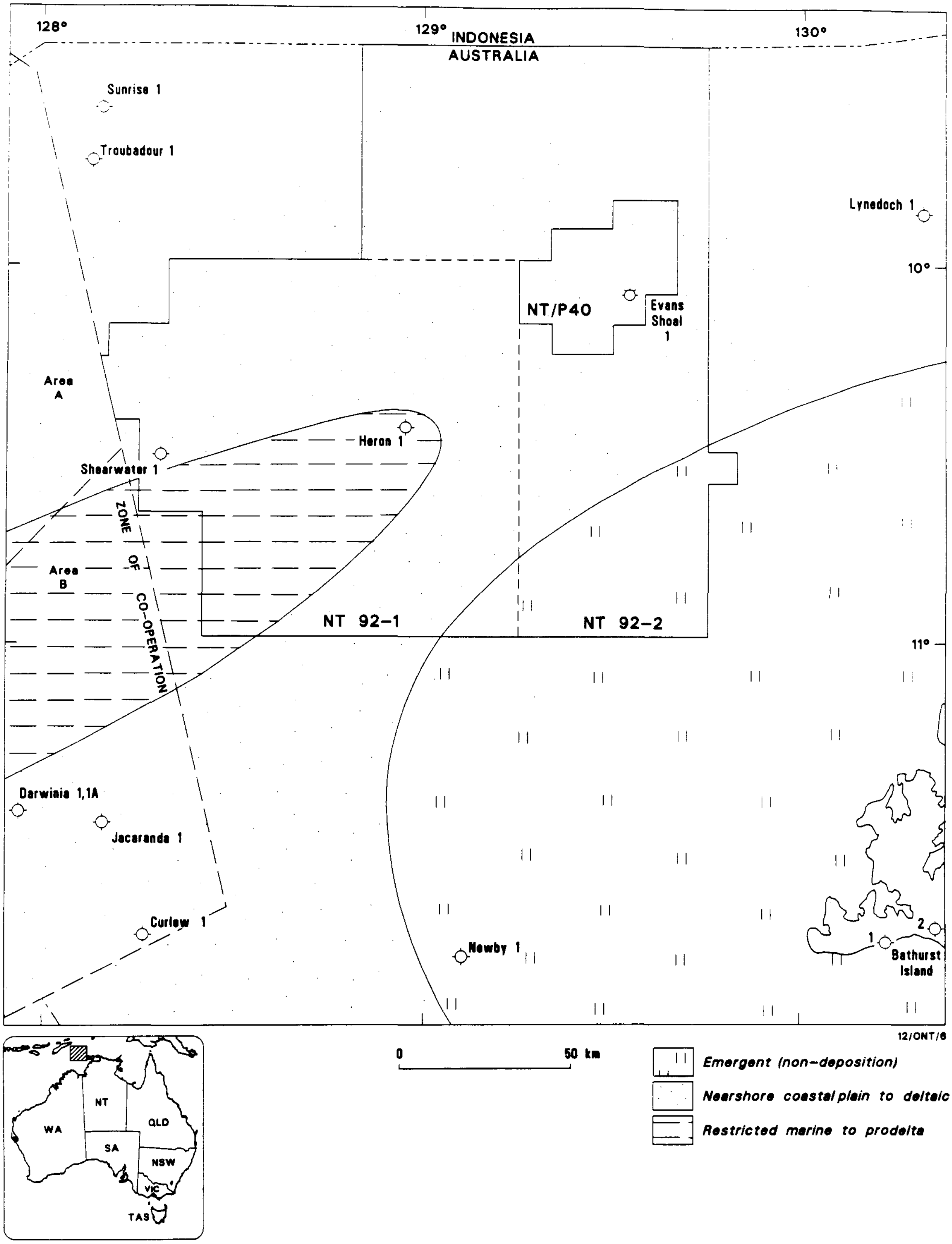


Figure 4. Early to middle Jurassic (pre-breakup) palaeogeography (after Mory, 1988)

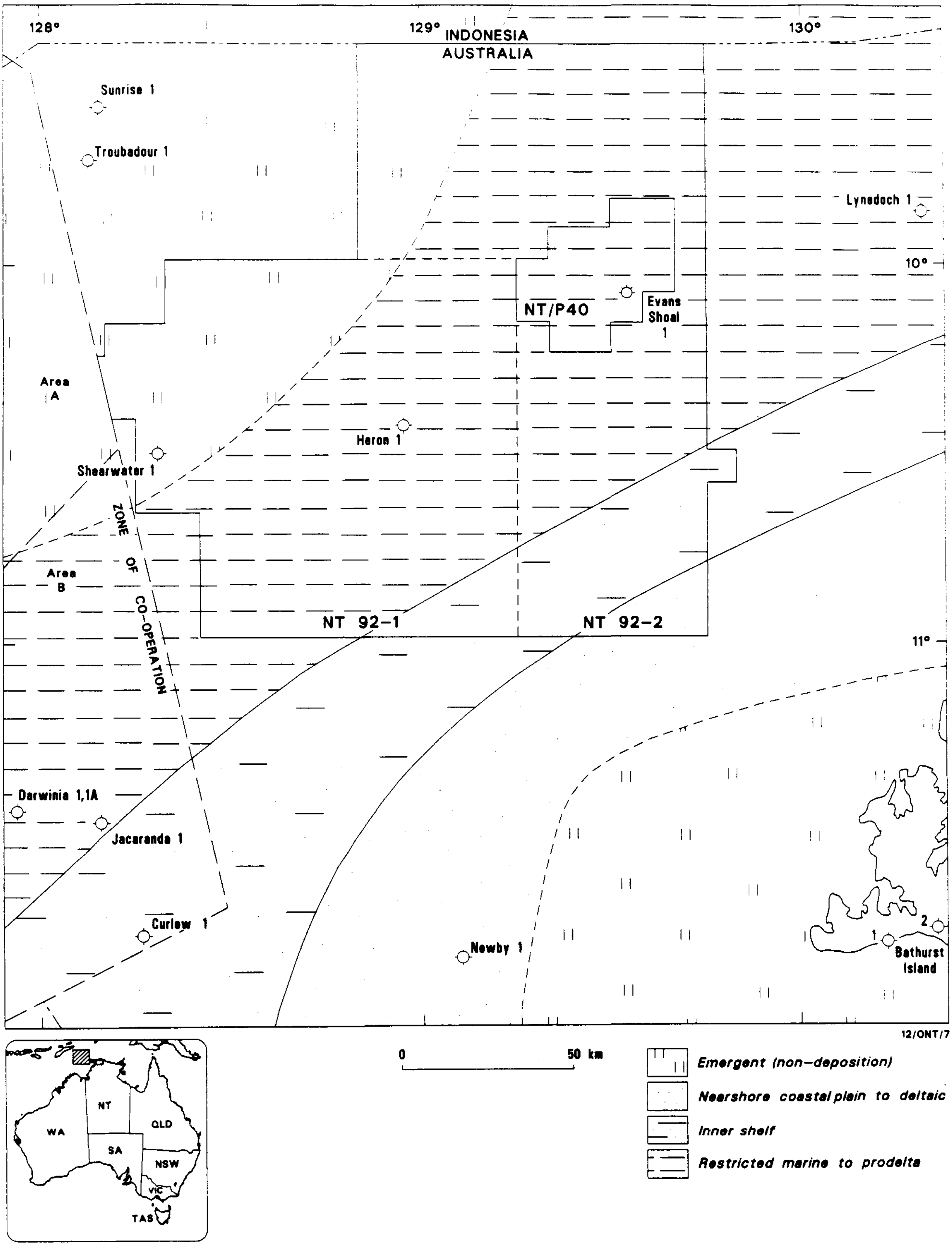


Figure 5. Late Jurassic to early Cretaceous (post-breakup) palaeogeography (after Botten and Wulff, 1990)

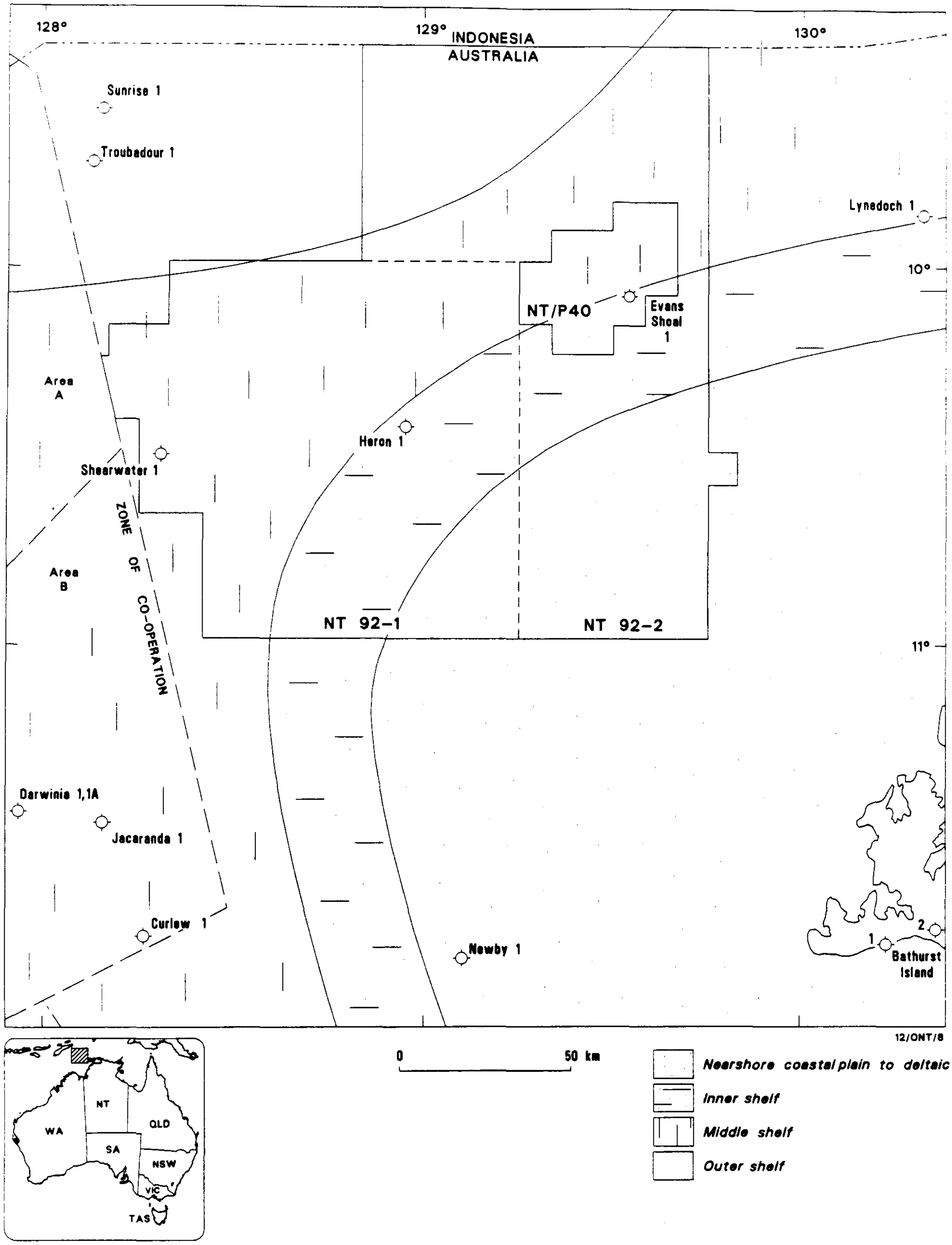


Figure 6. Middle to late Cretaceous (Bathurst Island formation) palaeogeography (after Mory, 1988)

the south, and the Sahul Platform to the north, where, in Troubadour 1, it contains coarser, interbedded sands, and is less than 8 metres thick. The thick claystones and finer clastics in the graben represent restricted marine to prograding delta deposits, whereas the more sandy, interbedded sequences on the palaeohighs to the south, represent nearshore deltaic deposits (Figure 5).

3.3 CRETACEOUS

An unconformity in the Valanginian marks the formation of a new sea floor spreading centre off the west coast of Western Australia (MacDaniel, 1988). This event gave rise to a period of uplift and erosion, removing large volumes of sediment from the Sahul Platform and Darwin Shelf. A regional marine transgression resulted in the deposition of the Bathurst Island Group, which represents a series of highstand parasequences laid down under prograding shelf and slope conditions (Botten & Wulff, 1990), and exceeding 2000 metres in thickness in the Malita Graben.

The condensed basal (Valanginian to Aptian) section consists of greensand, with radiolarian, glauconitic and calcareous claystone (Mory, 1988), varying in thickness from 152 metres in Heron 1 in the Malita Graben, to being absent on the Sahul Platform. Further erosion of emergent areas took place during the Late Aptian to Albian, followed by a major transgression, resulting in the deposition of a sequence of carbonates (Brown Gannet Limestone). These carbonates may have developed as mounded forms along the southern margin of the Sahul Platform, and grade into calcareous shales within the graben.

Overlying these carbonates is a thick sequence of siltstones, mudstones, shales and minor limestones which were deposited as inner to distal shelf sediments (Figure 6). The sequence is more sandy towards the basin margins. Eustatic falls in sea level during the Campanian and Maastrichtian resulted in the deposition of a marine siliciclastic sequence, which is probably equivalent to the Puffin Formation of the Vulcan Graben. These sandstones appear to be widespread across the Malita Graben and Darwin Shelf, where they reach a thickness of 168 metres in Heron 1, and 409 metres in Evans Shoal 1. Within the graben, the sands are clean, medium to fine frosted grains, well rounded and well sorted, with no visible organic matter, but minor glauconite. On the high shelf areas, these sands probably represent coastal plain to inner shelf deposits, but in the Malita Graben, they may represent extensive submarine fans deposited over mid shelf silts and shales.

3.4 CAINOZOIC

The northward tilt established during the Cretaceous was maintained throughout the Cainozoic. Along the axis of the Malita Graben, Paleocene to Miocene sediments were deposited, with a hiatus occurring during the Oligocene (Mory, 1988). The lower section is generally sandy, fining upwards into widespread shelfal carbonate development during Miocene time which appears to have transgressed the palaeohighs. Carbonate deposition continued in the Neogene.

4. EXPLORATION HISTORY (B.G. West)

Areas NT92-1 and NT92-2 were previously part of permits NT/P40 operated by WMC, NT/P12 operated by Woodside Offshore Petroleum Pty Ltd (Woodside) and NT/P4 and NT/P6 operated by Atlantic Richfield Company (ARCO). Exploration took place in two phases: from 1968 to 1974, and from 1985 to 1988. Between 1978 and 1985, exploration was disrupted by a border dispute between Australia and Indonesia. A seismic grid with a regional line spacing of 10 to 20 kilometres was established over much of the area, with some detailed seismic over potential leads. Two wells, Heron 1 and Shearwater 1, were drilled in the early 1970s within Area NT92-1. The most recent well, Evans Shoal 1, was drilled in the part of NT/P40 currently retained by WMC. A number of wells have been drilled in the permits adjacent to the release areas.

4.1 SEISMIC

Over 9000 kilometres of regional seismic were recorded between 1968 and 1985, providing a grid with a line spacing of 10 to 20 kilometres over much of the area. The majority was recorded by ARCO from 1968 to 1974, and by Woodside from 1969 to 1974. WMC recorded a regional survey in 1985, with a line spacing of 20 x 40 kilometres, totalling 1500 kilometres. Two subsequent surveys of 500 kilometres each were recorded in 1986 and 1987 to detail potential prospects. Durrant & Young (1988) have given a detailed account of the acquisition and processing of the 1985 to 1987 seismic data. A shotpoint location map showing the seismic coverage of the area is included as Plate 1.

4.2 DRILLING (V. Vuckovic)

The initial phase of exploration from 1968 to 1974 led to the drilling of two wells within the vacant areas: Heron 1 in 1972 and Shearwater 1 in 1974. The second phase of exploration began in the area in 1985 and led to the drilling of Evans Shoal 1 in 1988. Other wells immediately adjacent to the vacant areas that provide some measure of stratigraphic control include Lynedoch 1 (1973), Troubadour 1 (1974) and Jacaranda 1 (1984). Brief drilling summaries of these wells are presented below.

4.2.1 Shearwater 1

General well data

Operator	: ARCO Australia Limited
Rig	: *Margie*
Location	: 10° 30' 49" S; 128° 18' 37" E
Water depth	: 69.8 m
TD	: 3177 m
RKB to MSL	: 25.0 m
Spud date	: 19 September 1974
Rig released	: 4 November 1974
Status	: Plugged and abandoned

Hole sizes and depths

36" hole to 119 m
26" hole to 229 m
17 1/2" hole to 1073 m
12 1/4" hole to 2952 m
8 1/2" hole to 3177 m

Casing sizes and depths

30" casing shoe at 110.9 m
20" casing shoe at 218.8 m
13 3/8" casing shoe at 1059.5 m
9 5/8" casing shoe at 2937 m

Mud summary by hole section

36" hole	: Sea water
26" hole	: Sea water. Prior to running the casing a gel slurry was spotted.
17 1/2" hole	: Sea water and gel pills. : Mud weight: 1.02 to 1.07 s.g. : Funnel viscosity: 36 to 41 sec.

12 1/4" hole	: Spersene/XP-20 Resinex mud system. : Mud weight: 1.07 to 1.32 s.g. : Funnel viscosity: 37 to 50 sec.
8 1/2" hole	: Similar mud properties as in 12 1/4" hole prior to setting 9 5/8" casing. : Mud weight: 1.32 s.g. : Funnel viscosity: 45 sec.

Hole problems

Tight hole conditions through the Bathurst Island Group (1566 to 3054 metres).

Pore pressure evaluation

The formations penetrated by Shearwater 1 appear to be normally pressured from surface to total depth (Figure 7). There was no indication of overpressured intervals from the shale interval transit time, shale resistivity, shale density or penetration rates. Gas readings also remained low and steady throughout the well. No direct formation pressure survey was run in the well.

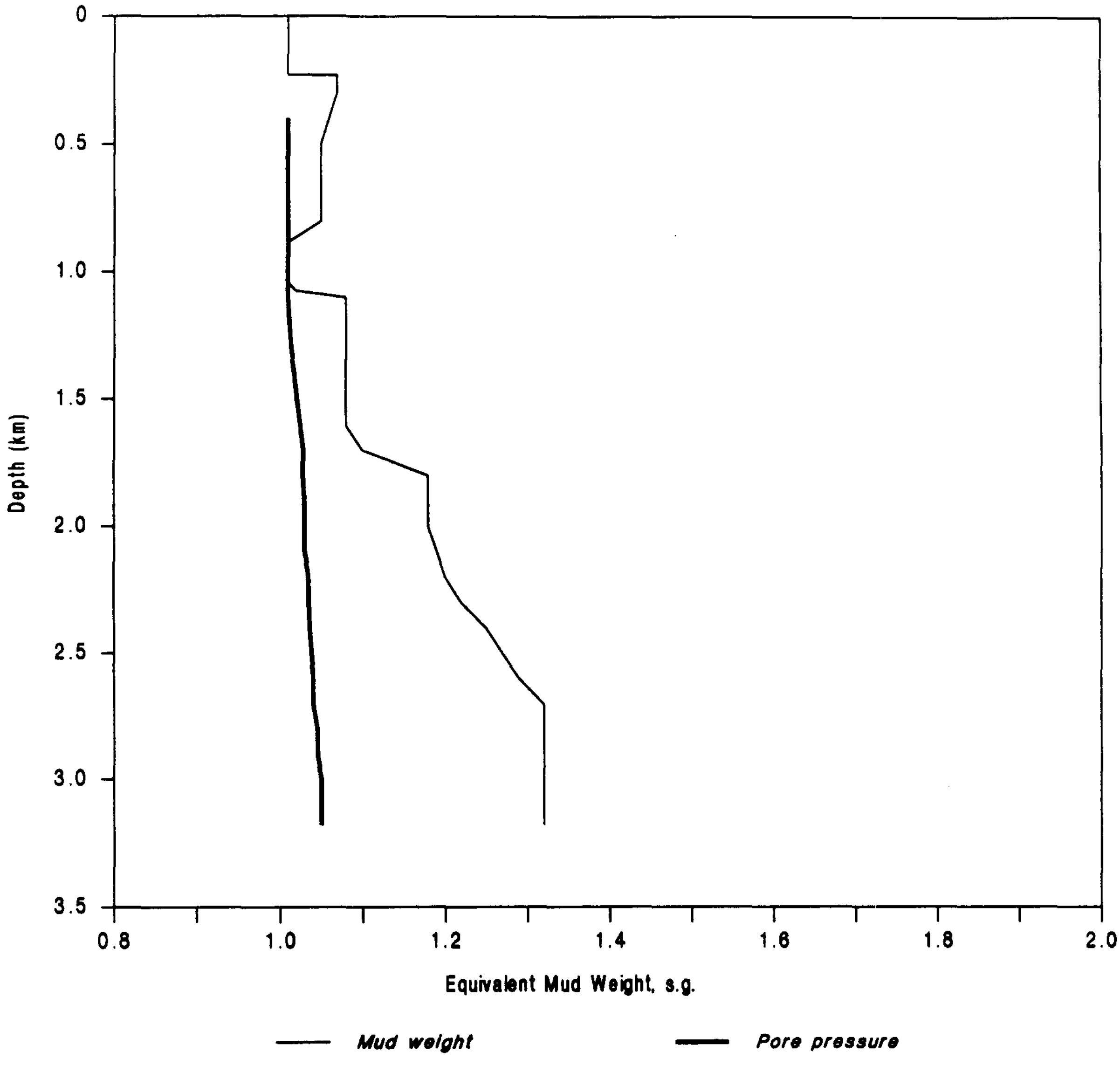


Figure 7 Pore Pressure Evaluation, SHEARWATER 1

4.2.2 Heron 1

General well data

Operator	: ARCO Australia Limited
Rig	: *Navigator*
Location	: 10° 26' 27" S; 128° 57' 5" E
Water depth	: 38.4 m
TD	: 4209 m
RKB to MSL	: 11.9 m
Spud date	: 13 September 1971
Rig released	: 5 February 1972
Status	: Plugged and abandoned before reaching programmed depth of 4725 m. The reasons for abandoning were slow penetration, lack of porosity in penetrated sandstones and junk in hole.

Hole sizes and depths

36" hole to 96 m
26" hole to 198 m
17 1/2" hole to 1067 m
12 1/4" hole to 3018 m
8 1/2" hole to 3828 m
5 7/8" hole to 4209 m

Casing sizes and depths

30" casing shoe at 80 m
20" casing shoe at 182.3 m
13 3/8" casing shoe at 1051.2 m
9 5/8" casing shoe at 2998.9 m
7" liner shoe at 3821.3 m

Mud summary by hole section

36" hole	: Sea water. Prior to running the casing a gel slurry was spotted.
26" hole	: Same as in 36" hole.

17 1/2" hole — ghtly treated sea water mud. LCM was added
hile drilling at 705 m to cure losses.
: Mud weight: 1.09 to 1.22 s.g.
: Funnel viscosity: 32 to 42 sec.

12 1/4" hole — : Seawater was used as the mud mixing fluid, but fresh water was used to prehydrate the bentonite prior to addition. Drilling below 2130 m precipitated the raising of mud weight to 1.66 s.g. due to tight hole and high gas readings.
: Mud weight: 1.22 to 1.66 s.g.
: funnel viscosit[illegible] 7 to 84 sec.

8 1/2" hole — : Same as in 12 1/4" hole.
: Mud weight: 1.66 to 1.98. s.g.
: Funnel viscosity: 52 to 90 sec.

5 7/8" hole — : Same as in 12 1/4 and 8 1/2" holes.
: Mud weight: 1.76 to 1.98 s.g.
: Funnel viscosity: 50 to 120 sec.

Circulation losses

One hundred barrels of mud were lost while drilling the pilot hole at 705 metres. However, the addition of LCM remedied the problem. At 3693 metres, the mud weight was raised to 1.97 s.g. due to a 20 barrels of mud gain in the pits, but the hole began taking mud. The mud weight was, therefore, reduced to 1.94 to 1.96 s.g. Drilling resumed with the mud maintained within those limits with intermittent mud losses and gains.

After drilling out a 7 inch liner shoe at 3821.3 metres, the formation broke down and the mud weight had to be reduced to 1.82 s.g. While drilling at 4188 metres with 1.89 s.g. mud, all mud returns were lost. A heavy addition of LCM helped regain of full returns, but only with a reduced mud weight of 1.80 s.g. While plugging the well at total depth, a hole in the casing was found between 1177 and 1186 metres. Large mud losses occurred through this hole before it was cemented.

Hole problems

Tight hole condition beginning at approximately 2134 metres caused heavy reaming. Gas incursions below 2832 metres precipitated drilling with heavy mud weights.

Pore pressure evaluation

The formations appear to be normally pressured to approximately 2100 metres, but below this depth there are indications of overpressuring (Figure 8). The sonic transit time plot (Figure 9) and resistivity plot (Figure 10) exhibit shifts from normal trend between 2100 and 2700 metres and again between 3100 and 3800 metres. Gas readings also increased below 2830 metres. However, the increase in pore pressure within those two intervals is not evident from the drilling exponent plot.

There is ample evidence that the mud weights used for drilling below 2100 metres were far in excess of actually required mud weights for balanced control of pore pressures within these intervals. The symptoms of excess mud overbalance were: loss of mud while circulating and gaining mud back when the pumps were off, high amounts of gas after connections and trips, and finally fractured formation below the 7 inch liner shoe at 3821.3 metres.

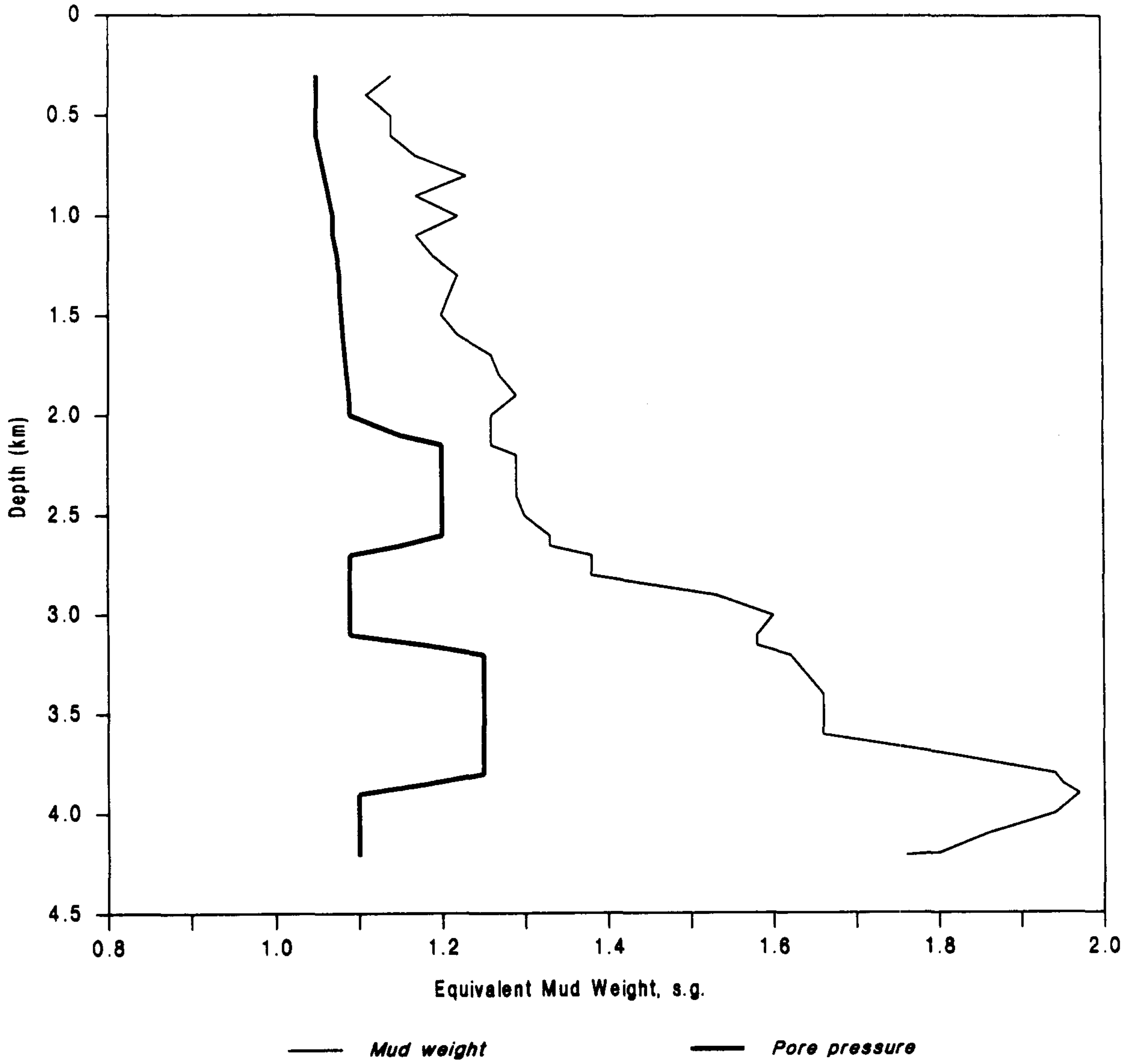


Figure 8 Pore Pressure Evaluation, HERON 1

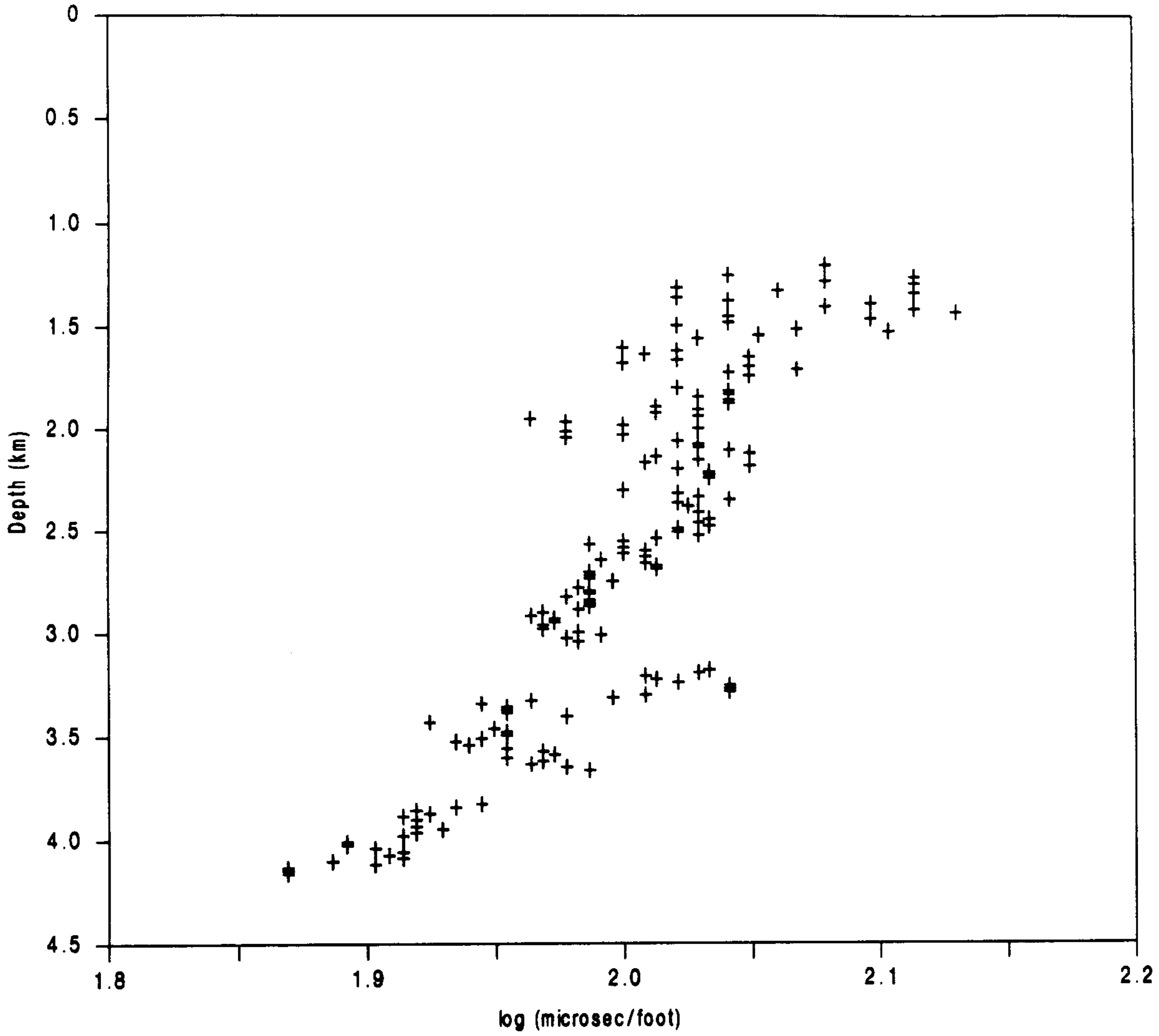


Figure 9 Sonic Transit Time in Shale Zones, HERON 1

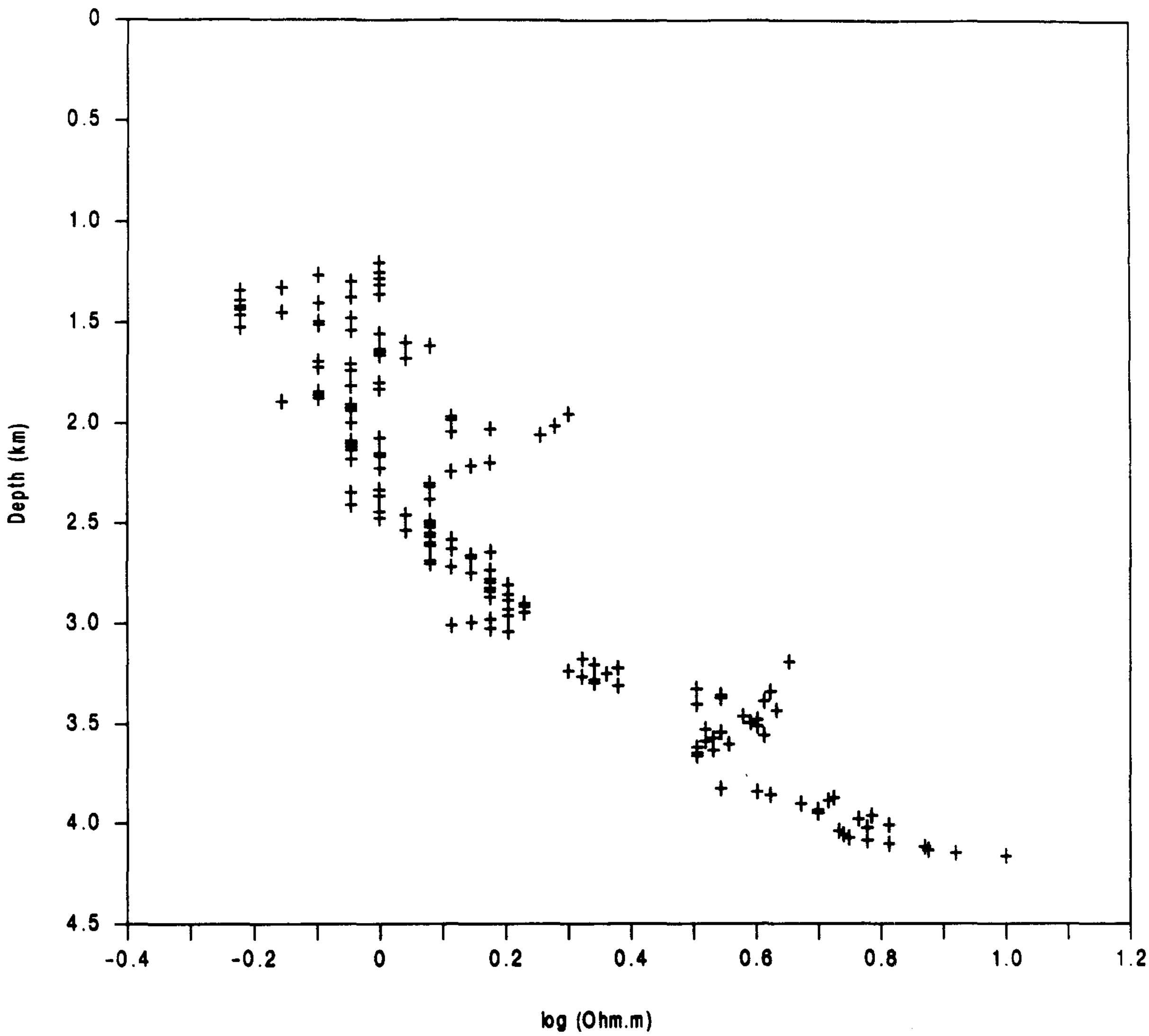


Figure 10 Induction Resistivity In Shale Zones, HERON 1

4.2.3 Evans Shoal 1

General well data

Operator	: BHP Petroleum
Rig	: *Energy Searcher*
Location	: 10° 04' 53.487' 'S; 129° 31' 55.202 "E
Water depth	: 110 m
TD	: 3712 m
RKB to MSL	: 17.7 m
Spud date	: 27 June 1988
Rig released	: 27 August 1988
Status	: Plugged and abandoned as a gas discovery

Hole sizes and depth

36" hole to 167 m
26" hole to 455 m
17 1/2" hole to 1587 m
12 1/4" hole to 3015 m
8 1/2" hole to 3712 m

Casing sizes and depths

30" casing shoe at 162 m
20" casing shoe at 450.3 m
13 3/8" casing shoe at 1575.6 m
9 5/8" liner shoe at 3001 m

Mud summary by hole section

36" hole	: Sea water and Hi-Vis pills.
26" hole	: Sea water and Hi-Vis pills.
	: Mud weight: 1.02 to 1.06 s.g.
	: Funnel viscosity: 100 sec.
17 1/2" hole	: Closed sea water/HI-Vis mud system.
	: Mud weight: 1.06 to 1.08 s.g.
	: Funnel viscosity: 34 to 40 sec.

12 1/4" hole	: KCl/Polymer mud system with added mica to cure losses. : Mud weight: 1.06 to 1.25 s.g. : Funnel viscosity: 31 to 45 sec.
8 1/2" hole	: KCl/Polymer mud system. : Mud weight: 1.25 to 1.26. s.g. : Funnel viscosity: 37 to 45 sec.

Circulation losses

1622 to 1815 m	: Losses of up to 100 barrels per hour were observed, but reduced to 15 to 20 barrels per hour after adding mica to the mud.
1815 to 2307 m	: Drilling continued with full returns maintained by adding mica to the mud.

Hole problems

Tight hole conditions were experienced between 2287 and 2250 metres with 45 tonnes overpull observed. Light reaming was required between 2309 and 2328 metres. At 3567 metres, high torque was experienced and further drilling below this depth required occasional heavy reaming. Also, abrasive sands were observed below this depth causing extreme gauge wear on bits.

Formation integrity

1590 m to 1.50 s.g. leak off
3020 m to 1.90 s.g. leak off

Pore pressure evaluation

The formations are normally pressured to 2520 metres, but below this depth there are some indications of possible overpressuring (Figure 11). Within the interval 2520 to 2870 metres, the indications of abnormally pressured formation were the splintery character of the ditch cuttings, the increase in background and connection gas, and the high torque, drag and overpull experienced during drilling through this section. However, there was no indication of overpressures from the "d" exponent plot. The shale compaction indicators from well logs, such as resistivity and shale transit time, also did not indicate overpressured formation.

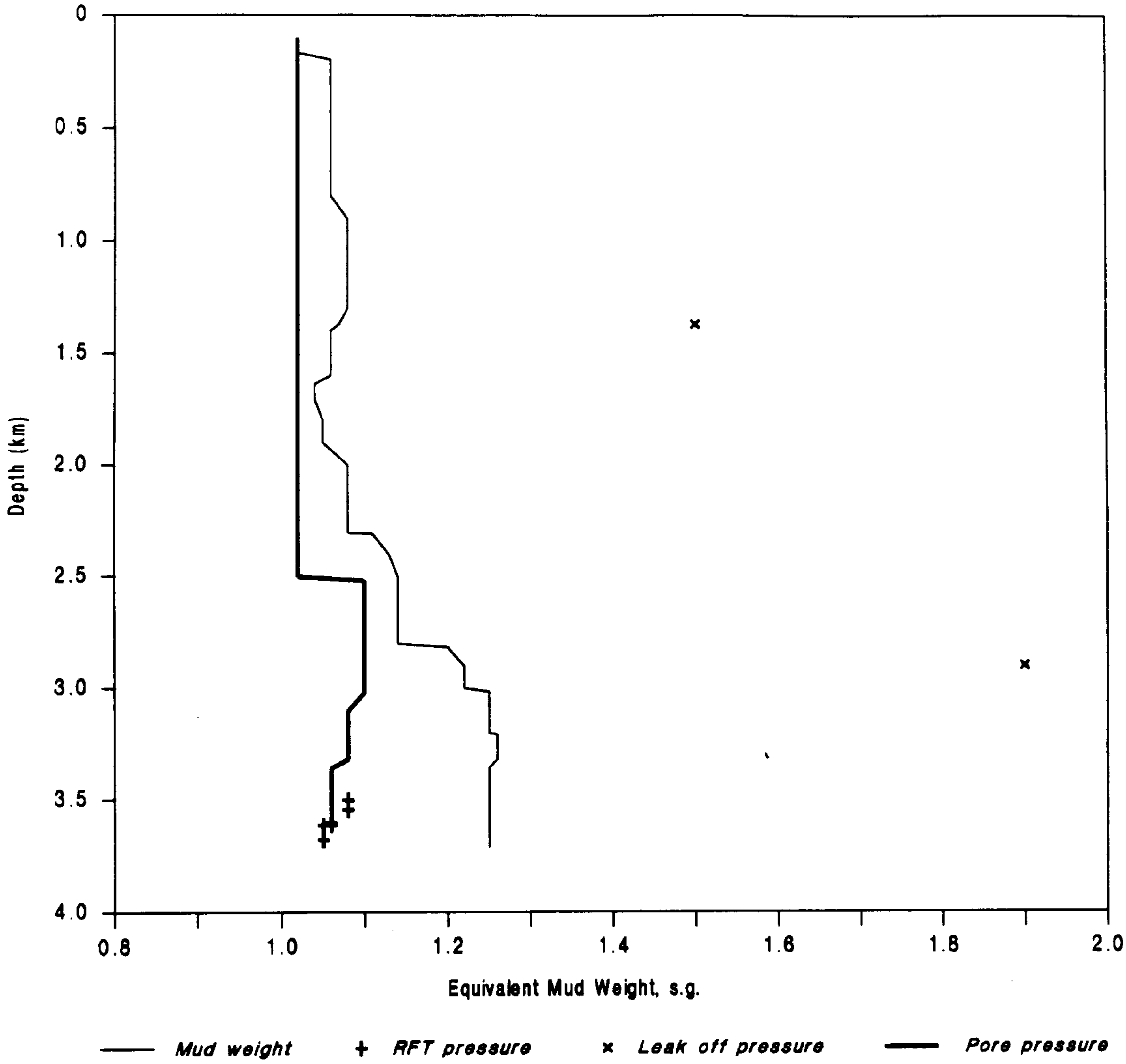


Figure 11 Pore Pressure Evaluation, EVANS SHOAL 1

Similarly, within the interval 3020 to 3320 metres, the primary indicators of possible abnormal pore pressures were high background and connection gas levels and splintery character of the formation cuttings. There was no indication of overpressures from the "d" exponent plot, although the corrected drilling exponent trend ("dcs" trend) decreases slightly below 3100 metres. The shale compaction indicators from the well logs also did not positively indicate abnormal pore pressures within this interval.

While drilling these intervals the mud weight was progressively raised to 1.25 s.g. and was kept at this level to total depth. RFT testing of the underlying Plover Formation sandstone reservoir below 3543 metres showed it to be normally pressured at about 1.05 to 1.08 s.g.

Because the qualitative abnormal pressure detection techniques based on the compaction indicators from the well logs did not indicate abnormal pressuring within the above mentioned intervals, the available evidence which suggests overpressuring is considered insufficient to definitively identify these intervals as overpressured. Paradoxically, the indication of overpressuring within these two intervals, high connection gas and splintery cuttings could have occurred not because of abnormal pore pressures, but because of significant mud pressure overbalance. Excess mud weight will induce artificial pore pressure around the open hole and ahead of the drill bit into the shale body. This makes drilling responses, such as cuttings size and shape, gas readings and drilling exponent, unreliable indicators of the true natural pore pressure while drilling with significant mud overbalance.

RFT results

Depth (m)	**Formation pressure (psi)**	**s.g.**	**Remarks**
3554.0	5414.32	1.08	Very good permeability
3544.0	5406.49	1.08	Very good permeability
3608.2	-	-	Tight formation
3608.5	5427.17	1.06	Very good permeability
3611.0	5431.30	1.06	Fair permeability
3610.8	-	-	Tight formation
3613.8	5438.53	1.06	Good permeability
3633.6	-	-	Tight formation
3633.0	-	-	Tight formation
3633.3	-	-	Tight formation
3633.7	-	-	Tight formation
3678.0	5467.17	1.05	Good permeability

4.2.4 Lynedoch 1

General well data

Operator	: Shell Development Pty Ltd
Rig	: *Sedco 445*
Location	: 9° 51' 43" S; 130° 18' 45"E
Water depth	: 235.6 m
TD	: 3966.9 m
RKB to MSL	: 11.3 m
Spud date	: 14 February 1973
Rig released	: 8 June 1973
Status	: Plugged and abandoned

Hole sizes and depths

26" hole to 509 m
18 1/2" hole to 1801 m
12 1/4" hole to 3504 m
8 1/2" hole to 3966.9 m

Casing sizes and depths

30" casing shoe at 280 m (casing jetted in)
20" casing shoe at 503 m
13 3/8" casing shoe at 1779 m
9 5/8" shoe at 3414 m

Mud summary by hole section

36" hole	: Casing jetted in with sea water.
26" hole	: Sea water with bentonite.
18 1/2" hole	: Sea water/CMC/Bentonite/Lignosulfonate . : Mud weight: 1.08 to 1.14 s.g. : Funnel viscosity: 35 to 55 sec.

12 1/4" hole	: Spersene was added for thinning and filtration control while Tufplug and mica were added to prevent formation losses. : Mud weight: 1.11 to 1.45 s.g. : Funnel viscosity: 37 to 71 sec.
8 1/2" hole	: Same as in 12 1/4" hole. : Mud weight: 1.19 to 1.61. s.g. : Funnel viscosity: 41 to 60 sec.

Circulation losses

947 to 1801 metres	: At 947 metres, minor losses were experienced. Further drilling to 1801 metres resulted in increased losses. Despite the addition of LCM into the mud some, 900 barrels were lost while drilling this section.

Hole problems

The total section from 509 to 1798 metres was underreamed from 12 1/4 to 18 1/2 inch with considerable difficulties experienced with underreaming equipment. Drilling continued to 3504 metres with continuous hole problems such as tight hole, fill and excessive caving. Because of poor hole conditions, logging of this section was difficult. Despite extensive reaming and mud conditioning prior to running a 9 5/8 inch casing, 45 metres of fill were found at the bottom, and the casing had to be set higher than programmed.

At 3714 metres, the string was stuck with a maximum overpull of 136 tonnes. The free point indicator established stuck pipe below 3551 metres. The drill string was backed off at 3541 metres. A cement plug was set from 3535 to 3472 metres and the hole was side tracked at 3474 metres. At 3702 metres, the well kicked and was killed with original mud weight. No kick was experienced in the original hole at this depth indicating a local occurrence of gas.

Drilling below 3714 metres required increased mud weight to avoid connection gas. Cavings caused severe overpull when tripping and drilling progress was periodically very slow due to hard and abrasive formations. The final logging program was carried out with difficulty because of tight and sticky hole conditions.

Formation integrity

1804 m to 1.63 s.g. leak off
3503 m to 1.82 s.g. leak off

Pore pressure evaluation

Pore pressures appear to be normal throughout the entire hole section (Figure 12). There is no evidence of abnormal pressures from any of the available abnormal pore pressure indicators.

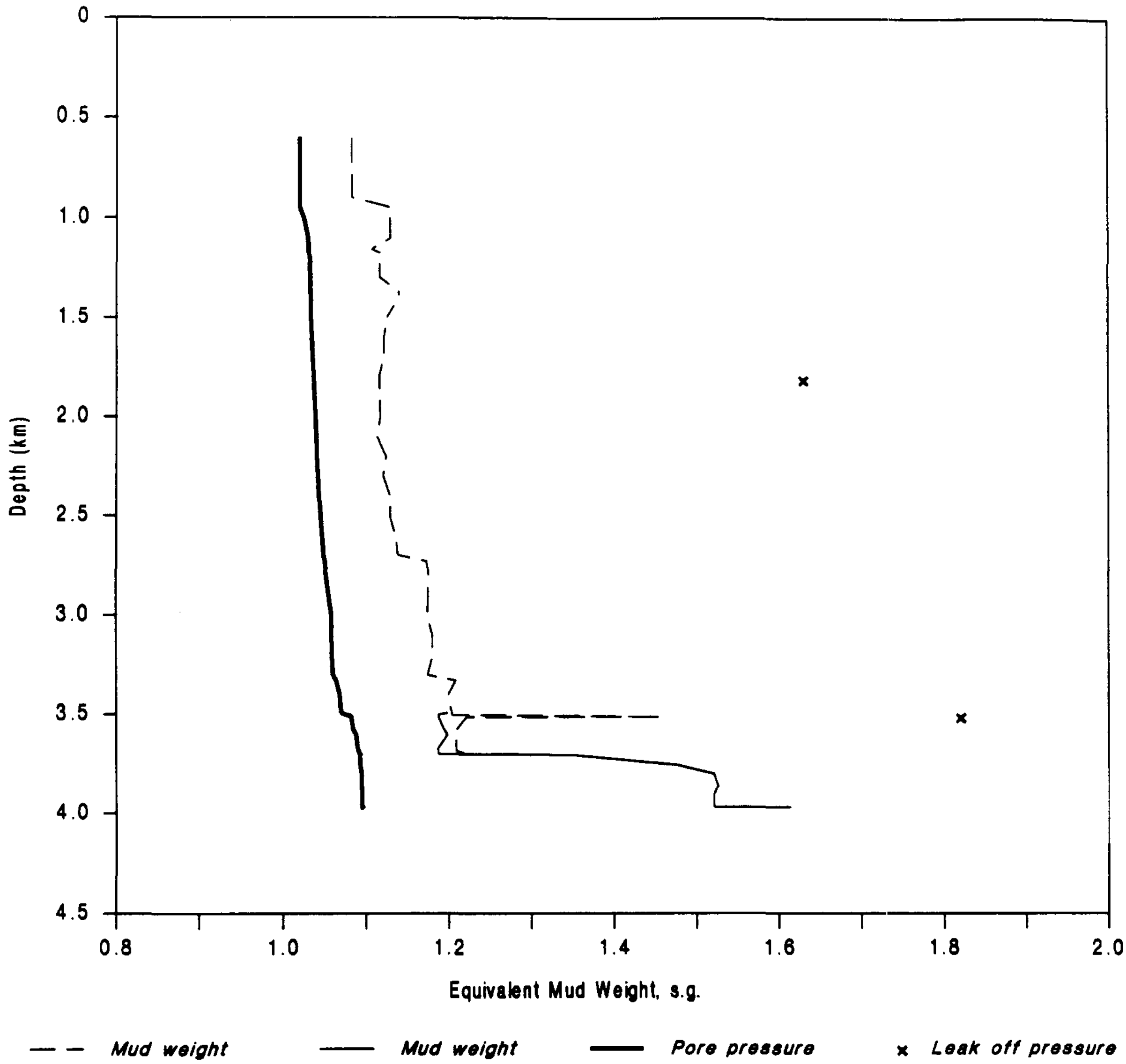


Figure 12 Pore Pressure Evaluation, LYNEDOCH 1

4.2.5 Troubadour 1

General well data

Operator	: BOC Australia Ltd.
Rig	: *Big John*
Location	: 9° 44' 03.82" S; 128° 07' 25.51" E
Water depth	: 96 m
TD	: 3459 m
RKB to MSL	: 13 m
Spud date	: 3 June 1974
Rig released	: 29 August 1974
Status	: Suspended as gas/condensate well

Hole sizes and depths

36" hole to 142 m
26" hole to 430 m
17 1/2" hole to 1195 m
12 1/4" hole to 2486 m
8 1/2" hole to 3459 m

Casing sizes and depths

30" casing shoe at 134.2 m
20" casing shoe at 420.0 m
13 3/8" casing shoe at 1181.0 m
9 5/8" shoe at 2473 m

Mud summary by hole section

36" hole	: Sea water with high viscosity gel slugs.
26" hole	: Sea water with high viscosity gel slugs.
17 1/2" hole	: Sea water and prehydrated gel system lightly treated with CMC. Severe lost circulation problems required use of high viscosity LCM plugs. A high viscosity mud was spotted prior to logging and running 13 3/8" casing. : Mud weight: 1.05 to 1.07 s.g. : Funnel viscosity: 31 to 33 sec.

12 1/4" hole	: Low solids saturated salt-polymer mud system. Barytes was used for weighting up the mud and fluid loss was controlled by Dextrid. Drispac and Bentonite were used for viscosity control. : Mud weight: 1.20 to 1.38 s.g. : Funnel viscosity: 34 to 49 sec.
8 1/2" hole	: Low solids lightly dispersed sea water-Q-mix. Lignosulphanate was used for dispersion and fluid loss was controlled with Dextrid and CMC. : Mud weight: 1.10 to 1.29. s.g. : Funnel viscosity: 35 to 47 sec.

Circulation losses

Complete loss of circulation was experienced at 523 metres. LCM plugs were not effective and several cement plugs were set in an attempt to cure the losses. These plugs were completely ineffective and drilling continued without returns. At 890 metres partial returns were observed. This was attributed to sealing by the drilled solids. Two more cement plugs were set but with no success and drilling to 1181 metres continued with only partial returns. Slight losses were observed at 2155 metres. Mud losses at 2831 metres were cured by pumping an LCM plug and reducing the mud weight.

Hole problems

Apart from the above mentioned mud losses no other hole problems were experienced.

Pore pressure evaluation

Pore pressures appear to be normal throughout the entire hole section (Figure 13).

FIT and DST results

Depth (m)	**Formation pressure (psi)**	**s.g.**	**Remarks**
2286.0	3351.00	1.04	FIT
2376.0	3310.00	0.98	DST
2376.0	3339.00	1.08	DST

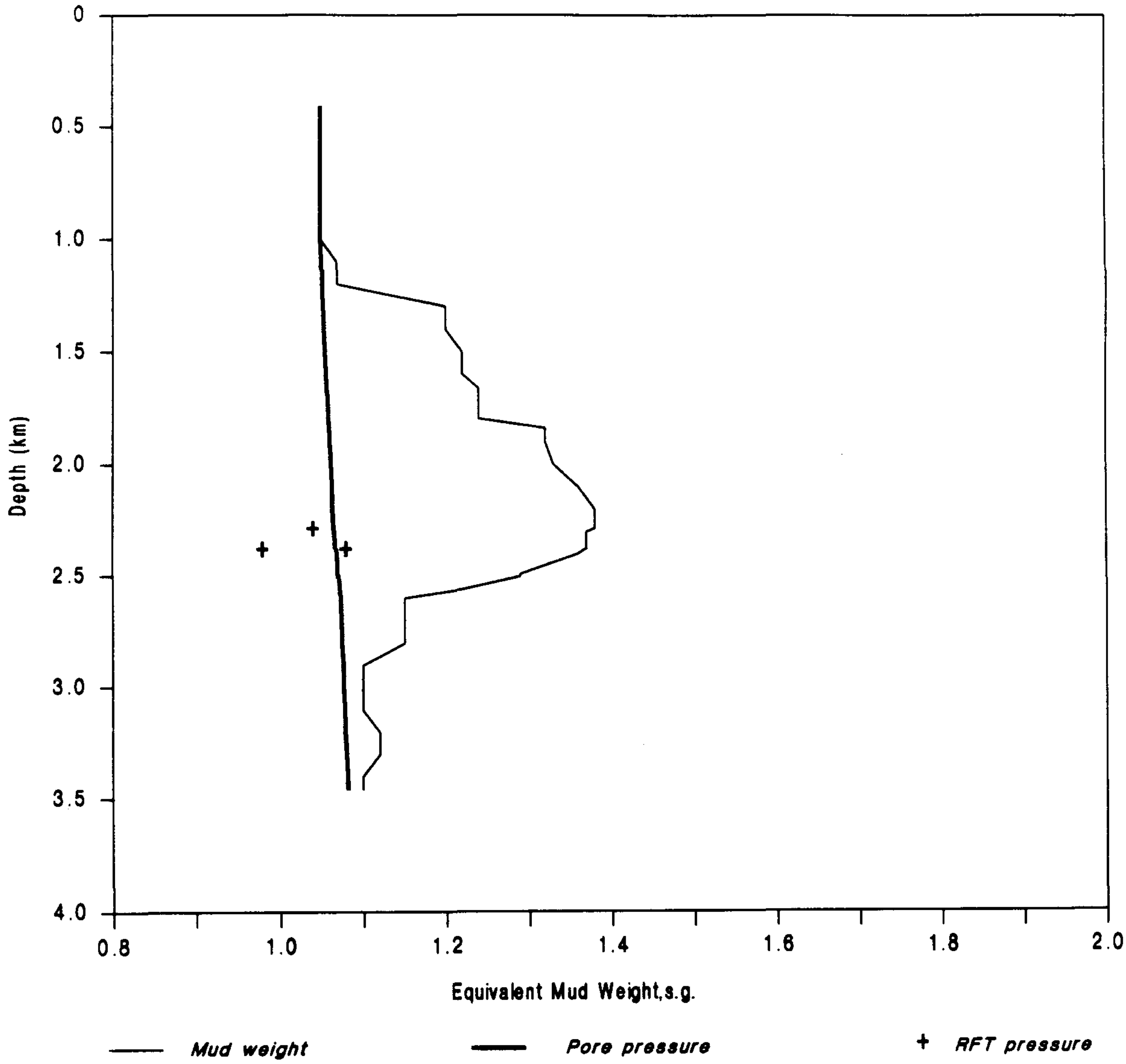


Figure 13 Pore Pressure Evaluation, TROUBADOUR 1

4.2.6 Jacaranda 1

General well data

Operator	: Tricentrol Exploration Overseas Limited
Rig	: *Glomar Main Pass III*
Location	: 11° 28' 15.417" S; 128° 09' 50.306" E
Water depth	: 78.35 m
TD	: 3783 m
RKB to MSL	: 26.2 m
Spud date	: 25 June 1984
Rig released	: 21 August 1984
Status	: Plugged and abandoned

Hole sizes and depths

36" hole to 136 m
26" hole to 568 m
17 1/2" hole to 1130 m
12 1/4" hole to 2599 m
8 1/2" hole to 3783 m

Casing sizes and depths

30" casing shoe at 135.0 m
20" casing shoe at 563.6 m
13 3/8" casing shoe at 1126.2 m
9 5/8" casing shoe at 2590.9 m

Mud summary by hole section

36" hole	: High viscosity spud mud. : Mud weight: 1.03 to 1.13 s.g.
26" hole	: Same as in 36" hole.
17 1/2" hole	: Sea water/Polymer mud system. : Mud weight: 1.05 to 1.08 s.g. : Funnel viscosity: 35 to 38 sec.

12 1/4" hole	: KCl/Polymer mud system. : Mud weight: 1.11 s.g. to 1.28 s.g. : Funnel viscosity: 36 to 45 sec.
8 1/2" hole	: Same as in 12 1/4" hole. : Mud weight: 1.18 to 1.27 s.g. : Funnel viscosity: 38 to 46 sec.

Circulation losses

Losses of approximately 9 barrels per minute were observed at 568 metres. The 20 inch casing was run and cemented with no returns to surface.

Hole problems

The upper section of the 12 1/4 inch hole (1130 to 1450 metres) was extensively washed out and high gel pills were required to clean abundant caving. Drag and fill were evident on connections, and tight hole conditions required jarring on tripping out at 1431 metres. Cavings were again evident from 1615 to 1830 metres. Logging of the 12 1/4 inch hole prior to running casing was difficult because of sticky hole conditions.

At 2624 metres, high torque was experienced. There was evidence of junk in hole. Tight hole condition was encountered between 3550 and 3619 metres. Wireline logging at total depth was hampered by a bridge/dogleg at 3612 metres with massive washouts of sandstones to more than 22 inches indicated in places

Formation integrity

570 m to 1.22 s.g. no leak off
1132 m to 1.88 s.g. leak off
2602 m to 1.52 s.g. leak off
2702 m to 1.70 s.g. leak of

Pore pressure evaluation

There is compelling evidence of increased pore pressure within the Tertiary and Cretaceous shales over intervals 1130 to 1450 metres and 1630 to 1880 metres (Figure 14). All formation compaction indicators within these intervals suggest increased pore pressure. The shale density is below the normal shale density trend. The shale resistivity decreases from the normal trend within these two zones. An increase in pore pressure over these intervals was also indicated by

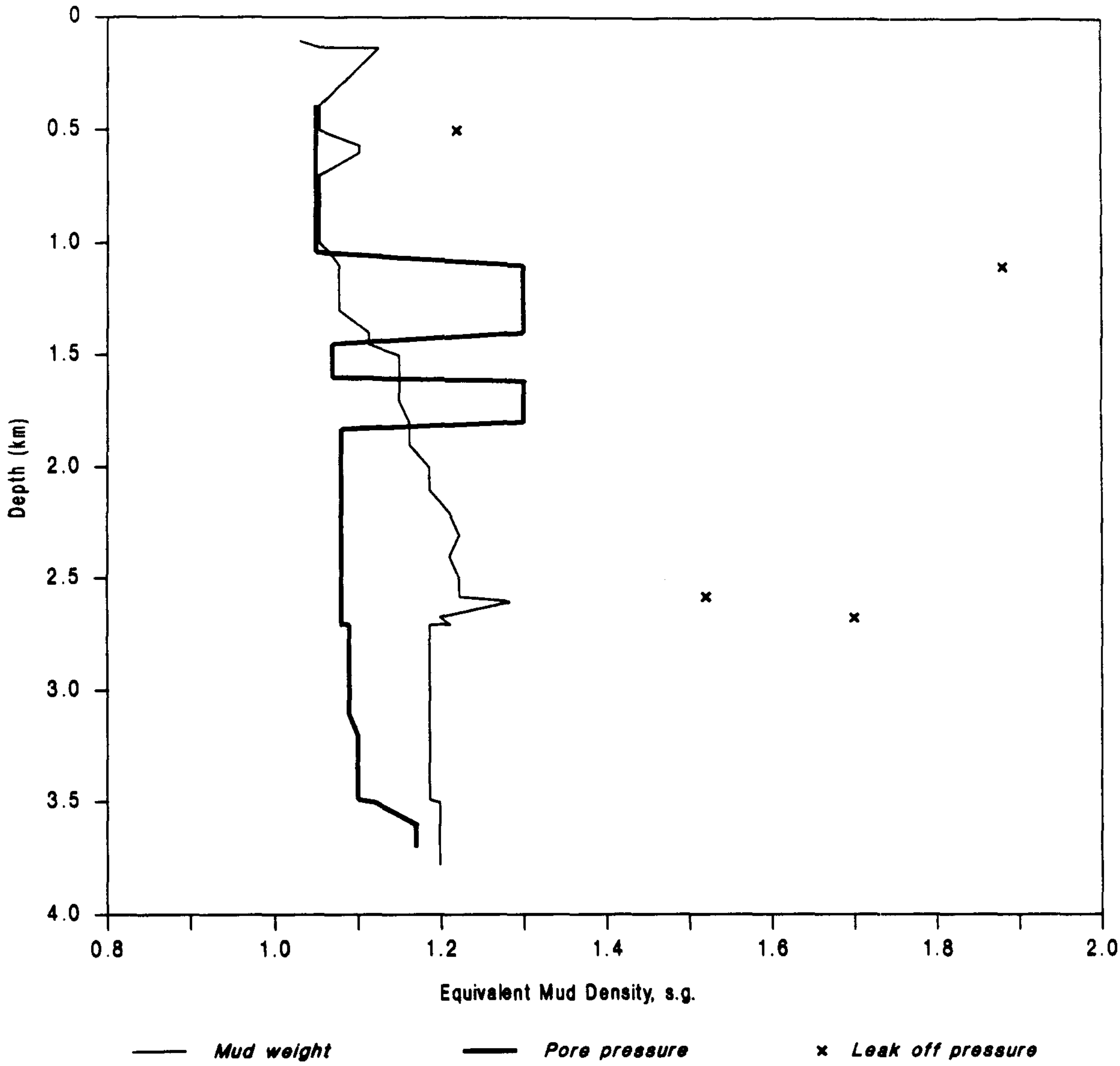


Figure 14 Pore Pressure Evaluation, JACARANDA 1

decrease in drilling exponent trend line, and increased background and connection gas. The appearance of splintery cuttings, extensively washed hole and drag on trips are further indications of increased pore pressure over these intervals. The pore pressure within these two zones is estimated at 1.3 s.g.

There are some indications of possible increased pore pressure between 3600 and 3783 metres from the presence of connection gas and increased formation temperature from 116° Celsius at 3576 metres to 132° Celsius at 3619 metres. However, there is no clear indication of increased pore pressure from sonic transit time and formation density logs within this zone. Furthermore, the interpretation of drilling exponent over this interval was hindered by junk in hole yielding unrealistic penetration rates. Limited drilling exponent interpretation indicates possible pore pressure within this section of 1.17 s.g. No direct pressure measurement such as RFT or DST was attempted in the well.

5. REGIONAL GEOPHYSICS (B.G. West)

5.1 DATA SETS

This study included the integration of WMC's 1985, 1986 and 1987 seismic data (WMC, 1986; 1987; 1988), several lines from ARCO's 1972 Baldwin Bank survey (ARCO, 1973), and well data from Shearwater 1 (ARCO, 1975), Heron 1 (ARCO, 1972) and Evans Shoal 1 (BHP, 1988) wells.

The shotpoint location map (Plate 1) shows the seismic coverage for the two release areas, and Figure 15 shows the location of the 20 interpreted lines included in this package. Composite well and velocity logs for Shearwater 1, Heron 1 and Evans Shoal 1 wells are included as Plates 2-10, and the generalised stratigraphy, seismic picks and two-way times for these wells are shown in Figures 16-18.

In addition, composite well logs for Lynedoch 1 (Shell, 1973), Troubadour 1 (BOC, 1974), Jacaranda 1 (Tricentrol, 1985a) and Darwinia 1 (Tricentrol, 1985b) are included as Plates 11-14, and the generalised stratigraphy and seismic picks are shown in Figures 19-22.

The twenty uninterpreted seismic lines (Plates 15-34), and corresponding interpreted lines (Plates 15a-34a) were drawn mainly from WMC's 1985 Marie seismic survey, providing a broad regional grid over a large part of the release areas, with several lines from WMC's 1987 Connie seismic survey providing a tie to Evans Shoal 1 well, and several lines from ARCO's 1972 Baldwin Bank seismic survey providing some control north of Shearwater 1 well.

Six plates (Plates 18b, 19b, 20b, 26b, 28b and 31b) were constructed from selected seismic sections showing, diagrammatically, the generalised stratigraphy and potential play types in the two release areas.

5.2 SEISMIC PICKS

Four horizons, representing both major seismic breaks and significant stratigraphic breaks, were plotted on the seven well sections (Figures 16-22) and keyed to the seismic data. The four horizons are represented on the interpreted sections as K (top Cretaceous), Kt (Turonian marker), Ka (Albian/Aptian Unconformity) and Jb (Callovian 'Breakup' Unconformity). A deeper seismic marker, interpreted to be near the top Permo-Triassic has been plotted on several sections, but should be regarded as unreliable as there is no well control.

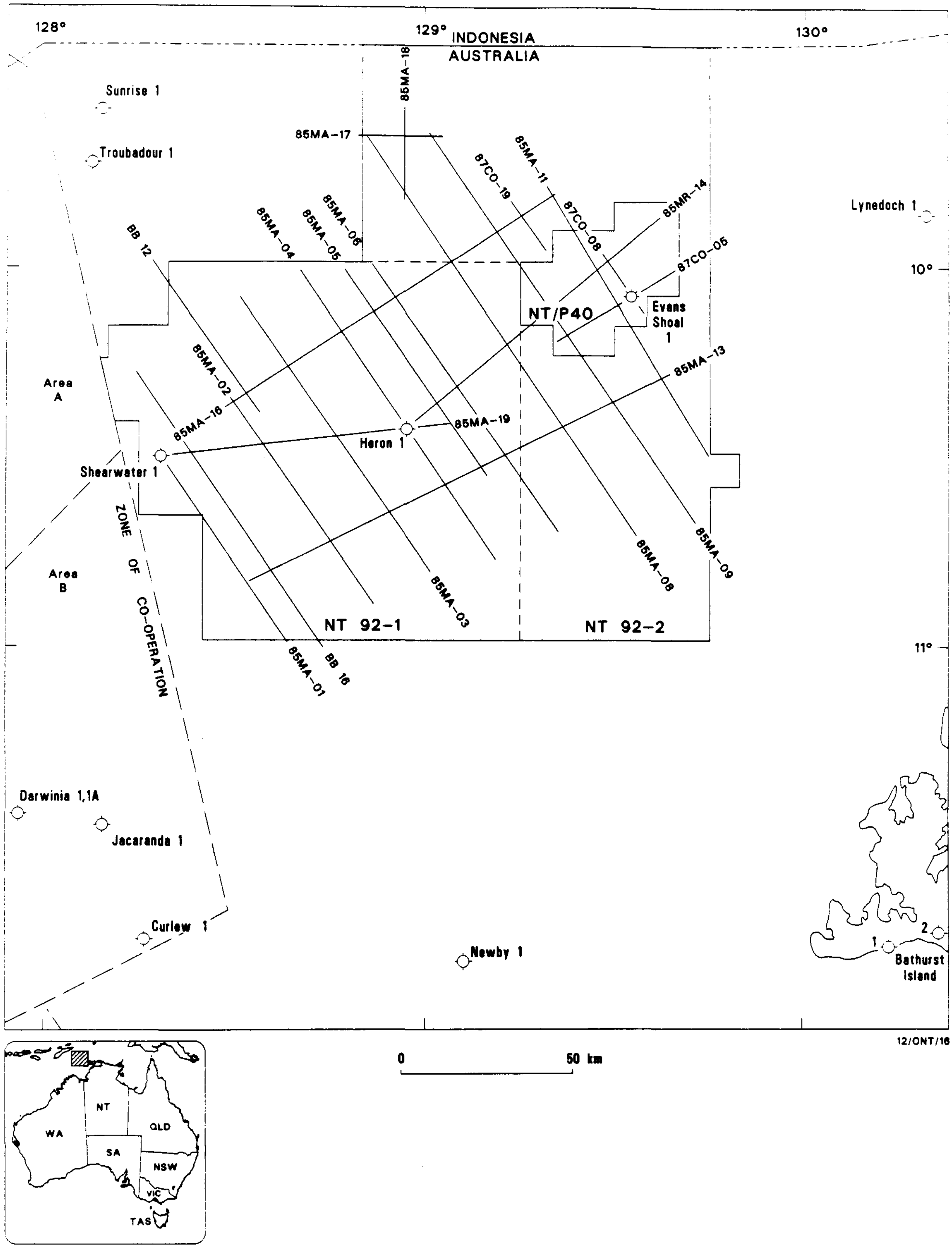


Figure 15. Seismic data included in package

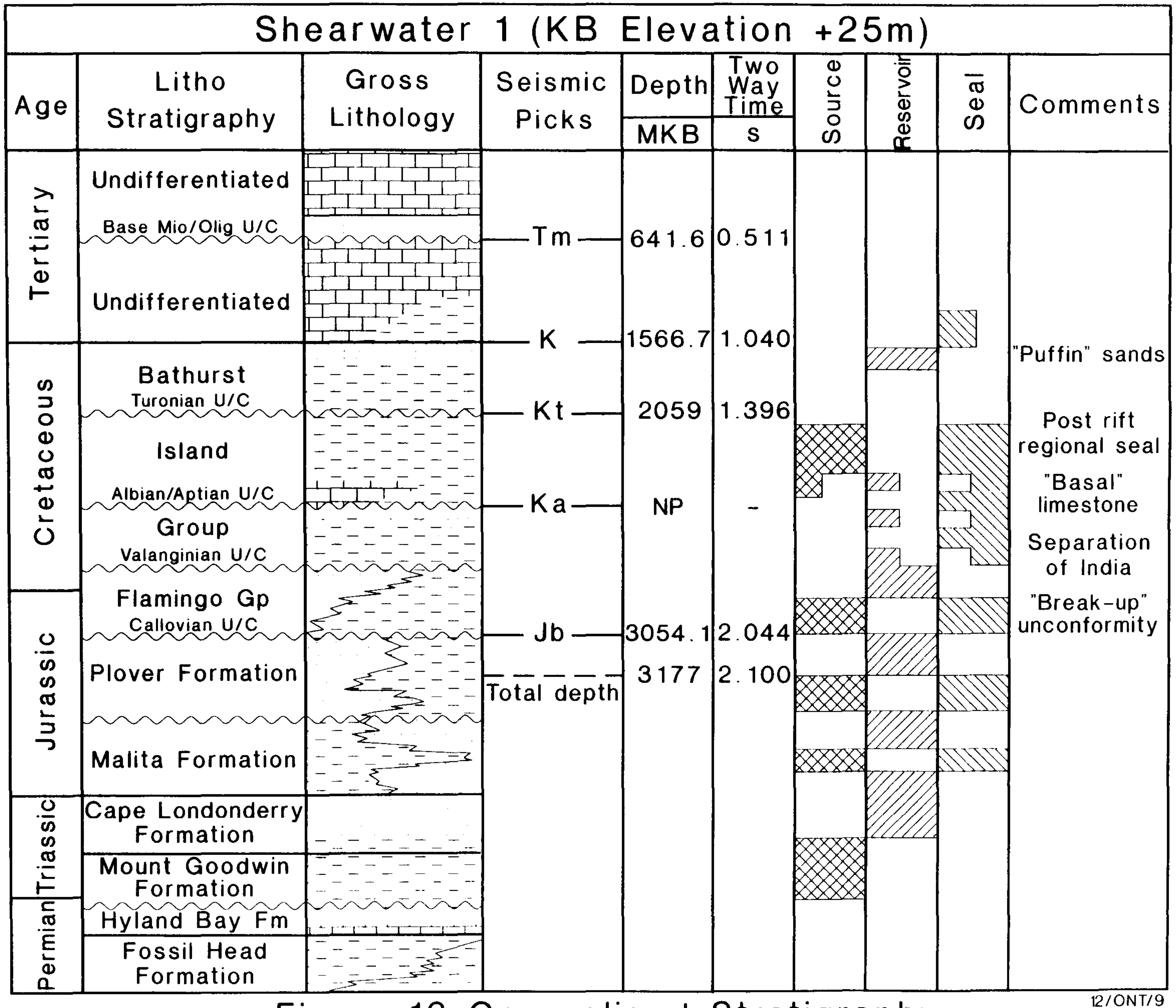


Figure 16 Generalised Stratigraphy

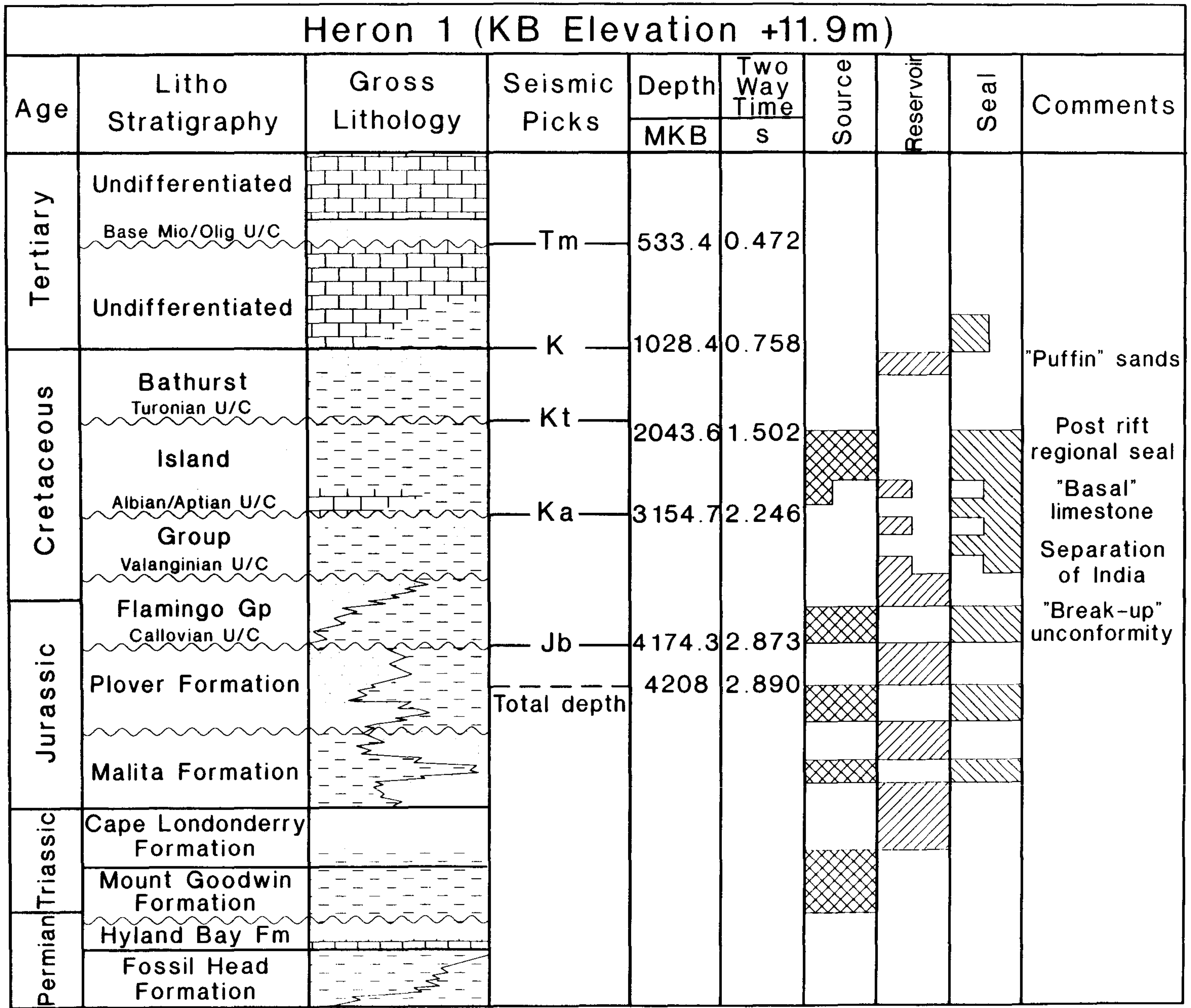


Figure 17 Generalised Stratigraphy

12/ONT/10

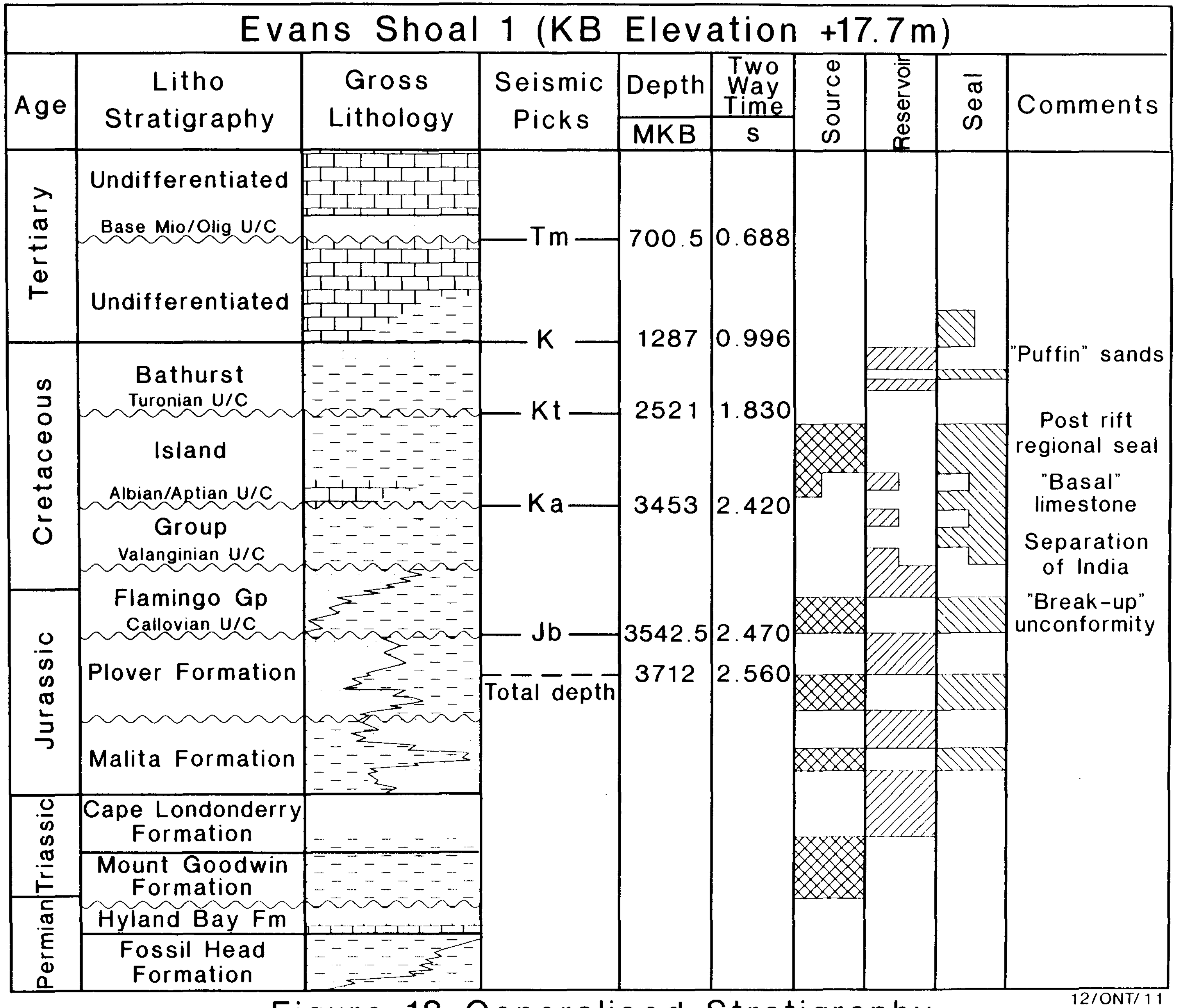


Figure 18 Generalised Stratigraphy

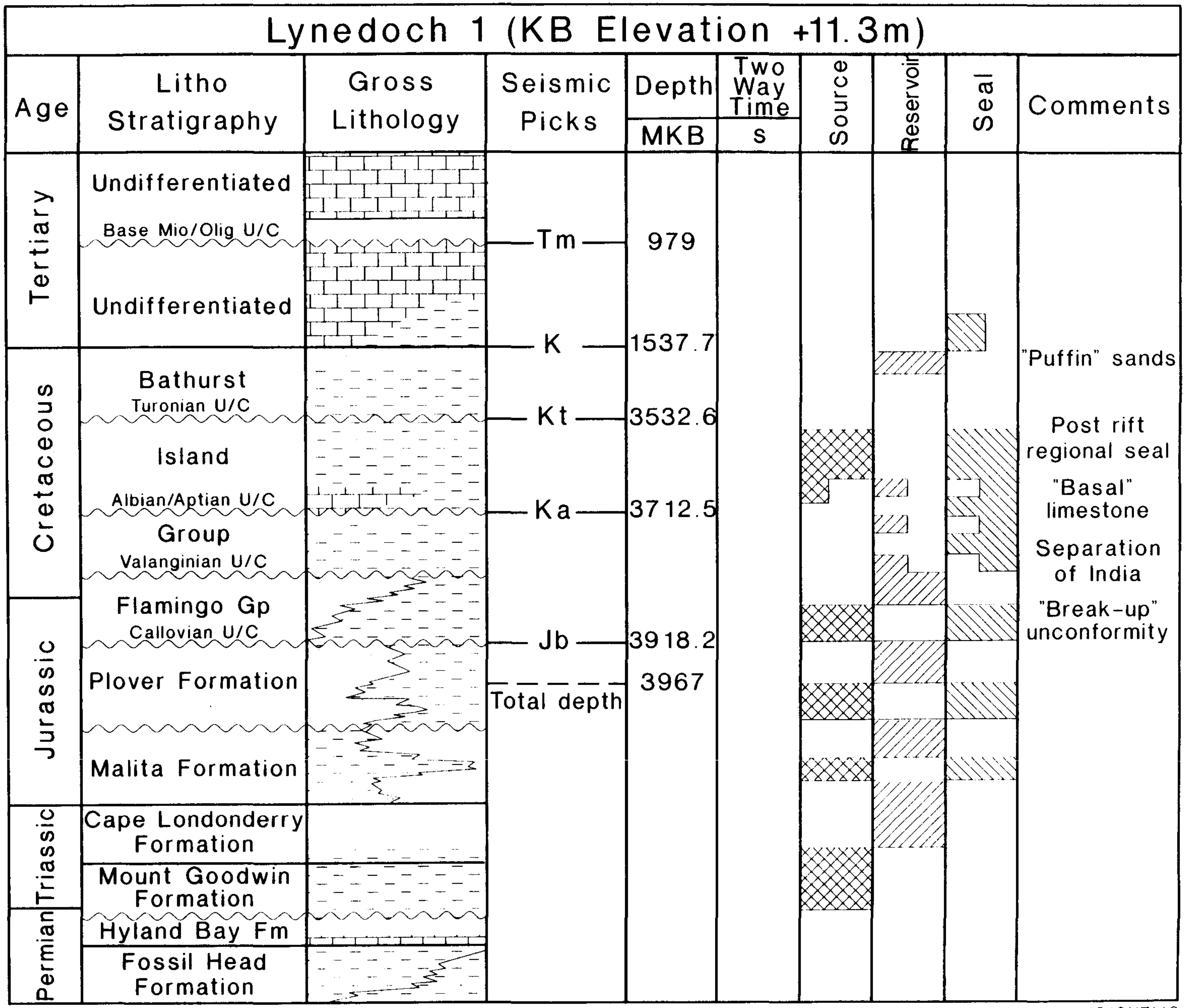


Figure 19 Generalised Stratigraphy

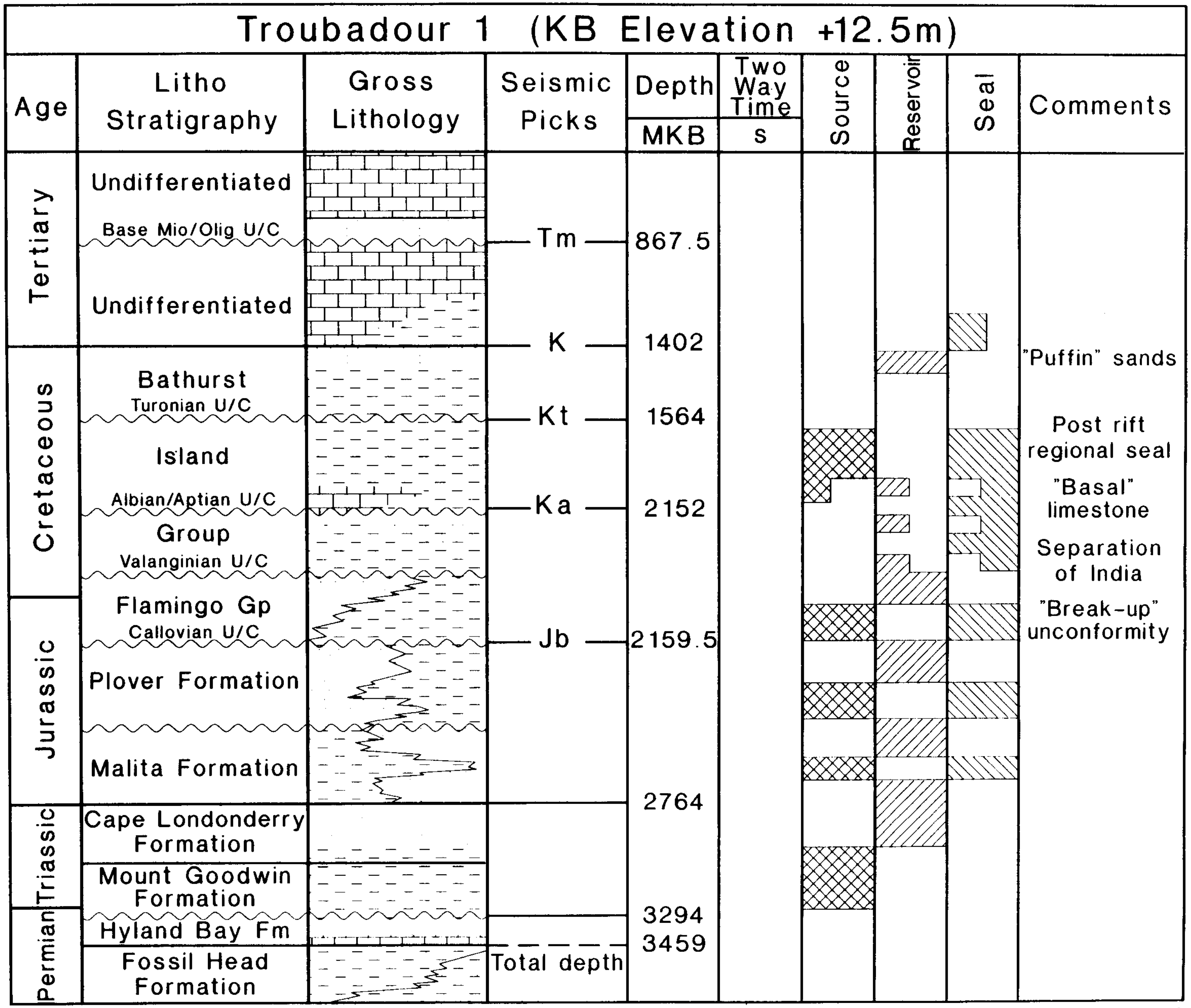


Figure 20 GENERALISED STRATIGRAPHY

12/ONT/ 13

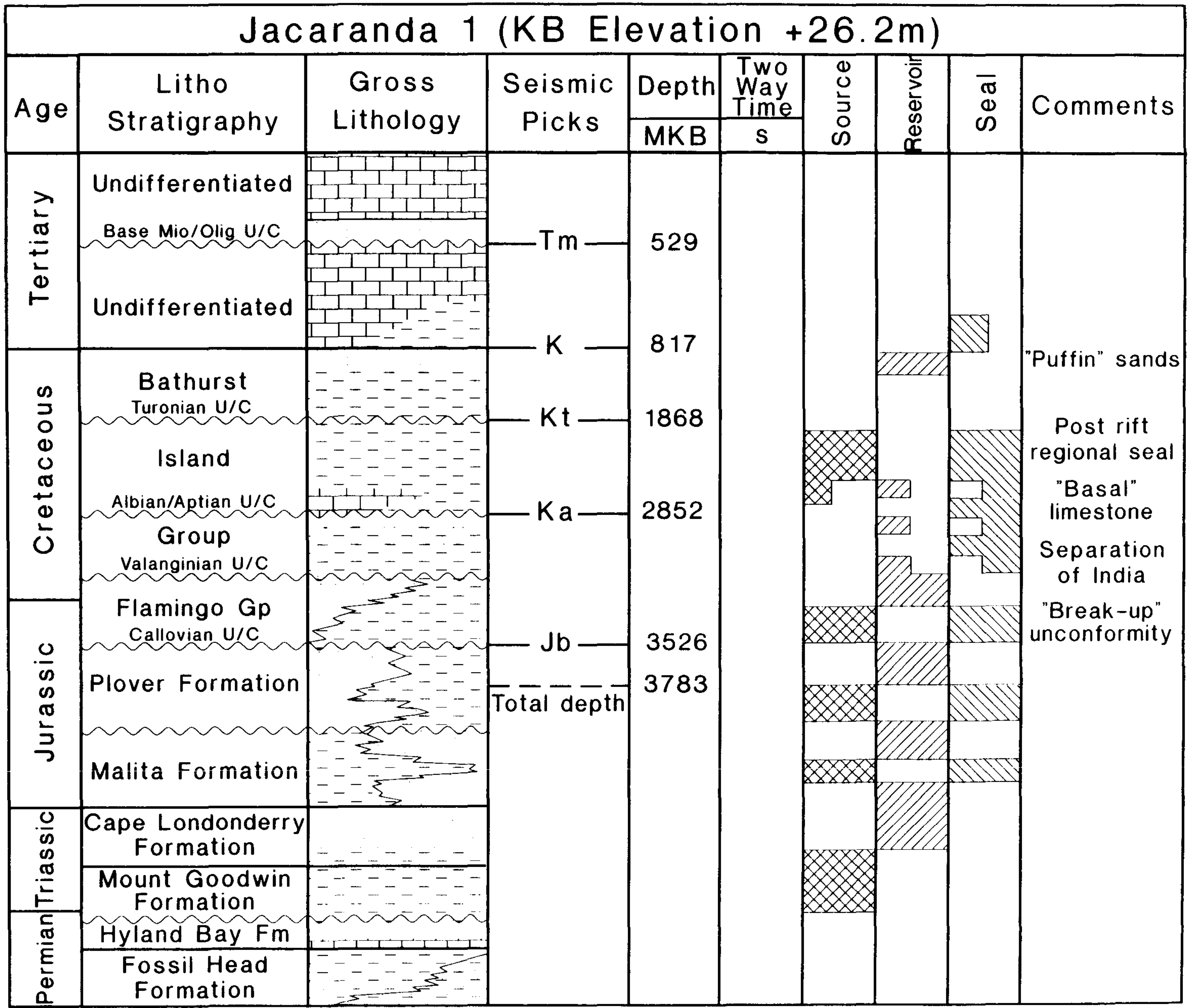


Figure 21 Generalised Stratigraphy

12/ONT/14

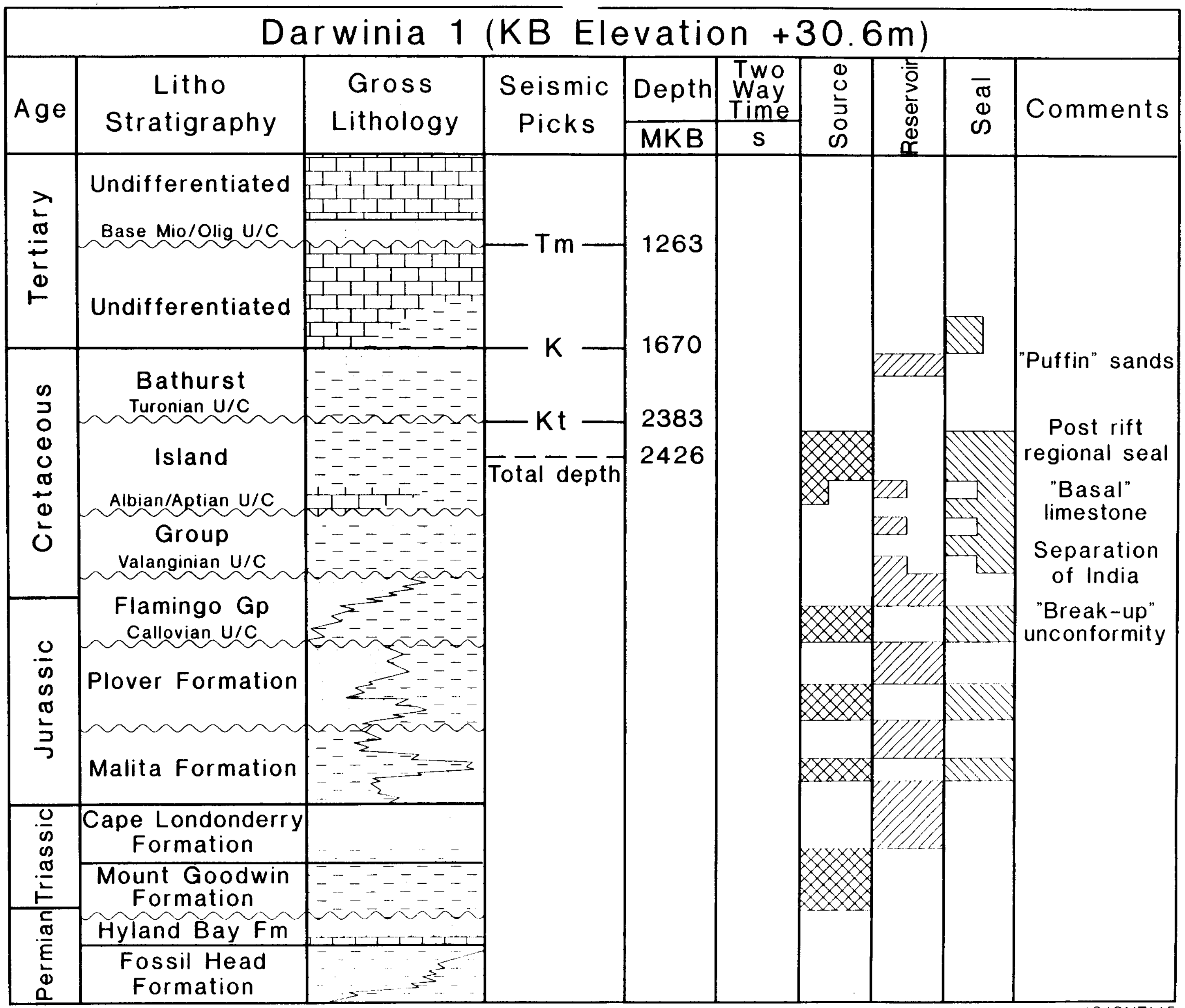


Figure 22 Generalised Stratigraphy

12/ONT/15

5.2.1 Near top Cretaceous (K)

This horizon occurs at about 1 second TWT over most of the area, and represents the boundary between hummocky Maastrichtian siliciclastics and the overlying continuous and parallel Tertiary carbonate sequences. It is generally quite distinct in the southern part of both release areas but, on some lines, tends to coalesce or bifurcate towards the north.

5.2.2 Turonian marker (Kt)

This is a strong, but somewhat discontinuous reflector, which can be mapped with a fair degree of confidence over most of the two release areas. Stratigraphically, it is probably equivalent, at least in part, to the top of the Wangarlu Formation (Mory, 1988) occurring within the Bathurst Island Group. It separates largely inner and mid-shelf siltstones, sandstones and calcareous claystones above, from distal marine claystones, marls and limestones below.

5.2.3 Albian/Aptian Unconformity (Ka)

The Albian/Aptian Unconformity is characterised by a very strong regional reflector, which is correlatable over the whole of the two release areas, and corresponds to the onset of a major transgression. Calcareous shales and limestones deposited immediately above the unconformity, give rise to high amplitude seismic events, whereas the underlying mixture of glauconitic siltstones and claystones, calcareous shales and radiolarian shales and sandstones give rise to variable seismic character, which is acoustically transparent in part.

5.2.4 Callovian ('Breakup') Unconformity (Jb)

The Callovian ('Breakup') Unconformity marks what has traditionally been the top of the primary reservoir target. Within the Malita Graben, this event is relatively weak, separating a thick overlying sequence of acoustically absorbent marine shales and sands of the Flamingo Group from the underlying, largely deltaic sediments of the Plover Formation. Towards the graben margins, and on the shelf areas to the north and south, the intervening Flamingo Group thins out, leading to interference from the high amplitude Albian/Aptian event.

5.2.5 Top Permo-Triassic

The only well that has intersected the Permian and Triassic sequences is Troubadour 1 on the Sahul Platform adjacent to the two release areas, making it difficult to positively identify on the seismic sections. A deep, high amplitude event overlying tilted fault blocks may represent the top of either the Triassic or Permian, and can be traced to some extent, on some of the sections.

5.2.6 Time-structure maps

Time structure maps at near top Cretaceous (Plate 35) and at Albian/Aptian Unconformity level (Plate 36), based largely on work from WMC's Marie Marine Seismic Survey (WMC, 1986), are included in this package.

6. HYDROCARBON POTENTIAL (B.G. West)

Because of the relatively sparse well control, few data relating to the hydrocarbon potential of the area are available. Consequently, this section is based largely on work by Kraus & Parker (1979) and NTGS (1990).

6.1 RESERVOIRS

Five potential reservoir horizons have been identified in the two vacant areas, of which the Middle Jurassic Plover Formation, the Late Jurassic to Early Cretaceous Flamingo Group, and the Late Cretaceous (Maastrichtian) sands form the primary objectives. Sandstones within the Early Jurassic Malita Formation and potential carbonate mounds in the basal Bathurst Island Group (Albian) provide secondary objectives.

6.1.1 Malita Formation

Few data are available about the reservoir potential of the Early Jurassic Malita Formation. Troubadour 1, drilled on the Sahul Platform, is the only well in the vicinity of the vacant areas to have intersected this unit. The section in that well consists of interbedded sand, silt and shale, totalling 293 metres in thickness. The individual sand units range in thickness from 1 to 27 metres, averaging about 5 metres, of well sorted, rounded to sub-angular, very fine to coarse sand. Petrel 2 well, drilled in the Bonaparte Basin to the southwest of this study area, reported core-derived porosities ranging from 13.2 to 21.7 per cent for the Malita Formation (NTGS, 1990).

6.1.2 Plover Formation

The Plover Formation consists largely of fluvio-deltaic to marginal marine sediments, and could prove to be a significant reservoir unit over much of the area. The depth of burial appears to have had a significant impact on the degree of diagenesis, and the reservoir quality is likely to be most favourable where the depth of burial has been less than 3000 metres and present day porosities are between 15 and 30 per cent (NTGS, 1990). Botten & Wulff (1990) consider the Plover Formation may also provide potential plays at depths greater than 3300 metres, where early hydrocarbon emplacement has inhibited diagenetic reservoir destruction.

Reasonable reservoir quality may be expected, particularly along the southern margin of the Malita Graben where the contribution of coarse-grained sediments from the Darwin Shelf is likely, and the depth of burial has been less severe.

6.1.3 Flamingo Group

The Flamingo Group consists largely of interbedded sandstones, siltstones and shales, deposited in environments varying from nearshore coastal plain on the Darwin Shelf to the south, through to a restricted marine sequence in the Malita Graben. Turbidite sandstones, eroded from the Sahul Platform in the north may also be present in the Malita Graben (Botten & Wulff, 1990).

Wells drilled in the Bonaparte Basin have generally reported log and core derived porosities ranging from 9 per cent in mid-basin areas to 30 per cent in basin margin locations (Botten & Wulff, 1990; NTGS, 1990). As with the Plover Formation, there is a general reduction in porosity with increased depth of burial. Reasonable reservoir quality may be expected in sandstones bordering and within the Malita Graben that may have been shed from the Sahul Platform or Darwin Shelf.

6.1.4 Albian/Aptian

A number of mounded features overlying the Albian/Aptian Unconformity, have been identified on seismic sections along the northern margin of the Malita Graben in Area NT92-1. These mounds have vertical relief of up to 300 milliseconds, and an areal closure of up to 25 square kilometres. They appear to be linearly distributed along the shallow northern margin of the Malita Graben.

Heron 1 well intersected a 122 metre thick section of limestone and limey shale between 3033 and 3155 metres, immediately above the Albian/Aptian Unconformity. It is assumed, therefore, that the Albian sequence on the shallower shelf above the northern margin of the Malita Graben was also lime rich, and these mounds may represent rudist carbonate mounds similar to those hosting large oil and gas fields in the Golden Lane Platform of Mexico and the Stuart City Reef Trend in Texas (Wilson, 1975).

6.1.5 Maastrichtian

Maastrichtian age sands, equivalent to the oil-bearing Puffin sands tested in the Puffin wells in the Vulcan Graben, have been intersected in Heron 1, Evans Shoal 1, Lynedoch 1, Jacaranda 1 and Darwinia 1 wells, and appear to be widely distributed within the two vacant areas. The thickness of the sands range from 158 metres in Heron 1 to 583 metres in Lynedoch 1.

Generally, the sands are medium to coarse, sub-rounded, and glauconitic in wells marginal to the Malita Graben (Lynedoch 1, Jacaranda 1 and Darwinia 1), and probably represent an inner neritic to coastal plain depositional environment. In Heron 1 and Evans Shoal 1, located in the Malita Graben, the sands are clean, fine to medium or coarse grained, and well rounded. We believe these sands may have been transported downslope from the Darwin shelf and into the graben as submarine fans. Log-derived porosities for these sands range from 19 to 32 per cent in Evans Shoal 1, 20 to 33 per cent in Heron 1, and up to a maximum of 38 per cent in Jacaranda 1, and provide potentially excellent reservoirs.

6.2 SEALS

The major regional seal in the area is the thick claystone and shale interval of the Bathurst Island Group. Many of the major oil accumulations presently discovered in the western Timor Sea, such as Jabiru, Challis, Talbot and Skua, occur immediately below this formation which forms a top seal for Jurassic and Triassic reservoirs. In the Malita Graben, it forms the top seal for Flamingo Group sandstones, but where the Flamingo Group is absent on the Sahul Platform and Darwin Shelf, it provides the top seal for the Plover Formation.

Intraformational shales and claystones have the potential to be seals within the Plover Formation, Flamingo Group, and within the postulated Maastrichtian submarine fans.

6.3 SOURCE

The presence of hydrocarbon shows in Shearwater 1, Heron 1 and Lynedoch 1, and the testing of gas in Evans Shoal 1 and gas/condensate in Troubadour 1 indicate that the Malita Graben has generated significant quantities of hydrocarbons.

6.3.1 Malita Formation

During the Early Jurassic, extensive redbed sedimentation (Malita Formation) took place over much of the area. The organic matter in these rocks is predominantly lignitic, with sapropelic material being locally distributed in some areas (Kraus & Parker, 1979), and is probably unsuitable for the generation of significant amounts of hydrocarbons.

6.3.2 Plover Formation

The Plover Formation was deposited in environments ranging from fluviodeltaic to marine and, consequently, most of the organic material is likely to be derived from terrigenous plant debris. In the Malita Graben and Sahul Platform areas, sapropelic material predominates over lignitic material, enhancing the petroleum-generating potential of the sediments (Kraus & Parker, 1979).

Overall, the Plover Formation contains potentially fair to good oil source rocks. TOC values averaged 0.81 per cent in Troubadour 1, 0.53 per cent in Shearwater 1, and 0.76 per cent in Lynedoch 1 (NTGS, 1990). In Evans Shoal 1, TOC values ranged from 0.34 to 3.6 per cent (NTGS, (1990).

Elsewhere in the Bonaparte Basin, the mixed terrestrial and marine sediments of the Plover Formation are regarded as the source of a number of oil discoveries (Botten & Wulff, 1990). In the Malita Graben, the source potential of the Plover Formation shales is considered likely to be generally moderate to very good.

6.3.3 Flamingo Group

The thick sequence of siltstones and shales of the Flamingo Group has good to excellent source potential, particularly in the Malita Graben, which was a probable centre of active downwarping during deposition of this unit. In Heron 1, TOC values are as high as 26.49 per cent, averaging 2.5 per cent, and in Evans Shoal 1, they range from 0.81 to 2.29 per cent. TOC values average 1.4 per cent in Lynedoch 1 (NTGS, 1990). The preservation of large quantities of organic matter is likely due to the relatively high rate of sedimentation in the rapidly subsiding Malita depocentre (Kraus & Parker, 1979).

On the peripheries of the Malita Graben, Jacaranda 1 and Shearwater 1 intersected a Late Jurassic section with little generative potential due to the poor preservation of organic matter (Botten & Wulff, 1990).

6.3.4 Bathurst Island Group

The lower part of the Bathurst Island Group (pre-Turonian) is a transgressive series of marine silts, shales and limestones, reaching over 1000 metres thick in the Malita Graben. Botten & Wulff (1990) believe the basal shales have significant oil generative potential within the Malita Graben where organic carbon content exceeds 1.0 per cent (Kraus & Parker, 1979).

The upper part of the Bathurst Island Group (post-Turonian) represents a largely regressive sequence of nearshore interbedded sandstones and shales, grading northwards to deeper water shales and marls. TOC values as high as 3.43 per cent from Lynedoch 1 and 1.79 per cent from Heron 1 have been reported (NTGS, 1990). However, the sapropelic content of the organic matter tends to decrease towards the palaeoshoreline (Kraus & Parker, 1979).

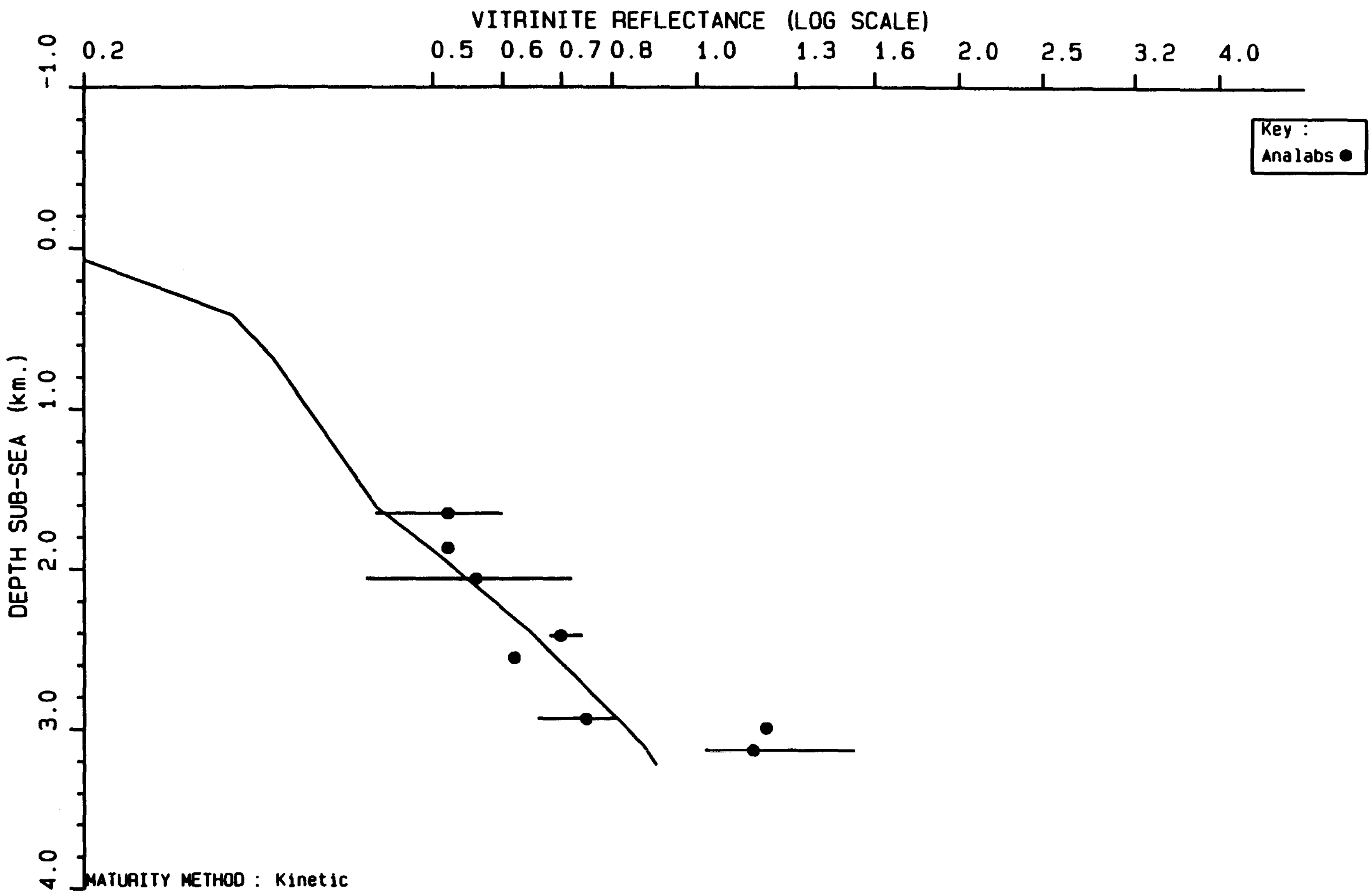
6.4 BURIAL AND MATURATION HISTORY (H. Struckmeyer)

Well temperature data, vitrinite reflectance data, lithological data and detailed chronostratigraphic data were combined to construct burial and maturation histories for Shearwater 1, Heron 1, Jacaranda 1, Lynedoch 1 and Troubadour 1, using BURY 5.42 geohistory analysis software supplied by Paltech Pty Ltd. The diagrams shown in Figures 23 to 32 show preliminary results of an ongoing study of the geohistory of well locations across the Bonaparte Basin (Struckmeyer, in preparation). All wells are modelled to total depth only, and breaks in sedimentation were entered as simple unconformities, that is, periods of non-deposition. No attempts to model variations in heatflow, to model halokinetic movements and to integrate the results into a regional tectonic framework have yet been made.

Temperature data were derived from maximum recorded formation temperatures, corrected for the factors of 'duration of circulation' and 'time since circulation', where possible. A factor of 10 per cent degrees Fahrenheit was added to measured values where circulation data were not available. Sea bottom temperature down to 100 metres water depth was taken as 25 degrees Celsius, decreasing to about 22 degrees Celsius at 200 metres and 10 degrees Celsius at 600 metres, following Horstmann (1988). Vitrinite reflectance data were compiled from well completion reports, Robertson Research (1986) and the BMR ORGCHEM database. Age-depth pairs are based on micropalaeontological and palynological data included in well completion reports, the STRATDAT database, well log picks and regional reports (for example, Apthorpe, 1988; NTGS, 1990; Mory, 1991). Lithostratigraphy, displayed on the geohistory diagrams in Figures 24, 26, 28, 30 and 32, was simplified for drafting purposes.

6.4.1 Burial history

With the exception of Troubadour 1, all wells bottomed in Early or Middle Jurassic sediments of the Troughton Group. Moderately thick Middle to Late Jurassic sediments are present at Heron 1, Jacaranda 1 and Troubadour 1, whereas very little Jurassic sediment is preserved at Shearwater 1 and Lynedoch 1. Early Cretaceous sediments are thin or absent in most of the wells,



COMPUTED vs OBSERVED VITRINITE REFLECTANCE PLOT : Shearwater 1

Figur 23.

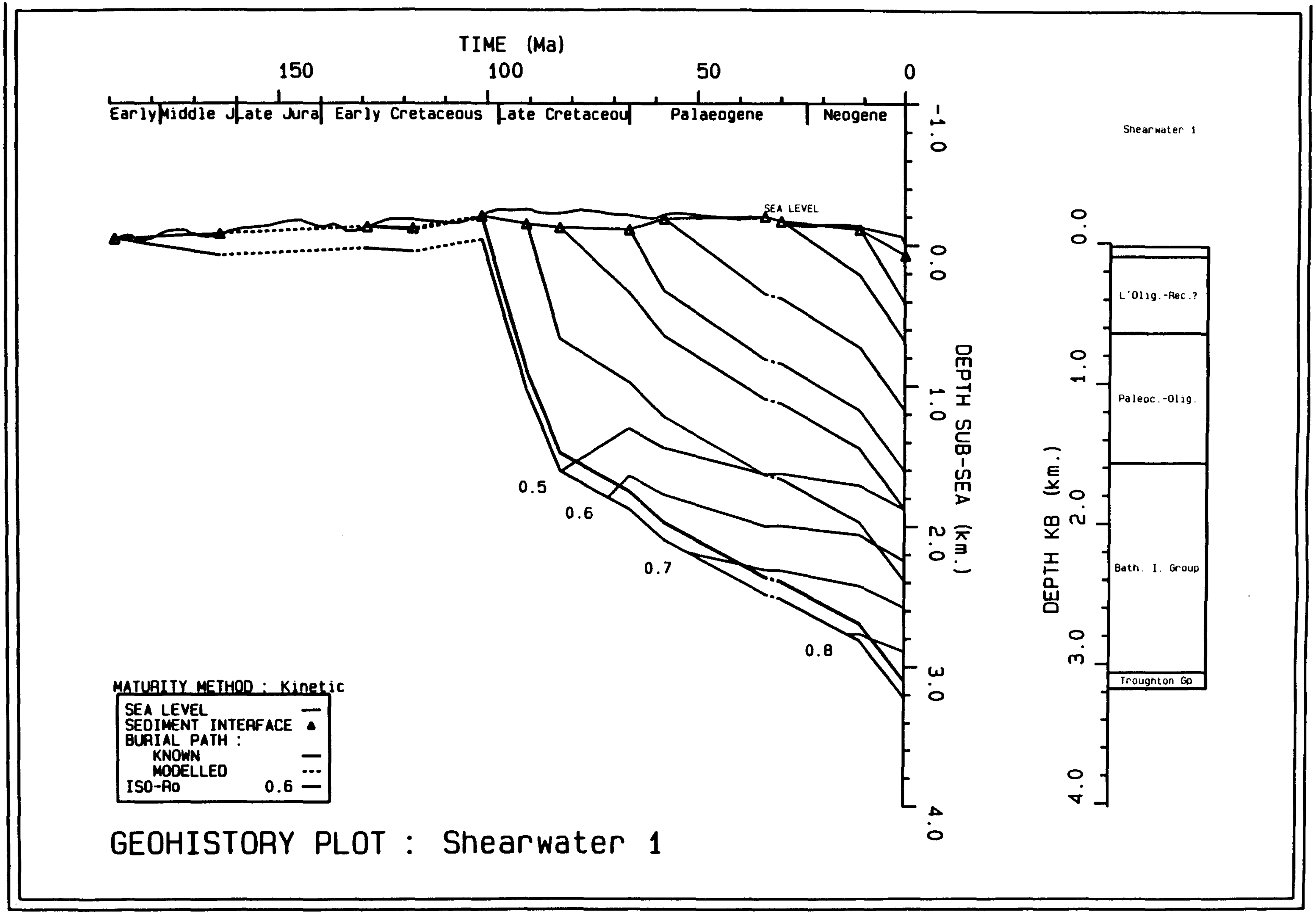
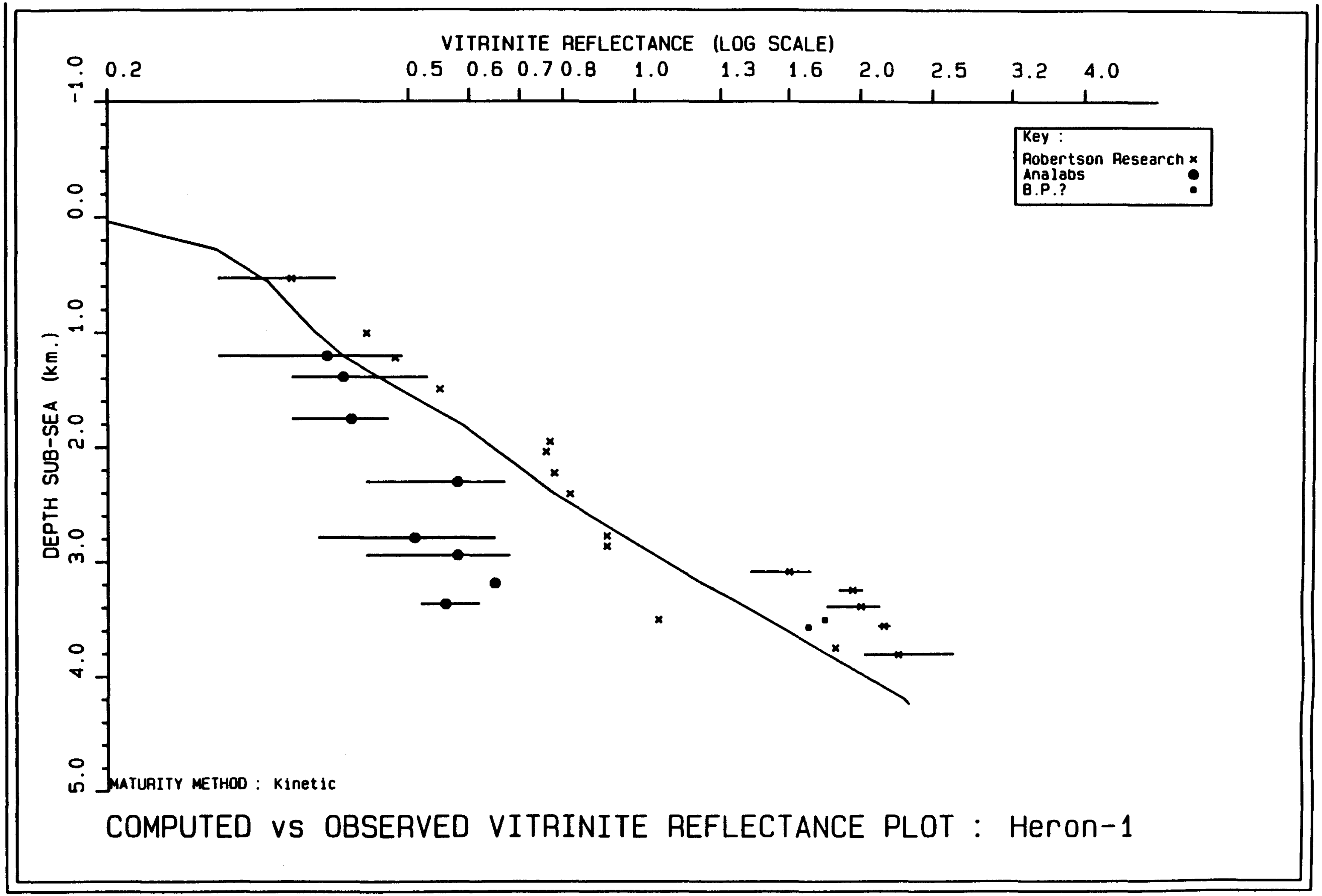
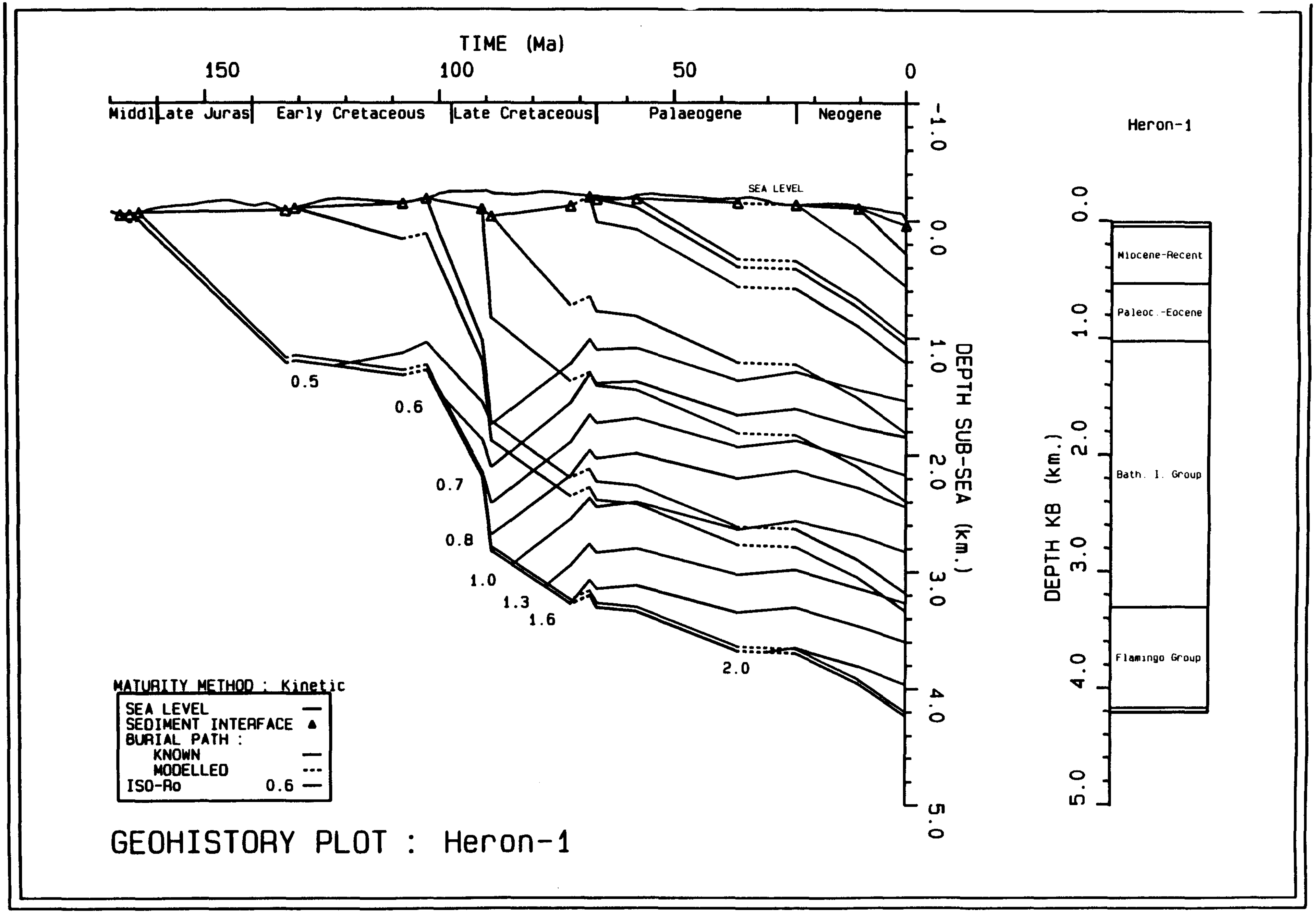

TIME (Ma)
150
100
50
0
Early
Middle J
Late Jura
Early Cretaceous
Late Cretaceou
Palaeogene
Neogene
SEA LEVEL
0.5
0.6
0.7
0.8
DEPTH SUB-SEA (km.)
-1.0
0.0
1.0
2.0
3.0
4.0
Shearwater 1
DEPTH KB (km.)
L'Olig.-Rec.?
Paleoc.-Olig.
Bath. I. Group
Troughton Gp
MATURITY METHOD : Kinetic
SEA LEVEL
SEDIMENT INTERFACE
BURIAL PATH :
KNOWN
MODELLED
ISO-Ro 0.6
GEOHISTORY PLOT : Shearwater 1

Figure 24.



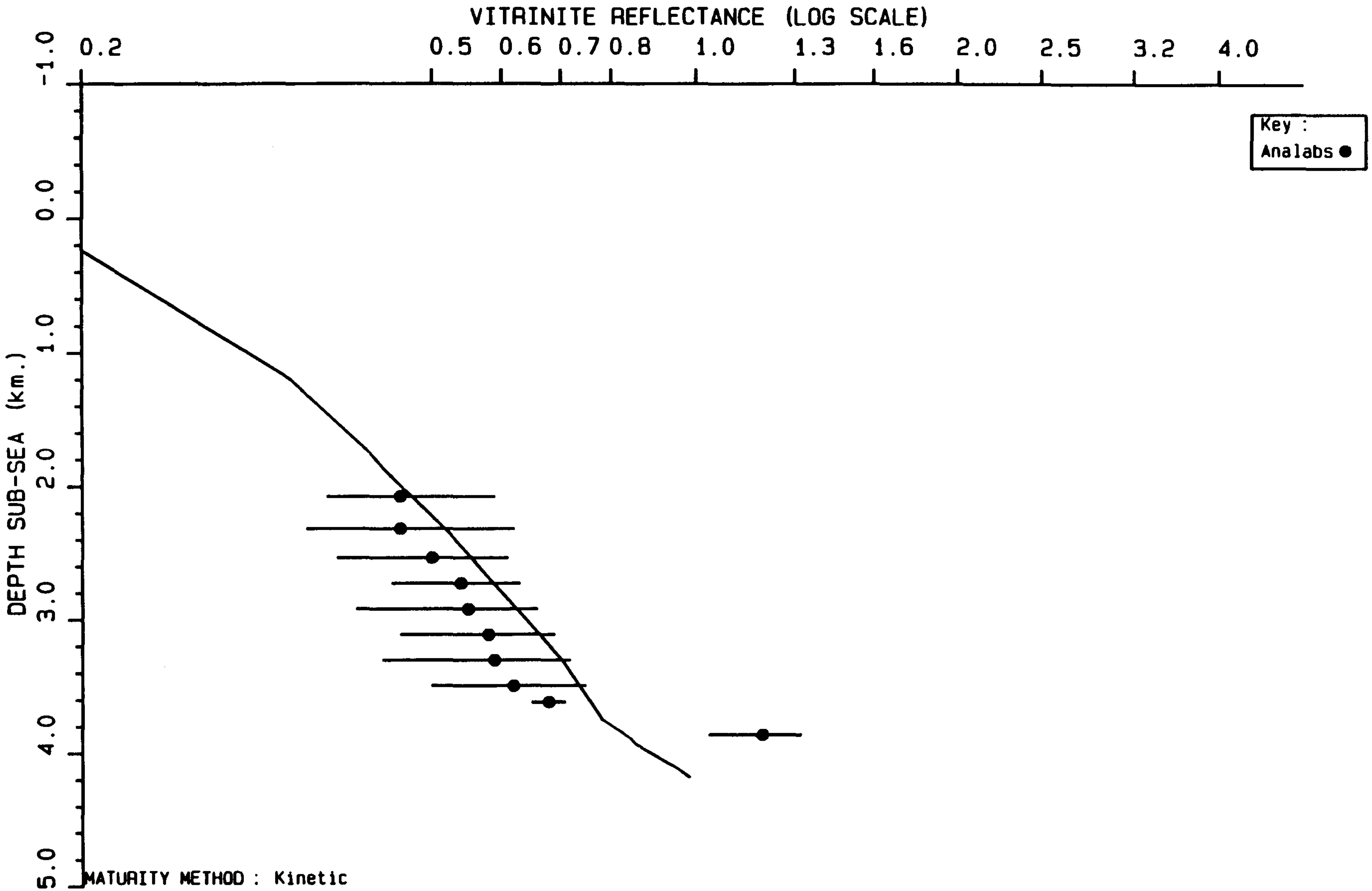
VITRINITE REFLECTANCE (LOG SCALE)
0.2
0.5
0.6
0.7
0.8
1.0
1.3
1.6
2.0
2.5
3.2
4.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
DEPTH SUB-SEA (km.)
Key :
Robertson Research
Analabs
B.P.?
MATURITY METHOD : Kinetic
COMPUTED vs OBSERVED VITRINITE REFLECTANCE PLOT : Heron-1

Figui 25.



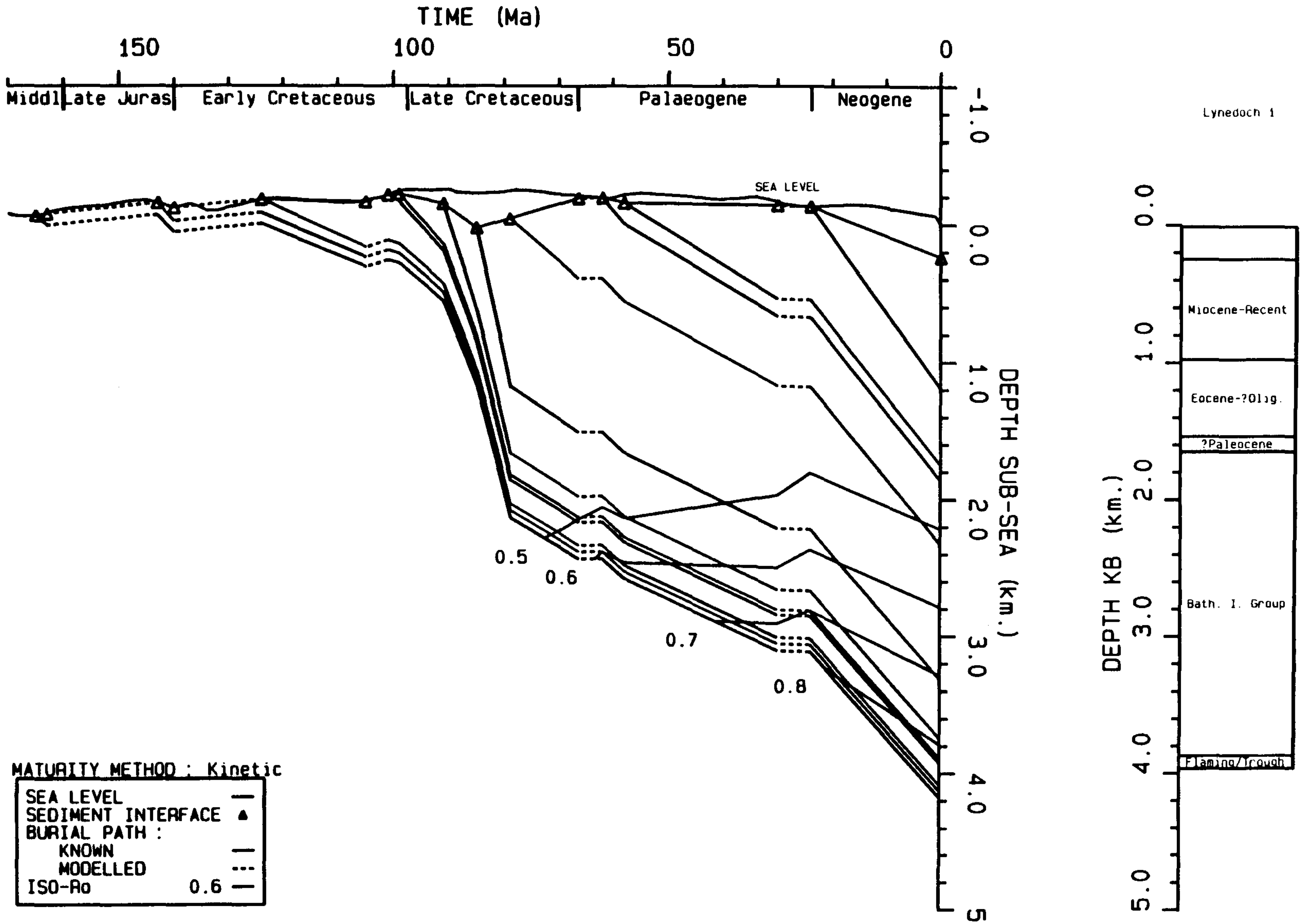
TIME (Ma)
150
100
50
0
Middl
Late Juras
Early Cretaceous
Late Cretaceous
Palaeogene
Neogene
SEA LEVEL
0.5
0.6
0.7
0.8
1.0
1.3
1.6
2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
DEPTH SUB-SEA (km.)
Heron-1
DEPTH KB (km.)
Miocene-Recent
Paleoc.-Eocene
Bath. I. Group
Flamingo Group
MATURITY METHOD : Kinetic
SEA LEVEL
SEDIMENT INTERFACE
BURIAL PATH :
KNOWN
MODELLED
ISO-Ro 0.6
GEOHISTORY PLOT : Heron-1

Figure 26.



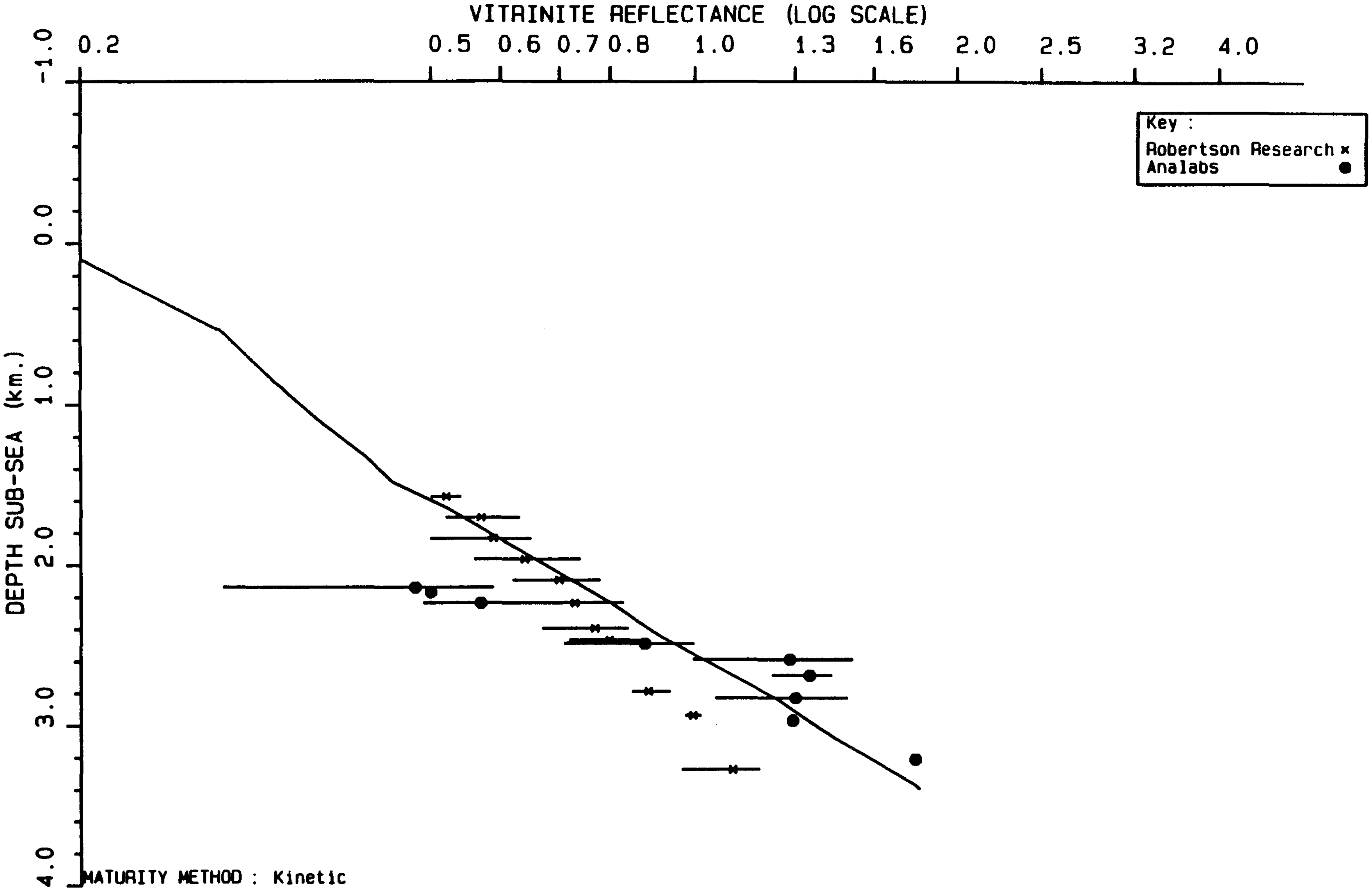
COMPUTED vs OBSERVED VITRINITE REFLECTANCE PLOT : Lynedoch 1

Figu. 27.



GEOHISTORY PLOT : Lynedoch 1

Figure 28.



COMPUTED vs OBSERVED VITRINITE REFLECTANCE PLOT : Troubadour 1

Figur 29.

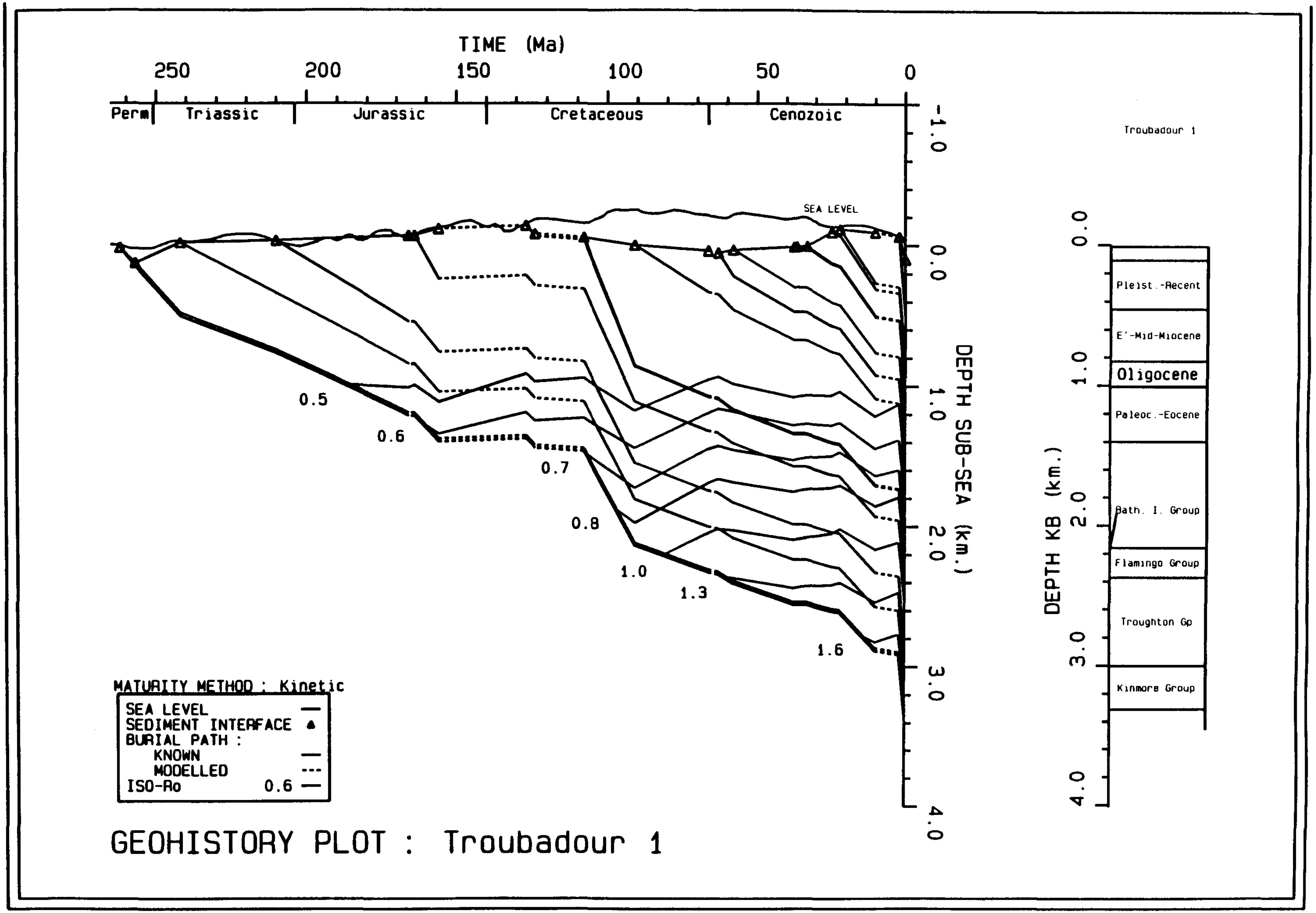
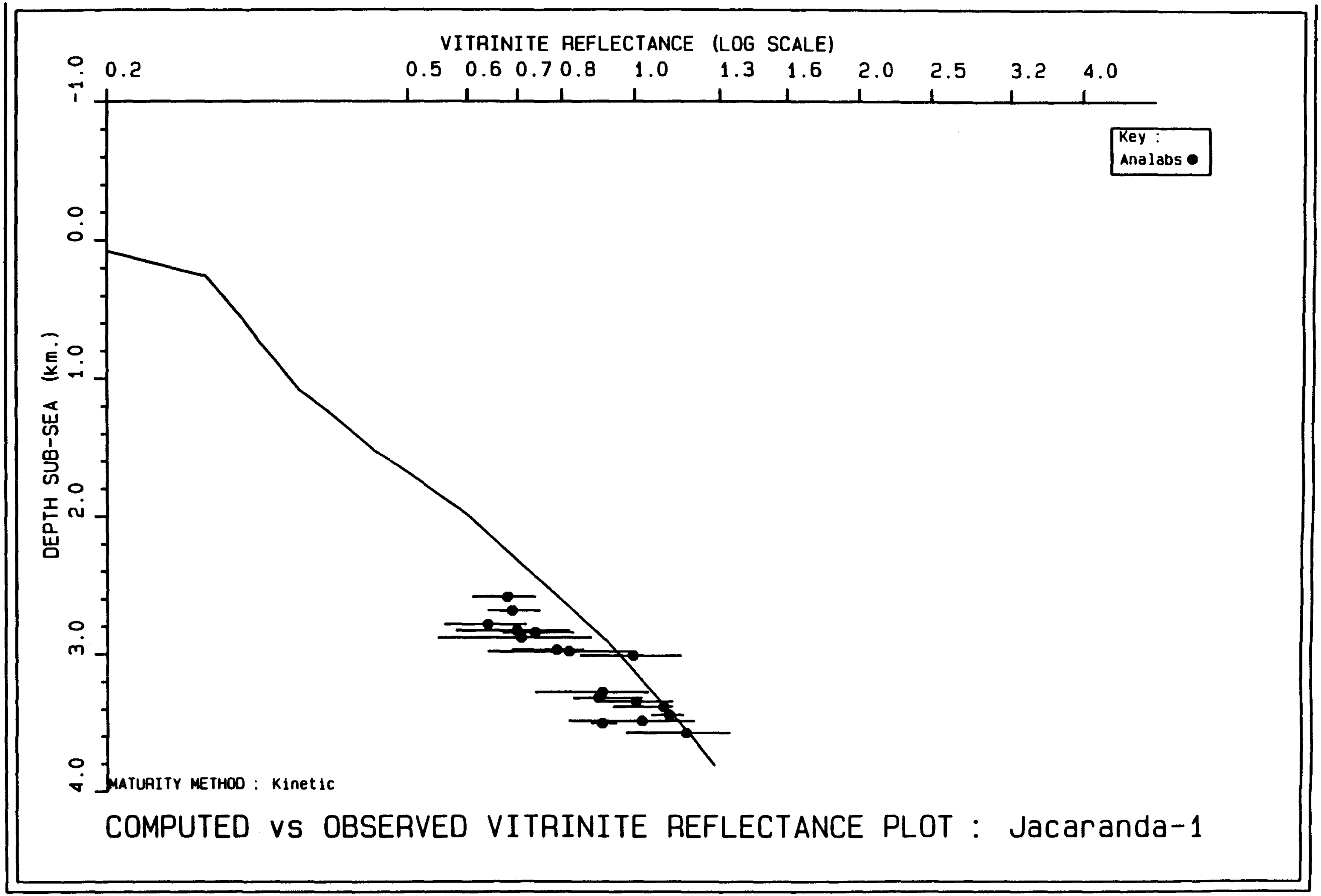

TIME (Ma)
250
200
150
100
50
0
Perm
Triassic
Jurassic
Cretaceous
Cenozoic
SEA LEVEL
0.5
0.6
0.7
0.8
1.0
1.3
1.6
-1.0
0.0
1.0
2.0
3.0
4.0
DEPTH SUB-SEA (km.)
Troubadour 1
Pleist.-Recent
E'-Mid-Miocene
Oligocene
Paleoc.-Eocene
Bath. I. Group
Flamingo Group
Troughton Gp
Kinmore Group
DEPTH KB (km.)
MATURITY METHOD : Kinetic
SEA LEVEL
SEDIMENT INTERFACE
BURIAL PATH :
KNOWN
MODELLED
ISO-Ro 0.6
GEOHISTORY PLOT : Troubadour 1

Figure 30.



VITRINITE REFLECTANCE (LOG SCALE)
0.2
0.5
0.6
0.7
0.8
1.0
1.3
1.6
2.0
2.5
3.2
4.0
-1.0
0.0
1.0
2.0
3.0
4.0
DEPTH SUB-SEA (km.)
Key :
Analabs
MATURITY METHOD : Kinetic
COMPUTED vs OBSERVED VITRINITE REFLECTANCE PLOT : Jacaranda-1

Figur⁻ 31.

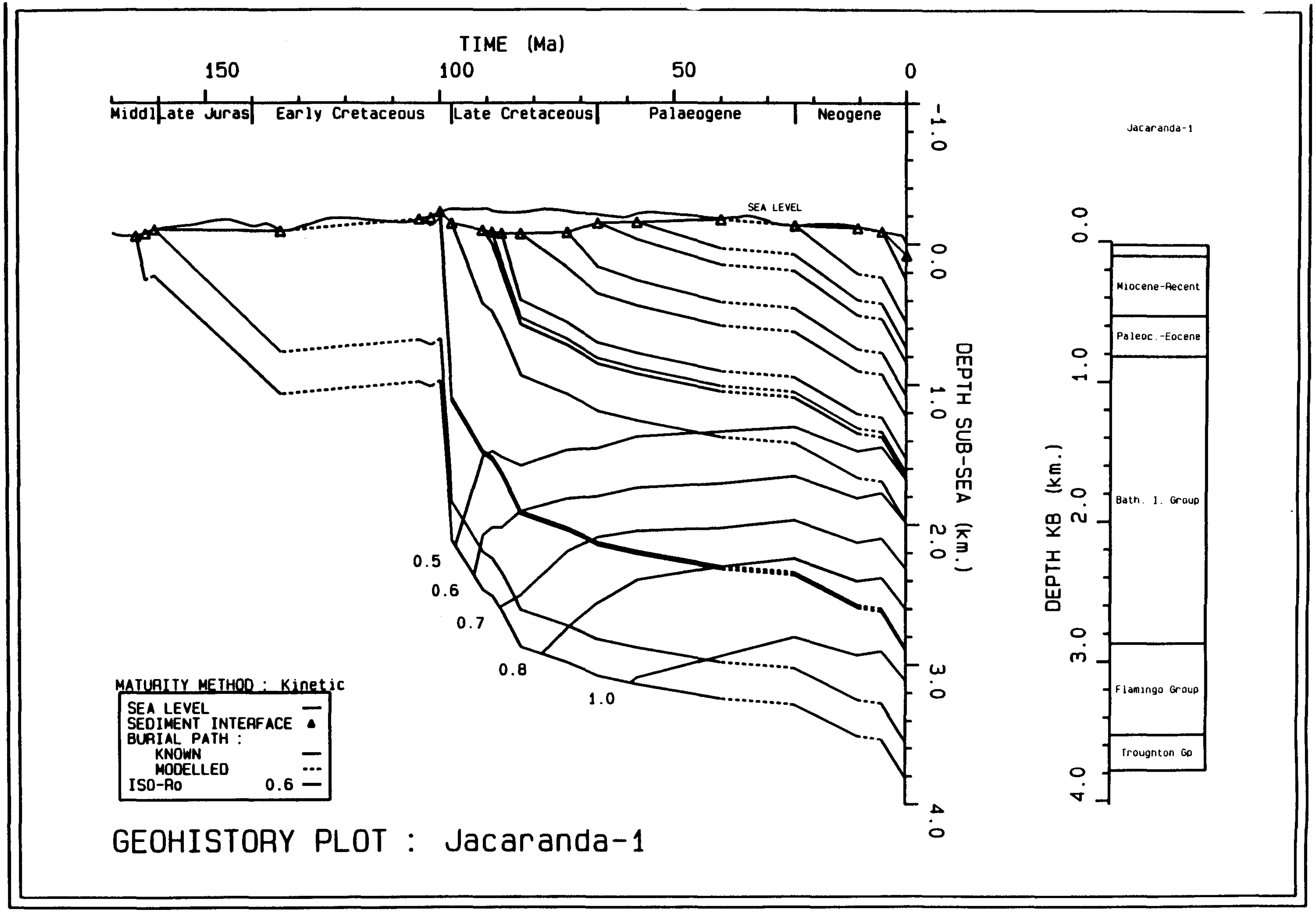

TIME (Ma)
150
100
50
0
Middl
Late Juras
Early Cretaceous
Late Cretaceous
Palaeogene
Neogene
SEA LEVEL
-1.0
0.0
1.0
2.0
3.0
4.0
DEPTH SUB-SEA (km.)
0.5
0.6
0.7
0.8
1.0
MATURITY METHOD : Kinetic
SEA LEVEL
SEDIMENT INTERFACE
BURIAL PATH :
KNOWN
MODELLED
ISO-Ro 0.6
GEOHISTORY PLOT : Jacaranda-1
Jacaranda-1
DEPTH KB (km.)
Miocene-Recent
Paleoc.-Eocene
Bath. I. Group
Flamingo Group
Trougnton Gp

Figure 32.

which may be due to rapid eustatic sea level variations in conjunction with local uplift during this time. From the Middle to Late Albian to Turonian/mid-Santonian, all five locations experienced a major phase of rapid regional subsidence with the deposition of mostly fine-grained, open marine sediments of the Bathurst Island Group. Sedimentation rates were highest in the Malita Graben depocentre where more than 1500 metres of sediment accumulated during this time, while approximately 700 metres of sediment was deposited across the now submerged Sahul Platform (for example, Troubadour 1). Subsidence continued at a reduced but more or less constant rate throughout the remainder of the Cretaceous to Eocene with a brief hiatus occurring at the Cretaceous/Paleocene boundary at some locations. Following the mid-Oligocene break, subsidence and marine sedimentation continued in the Miocene to Recent. However, sections with better age resolution indicate that a major increase in subsidence occurred in the late Neogene, probably as a result of the Australia/Timor collision.

6.4.2 Maturation history

Plots of computed versus observed vitrinite reflectance values (Figures 23, 25, 27, 29 and 31) indicate that although there is general agreement between the two parameters, the geohistory models need further refinement, particularly through manipulation of the heatflow history. However, some preliminary and generalised observations about the maturation history of potential source rocks at the locations studied can be made.

At Jacaranda 1 and Troubadour 1, Early to Middle Jurassic source intervals in the Troughton Group reached the main zone of oil generation (0.7-1.0 per cent vitrinite reflectance) in the Late Cretaceous, whereas at Shearwater 1 and Lynedoch 1 possible oil generation from this unit did not occur until the Eocene. With the exception of Lynedoch 1, where shales of the Late Jurassic to Early Cretaceous Flamingo Group entered the main oil generation zone at about 40 Ma, oil generation from this unit generally occurred in the Senonian to Eocene, and gas may have been generated at some locations since the Palaeogene.

At Heron 1, shales of the lower Bathurst Island Group have been in the main oil generation window since the Campanian and the lowermost part of the Group may have entered the gas window in the Late Palaeogene. At the remaining locations, shales of the lower Bathurst Island Group reached oil maturity during the Early to Middle Cainozoic with the upper units of the Bathurst Island Group typically being immature to marginally mature for oil generation at the present time.

6.4.3 Summary

Burial and maturation histories were modelled for five locations of the Malita Graben area. Although the results are preliminary at this stage, and no attempt has yet been made to relate the data to the regional tectonic history of the Northwest Shelf, a number of general trends are apparent. In particular, all five locations experienced rapid subsidence in the Middle Cretaceous, followed by moderate and mostly continuous subsidence in the Late Cretaceous to Cainozoic and again more rapid subsidence in the Neogene. The Middle Cretaceous event had a profound influence on the maturation history in the region, with potential source intervals of Middle to Late Jurassic age reaching the main oil generation zone during the Late Cretaceous.

7. PROSPECTIVITY

Release areas NT92-1 and NT92-2 cover an area of approximately 23 000 square kilometres of which about 80 per cent has been surveyed with relatively modern (post 1985) seismic, giving a regional grid of about 20 x 30 kilometres. Only three wells (Shearwater 1, Heron 1 and Evans Shoal 1) have been drilled. Hydrocarbon shows were reported throughout the Cretaceous and Jurassic sections in Heron 1. Gas was recovered from the Jurassic section in Evans Shoal 1 (located in the retained portion of Permit NT/P40). Hydrocarbon shows were also reported from the Cretaceous and Jurassic sections in wells drilled in permits adjacent to the release areas, including Lynedoch 1, Troubadour 1, and Jacaranda 1.

The main target for exploration to date has been the Plover Formation sands, situated in fault-controlled anticlines, and sealed by Bathurst Island Group shales. There is significant potential for at least three other play types in the area that warrant further investigation. These four play types are detailed below in Section 7.2.

7.1 PREVIOUS DRILLING RESULTS (S. Miyazaki)

7.1.1 Shearwater 1

Shearwater 1 was drilled by ARCO in 1974 on the southern margin of the Sahul Platform. The well reached total depth at 3177 metres in Jurassic sandstones of the Plover Formation. The kelly bushing elevation was 25 metres above sea level.

The Bathurst Island Group, intersected between 1566 and 3054 metres, consists of claystones with occasional limestones. It does not contain any potential reservoirs. The Plover Formation, intersected from 3054 metres to a total depth of 3177 metres, consists of shaly, silty and dolomitic sandstones with minor claystones. The sandstones are fine grained and well cemented with siliceous materials, and the visual porosity is poor.

Values of well-head gas reading remained small during drilling. Shaly sandstone cuttings, from 3124 to 3132 metres, displayed traces of dead oil stainings, very dull greenish gold fluorescence and dull white cut. This is the only hydrocarbon indication recorded while drilling the well. No hydrocarbon shows were observed from a total of 82 side-wall core recoveries.

The sandstones of the Plover Formation have log porosities ranging between 1 and 12 per cent with an average of 6 per cent. Secondary silicification appears to have resulted in the destruction of effective porosity. Wireline log data indicate that the entire formation is water-wet. A well velocity survey shows an interval velocity of 4407 metres per second for sandstones between 3054 and 3177 metres.

The maximum recorded bottom-hole temperature is 119 degrees Celsius. No fluid flow or recovery tests were attempted for this well. The well was plugged and abandoned.

7.1.2 Heron 1

Heron No 1 was drilled in the Malita Graben in 1972 by ARCO. The well reached total depth at 4208 metres in sandstones of the Plover Formation. The kelly bushing elevation was 12 metres above sea level. The well encountered a number of good gas shows, many of which were observed in Cretaceous and Jurassic fractured claystones, which appear to be over-pressured.

Maastrichtian sandstones were intersected from 1028 to 1186 metres at the top of the Bathurst Island Group, where they have a log porosity of 27 per cent. The rest of the Bathurst Island Group between 1186 and 3307 metres comprises claystones with occasional sandstones and limestones.

Well-head gas readings registered 12 per cent of methane (but no other hydrocarbons) from a thin sandstone at 1573 metres within claystones of the Bathurst Island Group.

A rapid increase in well-head gas was observed at 2824 metres, resulting in 32 per cent of total hydrocarbon gas (methane through pentane). However, this was not accompanied with an apparent drilling break. Immediately, mud weight was raised from 1.38 to 1.51 g/cc. This gas show appears to be from fractured silty claystones of the Bathurst Island Group.

Core-1 was cut from 2838 to 2848 metres with a recovery of 0.15 metres. The core sample consists of Cenomanian to Albian claystones with laminae of siltstones. The sample did not exhibit any hydrocarbon indications.

Core-2 was cut from 2848 to 2854 metres with a recovery of 6.2 metres (100 per cent), comprising Cenomanian to Albian claystones with laminae of limestone. The core sample has a vertical fracture and several irregular oblique fractures. Gas was bleeding from pin-point holes in both types of fractures, and the oblique fractures are filled with white calcite. No other shows were recognized in the core. Two claystone plugs were taken from the core sample to measure porosity and permeability. One has a porosity of 14.5 per cent and a vertical permeability of less than 0.1 millidarcys, and the other has a porosity of 12.3 per cent and a vertical permeability of less than 0.1 millidarcys.

High well-head gas readings continued down to 2926 metres in claystones of the Bathurst Island Group. However, wireline log data do not show any anomalies. Again, from 3109 to 3155 metres in claystones of the Bathurst Island Group, well-head gas readings surged up to 12 per cent (mainly methane, and traces of ethane and propane). A flapper junk basket recovered a 0.3 metre core sample from 3019 metres, consisting of claystones.

The Bathurst Island Group becomes calcareous at its base between 3100 and 3307 metres, where the lithology is dolomitic claystones with limestones. Limestone side-wall core samples were recovered from 3120, 3146, 3147 and 3149 metres. These samples have poor visual inter-granular porosity. Limestones between 3142 and 3149 metres have a log porosity of 12 per cent and a water saturation of 45 per cent, when formation water is assumed to have a salinity of 40,000 ppm.

The Late Jurassic Flamingo Group unconformably underlies the Bathurst Island Group, and was intersected from 3307 to 4174 metres, with claystone the dominant lithology, occasionally interbedded with limestones.

Well-head gas readings continued to be high, but ethane and heavier hydrocarbons were absent. The well started to blow out at 3690 metres with 39 per cent of methane at the well-head, and the well was shut down. Several side-wall core samples, consisting of claystones, were taken from near this depth. Gas bubbles were bleeding from fractures in the core sample taken from 3688 metres.

A flapper junk basket recovered a 0.3 metre core sample from 3826 metres, consisting of claystones. Gas bubbles were bleeding from hairline fractures.

Well-head gas readings gradually subsided while drilling the well with the use of heavy mud (up to 1.97 g/cc). However, notable amounts of connection gas were recorded regularly at each connection.

Drill cuttings between 4097 and 4101 metres indicate a lithological change from claystones to limestones, which showed yellow fluorescence but no cut. Core-3 was cut from 4101 to 4114 metres with a recovery of 12.9 metres (100 per cent).

While cutting the core, a drilling break occurred at 4107 metres, and 11 per cent of methane was recorded at well-head from 4107 to 4109 metres.

The core sample comprises claystones with apparent dip angles of zero to 20 degrees. The sample does not contain any limestones, although the claystones are slightly calcareous, and does not exhibit any lithological change which could explain the drilling break and the gas show. However, the sample is fractured along bedding planes below 4107 metres. A claystone plug taken from 4103.8 metres has a porosity of 3.6 per cent and a horizontal permeability of less than 0.1 millidarcys.

Below the Callovian 'Breakup' Unconformity at 4174 metres, the well intersected the Middle Jurassic Plover Formation to a total depth of 4208 metres. The section was largely claystones with thin sandstones.

Lost circulation occurred between 4185 and 4188 metres, followed by a lithological change from claystones to sandstones. Well-head gas readings increased while mud weight was lowered from 1.9 to 1.8 g/cc.

Core-4 was cut from 4198 metres to a subsequent total depth of 4209 metres with a recovery of 2.0 metres (19 per cent). The core sample consists of 1.1 metres of quartzose sandstones at the top, and 0.8 metres of claystones and 0.1 metres of siliceous and calcareous sandstones at the bottom. The top sandstones are very fine to fine grained, sub-rounded, well sorted and vertically fractured, with no visual porosity. Three plugs taken from these sandstones have porosities of 6.2, 4.2 and 1.8 per cent and permeabilities of less than 0.1 to 0.13 millidarcys. The claystones are also vertically fractured. A claystone plug has a porosity of 0.6 per cent and a horizontal permeability of less than 0.1 millidarcys. The bottom sandstones are fine to medium grained, sub-rounded and well sorted, with no visual porosity. No hydrocarbon indications were observed on the core sample.

Wireline log data indicate a porosity of 6 per cent, a formation-water salinity of 50 000 ppm and a water saturation of 50 per cent for the bottom-hole Jurassic sandstones. High temperatures in the borehole made the formation density tool inoperative below 3018 metres. A gamma-ray tool also failed between 3719 and 3804 metres due to high temperature. The well has a maximum recorded temperature of 196 degrees Celsius. No fluid flow or recovery tests were attempted for this well, which was plugged and abandoned.

In summary, good gas shows were encountered in the Cretaceous Bathurst Island Group and the Jurassic Flamingo Group and Plover Formation. However, many of the shows are in claystones. Observations indicate that these claystones are fractured and appear to be over-pressured. Cretaceous limestones from 3142 to 3149 metres might have a porosity of 12 per cent and a water saturation of 45 per cent. Bottom-hole Jurassic sandstones are marginal in regard to petrophysical parameters. In addition, bottom-hole temperature is too high to retain liquid hydrocarbons.

7.1.3 Evans Shoal 1

Evans Shoal 1 was located on the northern margin of the Malita Graben. The well was drilled by BHP Petroleum in 1988 and terminated at 3712 metres in Middle Jurassic sandstones of the Plover Formation. The kelly bushing elevation was 17.7 metres above sea level. The well discovered gas in sandstones of the Plover Formation.

The first porous rocks intersected in this well are Maastrichtian sandstones, from 1287 to 1697 metres, at the top of the Bathurst Island Group. This 410-metre section is unconformably overlain by Tertiary carbonates and has a sand:shale ratio of 7:3. The sandstones are well-sorted and have good visual porosity and a log porosity of 26 per cent.

The remainder of the Bathurst Island Group, intersected from 1697 to 3453 metres, consists of claystones and minor beds of siltstones, sandstones and limestones. The section between 1974 and 1983 metres comprises Campanian sandstones, overlain by thick (278 metres) Campanian claystones. This section was sticky while running wireline logs, and the sandstones have a log porosity of 23 per cent.

The Flamingo Group intersected between 3453 and 3542.5 metres. It is unconformably overlain by the Bathurst Island Group and unconformably underlain by the Plover Formation. The Flamingo Group consists of claystones and provides a seal for the underlying sandstones of the Plover Formation. The well intersected the Plover Formation from 3542.5 metres to a total depth of 3712 metres. The formation comprises sandstones with occasional claystones and siltstones, and has a sand:shale ratio of 4:1. The sandstones intermittently contain coally materials and pyrite.

Well-head gas readings remained fairly steady and moderate while drilling. On drilling into the primary target of the Jurassic section below 3543 metres, no notable changes in gas were seen and no heavy hydrocarbons were recorded. Weak fluorescence was seen in cuttings from 3558 to 3561 metres, and this show, observed in very fine to fine sandstones, was dull orange to gold in colour with a pale yellow instant streaming crush-cut, which left a thin patchy pale yellow residual ring. Traces of similar fluorescence were seen intermittently down to 3621 metres and again at 3672 metres. Otherwise there were no shows in the Plover Formation sandstones.

Although no substantial hydrocarbon shows were recorded while drilling the Plover Formation, wireline resistivity data indicated the presence of hydrocarbon-bearing sandstone units. These sandstones have an average porosity of 8 per cent and water saturations between 10 to 90 per cent with an average of 20 per cent. When a porosity cut-off of 6 per cent is applied, the formation has a net sand thickness of 33 metres. On average, each sandstone unit has a thickness of 0.9 metres. A well velocity survey shows an interval velocity of 4999 metres per second for an interval between 3595 and 3700 metres. This velocity would correspond to a sandstone porosity of 4 per cent.

Seven valid pressure data were obtained from between 3544.0 and 3680.3 metres, however, they do not indicate whether the entire interval is gas-bearing or whether the sandstone units are hydraulically in communication to each other.

Three RFT fluid samplings were carried out in sandstones of the Plover Formation. Each test was equipped with a 10.4 litre chamber and, for PVT analysis, a 3.8 litre chamber. RFT-1 at 3554.0 metres recovered 456.1 cubic feet of gas and 1.5 litres of mud filtrate with a black oil scum. The gas contains 78 mole per cent of methane, 2 mole per cent of ethane and 18 mole per cent of carbon dioxide, and has a condensate yield of 3 barrels per million standard cubic feet. This test also gives a formation pressure of 5414 psi (absolute). The sandstone at this depth has a porosity of 11 per cent and a water saturation of 19 per cent. RFT-2 at 3613.8 metres recovered 2.5 cubic feet of gas and 9.3 filtrate with a black oil scum. The sandstone has a porosity of 8 per cent, and a log calculation shows a water saturation of 27 per cent. RFT-3 at 3678.0 metres recovered 78.8 cubic feet of gas and 7.5 litres of filtrate with a trace of oil scum. The sandstone at this depth has a porosity of 7 per cent and a water saturation of 27 per cent.

After running the final suite of wireline, a bottom-hole core was cut from 3709 metres to a total depth of 3712 metres with a recovery of 2.44 metres (81 per cent). The core sample consists of sandstones interbedded with minor siltstones, claystones and oolitic carbonates. The core did not exhibit any hydrocarbon shows. The sandstones are grey and very fine grained, angular to sub-angular and cemented with siliceous materials, and have no visual porosity. The claystones are black to dark grey and finely laminated with irregular bedding, scours and ripples. Sandstones at the base, containing shell fragments and pyrite nodules, were bioturbated and burrowed. The presence of shell fragments and oolitic carbonates suggests nearshore shallow marine to estuarine deposition. Overall the core sample shows poor reservoir quality owing to the abundance of quartz cement and high degree in diagenetic alteration.

Eighteen plugs were taken from the core at regular intervals regardless of lithology. These samples have porosities ranging between 1.7 and 5.2 per cent, and horizontal permeabilities ranging between less than 0.1 and 581 millidarcys. Those samples that have a permeability greater than 100 millidarcys are vertically fractured. Sandstone samples have an average porosity of 4 per cent and a geometric average permeability of 1 millidarcy. No wireline logs were run over the interval cored.

The well has a maximum recorded bottom-hole temperature of 164 degrees Celsius and an extrapolated temperature of 170 degrees Celsius at 3700 metres. The temperature would be too high to retain any crude oil. No drill stem tests were attempted, and the well was plugged and abandoned.

7.1.4 Lynedoch 1

Lynedoch 1 was drilled in the Malita Graben in 1973 by Shell and terminated at 3967 metres in Jurassic sandstones. The rotary table elevation was 11.3 metres above sea level. A gas kick took place in Cretaceous limestones in a side-track.

Maastrichtian sandstones at the top of the Bathurst Island Group were intersected from 1538 to 2121 metres. They have a sand:shale ratio of 7:3, and are unconformably overlain by Tertiary carbonates. The sandstones are fine grained, sub-round and unconsolidated. The clean parts of the sandstones have porosities of between 25 and 30 per cent. The rest of the Bathurst Island Group between 2116 and 3917 metres comprises claystone, with minor limestones and sandstones.

The well kicked at 3702 metres, in a limestone zone from 3675 to 3716 metres, immediately after a trip in the side-track and was shut-in. Methane, ethane, propane and butane gases comprise 100 per cent of the well-head gas from 3702 to 3703 metres. The gas kick was killed by increasing mud weight from 1.19 to 1.27 g/cc. As there was no kick at this depth in the original hole, the occurrence of gas appears to be confined to a local area where the limestones may be fractured (no wireline logs were run over the limestone unit in the original hole because of a fish being left in the hole). These Cenomanian to Albian limestones have a porosity of 12 per cent and a water saturation of 40 per cent. Well velocity survey data indicate an interval velocity of 4176 metres per second, which correspond to a porosity of 18 per cent for the limestone unit. In order to avoid gas influxes while making drill-pipe connections, the mud weight was increased to 1.52 g/cc at 3714 metres. The Plover Formation intersected between 3918 metres and total depth of 3967 metres, and consists of sandstones and claystones, with a sand:shale ratio of 7:3. Although mud weight was 1.5 g/cc, ethane and propane as well as methane readings were fairly high at well-head.

Sandstones from 3918 and 3952 metres have a porosity of 7 per cent and appear to have a water saturation of greater than 50 per cent. Spontaneous potential (SP) wireline data suggest that the formation water has a salinity of 8000 ppm, which is extraordinarily low at these depths in an offshore well. No side-wall core samples were recovered from this sandstone zone, and the bullets were found to be shattered, suggesting that the formation is hard. The bottom part of the hole was not properly surveyed by wireline tools because of bad hole conditions. A total of 130 side-wall core samples were recovered from the well, but none of them gave fluorescence or cut. The well has a maximum recorded temperature of 135 degrees Celsius. No fluid flow or recovery tests were attempted, and the well was plugged and abandoned.

7.1.5 Troubadour 1

Troubadour 1 was drilled on the Sahul Platform by BOC in 1974 and terminated in granite at 3459 metres. The rotary table elevation was 12.5 metres above sea level. The well discovered gas with condensate in Plover Formation sandstones.

The Cretaceous section from 1402 to 2159.5 metres comprises marl, claystones and calcilutites. Well-head gas readings were fairly low, but claystones from 2152 to 2159.5 metres gave a sharp rise in gas readings. Palaeontological evidences indicate a hiatus between the Cretaceous and Jurassic sections.

The Middle Jurassic section between 2159.5 and 2470 metres consists of sandstones, siltstones and claystones. This section has a sand:shale ratio of 1:1. The thickness of each sandstone unit tends to decrease with depth. Gamma-ray logs for many of the sandstone units show funnel-shape patterns. Hydrocarbon indications, including fluorescence and cuts, were observed in the Jurassic section regardless of lithology.

Core-1 was cut from 2203 to 2211.25 metres with a recovery of 8.25 metres (100 per cent). The core gave moderate hydrocarbon odour and sample fluorescence, solvent fluorescence and solvent cuts. The upper 5.85-metre part of the core comprises sandstones interbedded with claystones. The sandstones are very fine grained, well sorted sub-angular to sub-round, fossiliferous in part, and well cemented with silica and dolomite, and visual porosity is poor. The lower 2.4-

metre part of the core consists of siltstones interbedded with claystones. Traces of dark brown oil were bleeding from fractures, bedding planes and some siltstones. The oil sample gave a bright gold to brilliant white fluorescence.

Sixteen sandstone plugs taken from the top part of the core have porosities between 7.1 and 14.9 per cent with an average of 12 per cent, permeabilities between less than 0.1 and 1.2 millidarcys with a geometric average of 0.5 millidarcys, and residual oil saturations between nil and 29.3 (pore space) per cent. Five siltstone plugs taken from the bottom part of the core have porosities between 4.4 and 9.3 per cent with an average of 8 per cent, permeabilities between less than 0.1 and 0.3 millidarcys, and residual oil saturations of between nil and 28.4 (pore space) per cent. The residual oils have gravities of 23 to 25 °API.

Wireline log data indicate that a sandstone zone (in which core-1 was cut) between 2202 and 2212 metres has a net thickness of 8 metres, a porosity of 10 per cent and a water saturation of 45 per cent.

Drill-stem test-3 was run with perforations between 2206 and 2211 metres for 24 hours. No surface choke was used during the test. Small quantities of gas, condensate and water flowed at 0.0415 million standard cubic metres a day, 2.08 cubic metres a day and 2.75 cubic metres a day respectively. The average condensate/gas ratio is 21.7 barrels per million standard cubic feet. A condensate sample had a gravity of 57.4 °API, and a molecular composition as shown in Table 1. Pressure build-up data suggest a formation pressure of 3380 psi (absolute) at 2190 metres, and the formation has a temperature of 117 degrees Celsius. Pressure draw-down data suggest a formation permeability of 2.3 millidarcys.

Drill-stem test-2 was carried out over two perforated intervals (2228 to 2233 metres and 2238 to 2244 metres). No surface choke was used. During an eight-hour flow period, gas flowed at 0.279 million standard cubic metres a day with condensate at 38.84 cubic metres a day, which gives a condensate/gas ratio of 26.6 barrels per million standard cubic feet. A trace amount of water also flowed. This unit had a net thickness of 11 metres, a porosity of 8 per cent and a water saturation of 35 per cent. A condensate sample had a gravity of 57 °API, with a molecular composition as shown in Table 2, and a water sample had a salinity of 51 000 ppm. This drill-stem test gave a formation temperature of 128 degrees Celsius, a formation pressure of 3387 psi (absolute) at 2220 metres, and a permeability of 4.8 millidarcys. The flat build-up of pressure may be an indication of local fracturing of the reservoir.

Table 1. Molecular composition of reservoir fluid (Troubadour 1, DST-3)

Component	Separator liquid	Separator gas	Re-combined reservoir fluid
(mole %)			
nitrogen	0.02	2.57	2.53
carbon dioxide	0.37	2.62	2.58
methane	3.28	85.40	84.11
ethane	0.75	4.87	4.80
propane	0.98	2.10	2.08
i-butane	0.61	0.47	0.47
n-butane	1.36	0.68	0.71
i-pentane	1.78	0.37	0.39
n-pentane	1.90	0.31	0.34
hexanes	6.61	0.35	0.45
heptanes	13.17	0.20	0.41
octanes	16.06	0.04	0.29
nonanes	13.28	0.00	0.21
decanes +	39.83	0.00	0.63
Molecular weight	128.00	19.671	21.395
Gravity (air = 1)	--	0.679	0.739

Cased-hole FIT-3 (formation interval test) was run at 2286 metres in a sandstone unit from 2284 to 2292 metres. A 22.7-litre chamber recovered 14.1 cubic feet of gas (including 13.4 cubic feet of free gas), 13.65 litres of water, and 2.85 litres of mud. The test gave a final shut-in pressure of 3600 psi. This unit has a porosity of 10 per cent and a water saturation of greater than 50 per cent.

A sandstone unit from 2386 to 2395 metres has a porosity of 18 per cent and a water saturation of greater than 50 per cent. Cased-hole FIT-2 was run at 2388.5 metres to determine, prior to running a DST, if this unit is abnormally pressured. A 22.7-litre chamber recovered 0.4 cubic feet of gas and 15.25 litres of water. The gas did not contain any free gas. A final shut-in pressure was not obtained owing to tool malfunction.

DST-1A was run for the sandstones, in which FIT-2 had been carried out, with a perforation interval from 2389 to 2393 metres. The test was not completed owing to mechanical failure.

Table 2. Molecular composition of reservoir fluid (Troubadour 1, DST-2)

Component	Separator liquid	Separator gas	Re-combined reservoir fluid
(mole %)			
nitrogen	0.10	2.48	2.42
carbon dioxide	1.29	4.96	4.87
methane	11.74	84.20	82.39
ethane	2.72	4.65	4.60
propane	3.09	1.91	1.94
i-butane	1.54	0.43	0.46
n-butane	3.14	0.61	0.67
i-pentane	3.35	0.25	0.33
n-pentane	3.44	0.19	0.27
hexanes	9.07	0.18	0.40
heptanes	13.36	0.12	0.45
octanes	13.29	0.02	0.35
nonanes	9.31	0.00	0.23
decanes +	24.56	0.00	0.62
Molecular weight	104.4	19.846	26.968
Gravity (air = 1)	--	0.685	0.758

Subsequently DST-1B was run for the same interval. No fluid flowed during this one-hour test, but water filled in drill pipes to 112 metres below the rotary table. No valid pressure data were obtained.

The sandstone units tested by DST-3 and DST-2 appear to be hydraulically in communication. Wireline resistivity data suggest the existence of a gas-water contact at 2245 metres, although it remains inconclusive. In the well completion report, BOC place the gas-water contact at 2285 metres.

The Early Jurassic section, intersected from 2470 to 2764 metres, comprises sandstones, siltstones, claystones and minor coal. This section has similar lithology and wireline log characteristics to the Middle Jurassic section. The Early Jurassic section has a sand:shale ratio of 1:2. Hydrocarbon indications observed in this section are similar to those for the Middle Jurassic section, but the intensity and frequency of hydrocarbon indications were comparatively weak. The top sandstone unit between 2470 and 2485 metres has a porosity of 12 per cent and a water saturation of 85 per cent.

Open-hole FIT-1 was run at 2598.3 metres (2592 metres after depth adjustment) in a sandstone unit from 2588 to 2605 metres (from 2582 to 2599 metres after depth adjustment). This test was invalid owing to a seal failure. A 22.7 litre chamber recovered 18.1 litres of mud. The sandstones have a porosity of 13 per cent and a water saturation of 100 per cent.

The Triassic section between 2764 and 3294 metres comprises claystones, siltstones, calcilutites, calcarenites, sandstones and minor coal. Well-head gas readings remained fair to moderate, with weak solvent fluorescence occasionally observed in claystones. Most of the Triassic sandstone units are thin and tight, and their reservoir potential is low. Triassic limestones (calcilutites and calcarenites) are recrystallised and have no reservoir potential.

The section between 3294 and 3315 metres are undated, but its lithology is interpreted to be of Late Permian age. This section consists of recrystallised calcilutites and well cemented sandstones, and has no reservoir potential. The bottom section of the well between 3315 and 3459 metres comprises altered granite.

Core-2 was cut from 3454.25 to the subsequent total depth of 3458.5 metres with a recovery of 2.25 metres (53 per cent). The upper 0.25-metre part of the core consists of claystones. However, in the context of the core's position in the well, the claystones appear to be a caved material. The lower 2-metre part of the core consists of granite with calcite-cemented fractures. No hydrocarbon indications were observed. The rock was considered to be unsuitable for geochronology and no data are available.

The granite section has a distinctive gamma-ray log signature and is saturated beyond 400 API units. This section has a sonic transit time of 54 microseconds per foot. Well velocity survey data show an interval velocity of 5660 metres per second. The well has a maximum recorded temperature of 168 degrees Celsius, and it has been suspended as a gas/condensate well.

7.1.6 Jacaranda 1

Jacaranda 1 was drilled by Tricentrol in 1984 in the Malita Graben and terminated at 3783 metres in Middle Jurassic sandstones of the Plover Formation. The kelly bushing elevation was 26.2 metres above sea level.

The Cretaceous Bathurst Island Group was intersected from 817 to 2872 metres, comprising of claystones, siltstones and sandstones with minor dolostones and limestones. The top (Maastrichtian) part of the Bathurst Island Group, from 817 to 1050 metres, has a sand:shale ratio of 1:1, and the lower part of the group, from 1050 to 2872 metres, has a sand:shale ratio of 1:4.

Well-head gas readings gave 6 per cent of methane (and no ethane) from a Campanian sandstone unit, from 1095 to 1126 metres, where the uncorrected sonic porosity value is 40 per cent and the water saturation value is 100 per cent. Two sandstone side-wall core samples taken from this unit gave no hydrocarbon indications. However, a claystone side-wall core sample taken from 1127 metres gave hydrocarbon odour, fluorescence and a cut.

While drilling two Santonian sandstone units from 1477 to 1495 metres and from 1505 to 1526 metres, 2.8 per cent of methane, 420 ppm of ethane and 82 ppm of propane were recorded at well-head. The sandstones have a porosity of 23 per cent and a water saturation of 100 per cent. Gamma-ray readings for the sandstones were high because of the nature of the KCl-based mud used for drilling.

At the base of the Albian section, a sandstone unit was intersected from 2867 to 2872 metres, where a five-fold drilling break took place, accompanying 2.9 per cent of methane, 166 ppm of ethane and 79 ppm of propane. Following this drilling break, core-1 was cut from 2868.5 to 2879 metres with a recovery of 9.63 metres (92 per cent).

Core-1 comprises sandstones from 2868.5 to 2869.3 metres and Valanginian claystones from 2869.3 to 2878.13 metres. The lithological boundary at 2869.3 metres (driller's depth) corresponds to 2872 metres (logger's depth). The sandstones are fine to medium grained, sub-angular to sub-rounded, glauconitic and cemented with siliceous materials and calcite. The sandstones are bioturbated and have no visual porosity and no hydrocarbon indications. The Valanginian claystones gave no hydrocarbon shows. Core analysis reports are not available.

The Late Jurassic to Valanginian Flamingo Group, from 2872 to 3526 metres, contains several sandstone units. A sandstone between 2925 and 2990 metres has a porosity of 11 per cent and a water saturation of 55 per cent at the upper shaly part, and a porosity of 8 per cent and a water saturation of 100 per cent at the lower clean part where 2.9 per cent of methane, 2300 ppm of ethane and 851 ppm of propane were recorded at well-head. Other Valanginian sandstone units also have similar porosity and water saturation values.

The Middle Jurassic Plover Formation was intersected from 3526 metres to a total depth of 3783 metres. This section has a sand:shale ratio of 9:1. The hole was heavily washed out from 3525 metres to the total depth, which has resulted in erroneous wireline data. Caliper data show that some intervals of the 8.5 inch hole section have hole diameters of greater than 22 inches. The jet velocity of drilling mud was high, which may have caused the wash-out. However, other factors, such as high pore pressure, could be involved in susceptibility to washing out, because the sandstones are well cemented and have low porosity and low permeability.

Twenty sandstone side-wall core samples were recovered from this section. All samples are tight and hard, but most of them exhibited weak fluorescence. Quantitative wireline log evaluation is not possible for the section. However, the low-porosity and low-permeability sandstones appear to have water saturations of about 50 per cent.

Core-2 was cut from 3766 to 3767.5 metres with a recovery of two pieces of core (a total of 0.13 metres, 8 per cent). The upper piece consists of glauconitic sandstones which appear to be an exotic material derived from a higher part of the well. The lower piece consists of sandstones which are fine to medium grained, moderately sorted and cemented with siliceous materials and have poor visual porosity. A trace of solid black bituminous-like material is contained on a bedding plane on the end of the lower piece of core, showing dull yellow fluorescence and slow weak pale yellow cuts, however, it contained no extractable organic matter.

The well has a maximum recorded temperature of 147 degrees Celsius. No fluid flow or recovery tests were attempted for this well, and the well was plugged and abandoned.

7.2 PLAY CONCEPTS (J.R. Conolly, B.G. West, J.E. Blevin)

A discussion of possible reservoirs, seals and trap types is given for each of the four play types identified in this study. Two of the plays, the postulated Albian/Aptian carbonate mounds and the Maastrichtian submarine fans, are untested, but provide significant potential new exploration targets.

7.2.1 Plover and Malita Formations

The pre-breakup Plover and Malita Formations are likely to contain thin to very thick reservoir quality sands, which could be charged with hydrocarbons generated from the same formations. Reservoir quality is likely to be poor in the central Malita Graben, where depth of burial has been substantial, but would be expected to be more favourable towards the shallower margins of the graben, and on the Sahul Shelf and Darwin Platform.

Tilted fault blocks, particularly along the southern margin of the Malita Graben, offer suitable structural traps, where reservoirs are likely to be sealed by the overlying Flamingo Group or Bathurst Island Group shales, or by intraformational shales. Faulted (or fault-controlled) anticlines, which have provided the major exploration target to date, occur both in the graben and on the shallower platform areas. As with the tilted fault blocks, reservoirs are likely to be sealed by the Flamingo Group or Bathurst Island Group shales, or by intraformational shales. Many of these anticlinal features, for example, the one tested by Evans Shoal 1 well, appear to be coincident with shallower reef anomalies.

7.2.2 Flamingo Group

The play types in the Flamingo Group are generally expected to be similar to those in the underlying Plover Formation. Fault blocks marginal to the Malita Graben would be the prime target, although anticlinal features within the graben may offer some potential. The Flamingo Group thins or is eroded on the Sahul Platform and the Darwin Shelf and is not considered to be a viable target in these areas.

7.2.3 Albian/Aptian carbonate mounds

Mound-like features (referred to as mounds in the following discussion) immediately above the Albian/Aptian Unconformity, have been identified on seismic lines traversing the northern margin of the Malita Graben to the east of Shearwater 1 well. Seismically, these features are similar to carbonate buildups described by other researchers, for example, Bubb & Hatlelid, 1977, Harwell & Rector, 1972 and Wilson, 1975. These mounds have a vertical relief of up to 300 milliseconds, and areal closure of up to about 25 square kilometres. They are linearly distributed along the northern margin of the graben.

Heron 1 well, located in the Malita Graben to the south of these mounds, intersected a 122 metre thick sequence of limestone and limey shale of Albian age. The sequence contains foraminiferal micrites and pelagic fauna consistent with a deepwater depositional environment. During the Albian, the Malita Graben probably formed a broad depression between the Sahul Platform in the north, and the Darwin Shelf in the south, and shallow water carbonates may have formed on the outer shallow shelf, marginal to the graben.

The palaeolatitude of this area during the Albian was about 30 to 35 degrees south (Marita Bradshaw, pers. comm.), which would have been within the range for the development of carbonate platforms and banks (Wilson, 1975). It is postulated that rudist mounds may have developed on the outer edge of a carbonate platform, somewhat similar to the model described by Schlager and Philip (1990), and Wilson (1975), and that they have eventually drowned as a result of sea level rise in the Turonian. A number of major oil and gas discoveries has been made in Albian rudist buildups at shelf margins, including the Golden Lane Reef trend in Mexico and the Stuart City-Edwards Reef trend in Texas (Wilson, 1975).

Because of inadequate well and seismic control, it is speculated that these mound features are carbonate buildups. It is possible they are not artefacts of the seismic processing because of the nature of the distribution and seismic character of the features.

7.2.4 Maastrichtian submarine fans

The two wells drilled in the Malita Graben (Heron 1 and Evans Shoal 1) both encountered a thick (158 and 409 metres respectively) sequence of Maastrichtian age sands. Stratigraphically, these sands are similar to the sands encountered in the Lynedoch 1, Jacaranda 1 and Darwinia 1A wells. These three wells are all located on the palaeoshelf, and the sands they intersected are interpreted to have been deposited in an inner neritic to coastal plain environment.

The sands in Heron 1 and Evans Shoal 1 are somewhat finer grained, cleaner, well rounded and frosted, suggesting additional reworking has taken place. On the seismic sections, these sands appear as widespread, hummocky clinoform reflections, with apparent mounding, possible clay drape and foresetting. It is postulated that these sands may be lobes of submarine fans derived from the reworking of coastal plain and shelfal sands, and transported into the deeper water of the Malita Graben during relatively low sea level stands (Plate 37).

The sand sequences can be subdivided into several sub-sequences, similar to other studies of both modern and ancient submarine fan complexes (Heritier & others, 1979; Normark, 1978; Sarg & Skjold, 1982; Shanmugan & Moiola, 1988; Shanmugan & Moiola, 1991; Walker, 1978; Weimer & Link, 1991).

A subdivision of the postulated submarine fans deposited in the Malita Graben is described below.

Proximal foresetting sequences

Proximal foresetting sequences are seen as dipping foresets on seismic sections and are proximally located to the shelf edge but, in most cases, are still located within the graben. No wells have penetrated the foresets in this setting, but it is postulated that they consist of alternating sand-shale sequences.

Main fan complex

The main fan complex is characterised by an intercalation of mounded sand sequences, sheet sands and/or shale sequences, and channels. It is identified on seismic sections, where individual mounds are up to 100 milliseconds TWT in thickness. This facies is widely distributed within the central Malita Graben and merges with the proximal foresetting facies towards the southern margins of the graben, indicating a northerly or northeasterly distribution from the southern shelfal and coastal plain areas (Plate 37).

The main fan complex can be subdivided into distinctive sub-facies as follows.

Upper shale sequence cap

Once the main fan lobe has been deposited and the major feeding channels have prograded further basinwards, finer-grained sediments are deposited over the "old" fan surface. These sediments are exceptionally important as they form a cap and a seal to the underlying reservoir sands.

Two shale caps can be identified in the Evans Shoal 1 well. The uppermost shale cap (1306 to 1327 metres) is the most doubtful in terms of forming a good seal as it is likely to be interbedded with lime muds and limestone of the overlying Tertiary sequence away from the well. The lower shale cap (1476 to 1590 metres) would most likely form a good seal in the vicinity of the Evans Shoal 1 well.

Unfortunately, the sparse well control makes it extremely difficult to fully predict good reservoir/seal couplets. There is still sufficient seismic and well control, however, to be positive about the possibilities of finding good shale seals over mounded sands, particularly if the mounds are obvious on seismic sections.

Upper channel-levee sequence

The proximal channel-levee distributary system eventually progrades over the fan sand mounds, and this sequence is seen as a complex of small channel cuts and gently sloping levee beds lying on top of a mounded sequence. The channel deposits are characterised by fining upwards sequences (Plate 37).

Distributary-mouth bar sands

Distributary-mouth bar sands formed by modern deltas, for example, the Mississippi Delta, are commonly fairly well sorted, sheet-like sand bodies. Depending on the size of the feeding sand system, they can be quite thick (more than 100 metres) and areally extensive (two to five kilometres wide). The sands within the Maastrichtian of the Malita Graben are of a similar dimension.

Distal and/or basal sheet sands

Distal and/or basal sheet sands are deposited farthest away from the channel and mound system which will eventually prograde over them. These sands tend to be finer-grained, consisting of flat sheet-like beds as seen on seismic sections. They are likely to contain individual graded sand beds, characterised by upwards fining sequences.

Comparison of Malita Graben submarine fans with Viking Graben (North Sea) turbidite fans

The Paleocene-Eocene turbidite fan sands of the Balder oil field (Sarg & Skjold, 1982) and the Frigg gas field (Heritier & others, 1979) in the Viking Graben of the North Sea may serve as analogues for the Malita Graben Maastrichtian sands (Plate 37).

Heritier & others (1979) interpret the fan systems of the Viking Graben as being derived from shelf and coastal plain sands deposited on the Shetland Platform, which were distributed by mass flow (turbidity currents) into the deeper water of the Viking Graben during low sea level stands. They form the reservoirs for a number of important oil and gas fields including the Balder, Brae, Bruce, Forties, Frigg, East Frigg and Ninian fields. The Puffin area in the Vulcan Graben may probably be the first commercial development of oil from Upper Cretaceous turbidite fan sands on the North West Shelf of Australia.

In the Malita Graben area, two wells (Heron 1 and Evans Shoal 1) intersected postulated Upper Cretaceous turbidite sands with excellent reservoir potential. In Evans Shoal 1 well, the upper sand lobe is about 200 metres thick (1287 to 1476 metres) and consists mainly of fining-upwards (channel) sequences. The lower sand lobe comprises a massive sandstone about 100 metres thick (1590 to 1696 metres). A 100 metre thick marine claystone separates the two lobes.

In Heron 1 well, only the upper fan lobe is well developed and comprises two thick (52 and 55 metres) fining upwards channel sequences, underlain by a 49 metre thick coarsening upwards basal sequence, and is similar to the fan sand deposits intersected in the Frigg field (Plate 37).

Sourcing for the Maastrichtian sands is likely to be from the marine shales in the lower part of the Bathurst Island Group. Late Miocene reactivation of pre-existing faults may provide suitable migration pathways. Faulting and intraformational shale drapes are likely to allow adequate sealing of traps.

7.3 LEADS (J.R. Conolly, B.G. West, J.E. Blevin)

Twenty interpreted seismic sections (Plates 15a to 34a), seven schematic sections (Plates 18b, 19b, 20b, 26b, 28b, 31b and 34b), and two maps (Plates 35 and 36) are used to illustrate the leads in Areas NT92-1 and NT92-2. Most of the leads are controlled by northeast-southwest trending faults that can be identified at the Albian/Aptian Unconformity level, and have been plotted onto the time structure map at that level (Plate 36). It is likely that future seismic surveying will delete some of these leads and add others.

Area NT92-1 comprises 138 blocks, covering an area of approximately 12 000 square kilometres, with water depths ranging from 40 to 200 metres. The southeastern part of the area overlies a shallow continental shelf, which slopes northwestwards into the present day expression of the Malita Graben. The northwestern corner of the area rises up onto the Sahul Platform.

Area NT92-2 comprises 133 blocks, covering an area of approximately 11 000 square kilometres. It is immediately adjacent to Area NT92-1, and is almost bisected by permit NT/P40 currently held by WMC. The southern portion overlies a shallow continental shelf, with water depths ranging from 40 to 100 metres. The northern portion extends across the shelf break into the outer shelf, with water depths ranging from 100 to over 400 metres.

In the following sections, the seismic markers are referred to as K, Ka and Jb, consistent with Chapter 5, where K is near top Cretaceous (Bathurst Island Group), Ka is Albian/Aptian Unconformity, and Jb is Callovian 'Breakup' Unconformity.

7.3.1 Area NT92-1

Eighteen leads have been mapped in area NT92-1 (Plate 36). Most are related to block faulting at the margins of the Malita Graben, or to the postulated Albian carbonate mounds. Maastrichtian sands are likely to be widely distributed in the central graben, particularly around the 'Heron High' feature.

Lead A

Lead A is a large mounded feature, immediately above the Albian/Aptian Unconformity at about 2.3 secs TWT. It is illustrated on lines 85MA-05, 85MA-06 and 85MA-16. It has a vertical relief of approximately 300 milliseconds, and areal closure of about 25 to 30 square kilometres.

Leads B, B1 and C

Leads B, B1 and C are similar to lead A, and together are linearly distributed about the northern margin of the Malita Graben. They are illustrated on lines 85MA-3A, 85MA-4A and 85MA-16. There may be some pull-up associated with these three leads due to the effect of surface reefs.

Leads A, B, B1 and C are postulated Albian carbonate mounds, and are considered to be a major potential play in Area NT92-1.

Lead D

Lead D is a possible Devonian? salt diapir with lateral drape at Ka and Jb levels. It is best illustrated on line BB16.

Lead E

Lead E is a low relief rollover into the graben margin fault. It is illustrated on line 85MA-02, where potential targets exist in Flamingo Group sands beneath Ka (2.4 secs TWT), and Plover Formation sands below Jb (2.8 secs TWT).

Lead F

Lead F is a low relief anticline associated with a horst block. It is illustrated on line 85MA-06 where potential targets exist in Flamingo Group sands beneath Ka (2.35 secs TWT), and Plover Formation sands beneath Jb (2.6 secs TWT). Maastrichtian sands with intraformational shale drape may occur beneath the K marker.

Leads G and H

Leads G and H are low relief anticlines at Ka level (2.4 secs TWT) and Jb level (2.7 secs TWT). They are illustrated on line 85MA-08, where potential targets are Flamingo Group sands below Ka, and Early Jurassic mounded sands below Jb.

Lead I

Lead I is a low relief anticline at Jb level (3.05 secs TWT). It is illustrated on line 85MA-06. Potential targets are Early to Middle Jurassic sands. Secondary targets may exist in Maastrichtian sands below the K marker.

Leads J and K

Leads J and K are related to fault blocks along the southern margin of the Malita Graben. They are illustrated on line 85MA-4A. Potential targets exist in the Flamingo Group sands below Ka, and Plover Formation sands below Jb.

Lead L

Lead L is a rollover into the northern bounding fault of the graben. It is illustrated on line BB16. Potential targets exist in Flamingo Group sands below Ka level (1.45 secs TWT), and in Plover Formation sands below Jb level (2.05 secs TWT).

Leads M and O

Leads M and O are low relief anticlines, fault bounded to the south. They are illustrated on line BB12. Potential targets exist in Flamingo Group sands below Ka level (1.95 secs TWT), and in Plover Formation sands below Jb level (2.35 secs TWT).

Lead N

Lead N is related to a horst block separate from the main 'Heron High' feature. It is illustrated on lines 85MA-05 and 85MA-06. A number of potential targets is possible in this lead. Below Jb level (2.95 secs TWT), potential targets exist in Early to Middle Jurassic and, possibly, Permo-Triassic sandstones in tilted fault blocks. Below Ka level (2.4 secs TWT), Flamingo Group sands may exist, juxtaposed against the southern bounding fault. Below K (0.85 secs TWT), there is significant potential for thick Maastrichtian sands to be present, sealed by intraformational shales, and juxtaposed against the southern bounding fault.

Lead P

Lead P is a low relief rollover at Ka level, into one of the graben southern margin faults. It is illustrated on line 85MA-01. At this location, the Flamingo Group is thin or absent, and the prime target is Plover Formation sands beneath Ka (at 2.2 secs TWT).

Lead Q

Lead Q is related to closure against the main southern bounding fault system of the graben. It is illustrated on line BB16. Potential targets exist at several different stratigraphic intervals. At Ka level (2.45 secs TWT), rollover into the fault provides potential targets in Flamingo Group sands below the unconformity. At K level (1.1 secs TWT), Maastrichtian sands may be trapped against the bounding fault, sealed by intraformational shales, or the overlying Tertiary sequence.

7.3.2. Area NT92-2

Fourteen leads have been mapped in Area NT92-2 (Plate 36). In the southern part of the area, most of the leads are associated with faults bounding the southern margin of the Malita Graben. In the northwestern part of the area, most of the leads are fault controlled, low relief anticlines which, in many cases, may be influenced by pull-up due to surface reefal features. The northeastern part of the area is in relatively deep water (200 to 450 metres) and has limited seismic coverage. Little is known, therefore, of potential leads.

Leads A to F

Leads A to F are located on the shelf edge of the Sahul Platform, in an area generally referred to as Martin Shoals (NTGS, 1990). They are illustrated on lines 85MA-08, 85MA-09, 85MA-17 and 85MA-18. They are all fault-controlled and/or fault-bounded, low relief, anticlinal features at the Ka and Jb levels. Most of these leads may also be affected by pull-up resulting from surface reefal features. Potential targets are sands in the Flamingo Group below Ka and Plover Formation below Jb. They are similar to the structure tested by Evans Shoal 1 well.

Lead A has been mapped by WMC at near base Bathurst Island Group (near base Cretaceous) as the Martin Shoals prospect. It is shown as a drape closure over a crestal fault-bound horst, with a vertical relief of 75 metres, and areal closure of approximately 30 square kilometres (NTGS, 1990).

Lead G

Lead G is a low relief faulted anticline similar in style to those in the Martin Shoals area. It is illustrated on line 85MA-09. Potential targets are Plover Formation sands below the Jb 2.9 secs TWT.

Lead H

Lead H is a low relief anticline, fault controlled at Ka level and fault bounded at Jb level, and is similar in style to the leads in the Martin Shoals area. It is illustrated on line 87CO-19. There is also some pull-up which is probably related to surface reefal features. Potential targets are Flamingo Group sands below Ka (2.4 secs TWT) and Plover Formation sands below Jb (2.7 secs TWT).

Lead I

Lead I is a low relief anticlinal drape at Ka level (2.55 secs TWT), over a horst block at Jb level (2.8 secs TWT). It is illustrated on lines 85MA-09 and 85MA-11. Potential targets exist in Flamingo Group sands below Ka, and in Plover Formation sands below Jb. In addition, Maastrichtian sands may be present below the K marker, providing a potential secondary target where it is juxtaposed against the south bounding fault.

Leads J, K and L

Leads J, K and L are related to faulting along the southern margin of the Malita Graben. They are illustrated on line 85MA-09. Leads J and K are fault blocks containing potential targets in Plover Formation sands, and Permo-Triassic sands at depths of less than 3.0 secs TWT. The Flamingo Group is either thin or absent in this location. Lead L is a fault controlled, low relief anticline updip from leads J and K. Here, the Flamingo Group is most likely absent, and potential targets are Plover Formation and Permo-Triassic sands at depths of less than 2.5 secs TWT.

Lead M

Lead M is a low relief, fault-controlled anticline down dip from a bounding fault on the southern margin of the Malita Graben. It is illustrated on line 85MA-08. Possible targets are Plover Formation sands below Jb level (2.35 secs TWT), and Permo-Triassic sands below 2.65 secs TWT.

Lead N

Lead N is a rollover into the southern Malita Graben margin fault. It is illustrated on line 85MA-06. Here, the Flamingo Group is thin or absent, and potential targets are Plover Formation sands below Jb (2.1 secs TWT) sealed by intraformational shales or by overlying Bathurst Island Group shales.

7.4 SUMMARY (B.G. West)

Wells drilled in and adjacent to Release Areas NT92-1 and NT92-2 have yielded hydrocarbons, either as recoveries or shows, from most potential reservoir units in the Cretaceous and Jurassic sequences. These results, together with the interpretation of limited source rock and maturation data, confirm that hydrocarbons have been generated from the Jurassic Plover Formation and the lower part of the Middle Cretaceous Bathurst Island Group. Based on a broad regional grid of fair quality seismic data, 32 potential leads have been identified in the two release areas. Those leads encompass a variety of play types in each of the areas.

In Area NT92-1, leads are mainly related to fault blocks at the margins of the Malita Graben, postulated carbonate mounds on the northern margin of the graben, and low relief fault-controlled anticlines in the graben and on the higher platform areas. Potential targets are likely to be sands in Plover Formation and Flamingo Group, Albian/Aptian carbonate mounds, and Maastrichtian sands.

In Area NT92-2, leads are generally related to low relief, fault-controlled anticlines in the northern part of the area, with potential targets in Plover Formation, Flamingo Group and Maastrichtian sands, or with graben margin faults in the southern part of the area, with potential targets in Plover Formation or Permo-Triassic sands.

The two release areas, totalling nearly 23 000 square kilometres, have only been sparsely explored, and we consider there is significant potential for additional exploration, particularly in relation to the postulated Albian/Aptian carbonate mounds and Maastrichtian fan sands.

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APPENDIX 1

NORTHERN TERRITORY GEOLOGICAL SURVEY (1990) - PETROLEUM BASIN STUDY: BONAPARTE BASIN.

(REPORT ENCLOSED SEPARATELY IN VOLUME 1)

APPENDIX 2

QUATERNARY EVOLUTION, MODERN GEOLOGICAL PROCESSES AND POTENTIAL EFFECTS OF ADDITIONAL PETROLEUM EXPLORATION ACTIVITY ON THE VAN DIEMEN RISE, TIMOR SEA (EAST MALITA GRABEN AREA) - RELEASE 1 OF 1992.

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Abstract

To meet the formal requirements for the collection, interpretation and analysis of environmental baseline data in Australia's offshore areas, in which further petroleum exploration could take place, the modern geological processes, Quaternary evolution and environmental features of the potential release area(s) in the Van Diemen Rise (East Malita Graben, Timor Sea), which will be included in the first release of 1992, are described, analysed and interpreted.

The potential release area(s) overlies part of the Van Diemen Rise in the eastern part of the Timor Sea in the vicinity of Cootamundra and Evans Shoals. Sea bottom sediments in the region are dominantly calcareous sand grade and are derived from the breakdown of skeletal material which has developed on an extensive number of banks and shoals which characterise this part of the continental shelf.

The sea bottom is also marked by a number of sinuous and narrow curvilinear channel-like features which, along with other geomorphic elements, are attributed to the effects of subaerial exposure and weathering of the carbonate shelf sediment wedge during Quaternary lower sea level stages, as well as marine and coastal processes, which occurred during sea level rise and marine inundation.

The Holocene rise in sea level has resulted in inundation of a large number of wave-cut scarps, channels and flat top banks, the latter becoming the focus of carbonate reef growth and hence a source of much of the sand-grade carbonate sediments evident on the sea floor.

Sea bottom sediments of the East Malita Graben area have been strongly affected by Holocene transgression. At approximately 18 000 years B.P., sea level was of the order of 120 metres below the present shoreline and much of the present shelf was subjected to subaerial exposure and erosion. A narrow shelf existed close to the edge of the continental shelf; shallow banks and shoals on the shelf were the focus of significant coral reef growth. Calcrete concretions formed on the exposed land surface under the influence of a low rainfall climate and a restricted estuarine embayment developed in the Bonaparte Depression.

Transgression rapidly flooded the shelf region and formed transgressive skeletal calcarenites with some calcareous concretion pellets. Around the banks and rises of the shelf, transgressive calcarenite has accumulated from coral debris. Landward of the present 50 metre depth contour, sedimentation is largely clastic and derived from the input of rivers which are most active in the monsoon (wet) season.

Foraminiferal calcarenites, forming at present on the outer shelf, are finer grained and contain more planktonic components the greater the water depth. Silty clays and molluscan debris are accumulating in the sheltered channels and the remains of large foraminifera and coralline algae are accumulating on the shallow banks and rises. A similar assemblage dominated by *Halimedia* is growing on the very shallow shelf edge banks.

Major ecological features of the current coastal zone, adjacent to the potential release area(s), include mangrove, seagrass and reef communities. Human activities which can adversely affect each of these elements include increased nutrient levels from runoff and other discharges associated with human settlements and activities.

Seismic surveying and, possibly, drilling are the main petroleum exploration activities likely to be undertaken in the potential release areas. The transitory nature of these activities and their variable location would, in normal circumstances, result in no long-term visible impact on environmental conditions and at worst only very minor short-term localised disturbance. At the completion of exploration work, the only visible signs of drilling would be the presence of rock fragments on the sea bottom. Normal current and tidal action would disperse these fragments within a short period. The impact of the installation of production facilities would require more specific examination beyond the scope of this analysis.

Introduction

Petroleum operations in Australia, beyond coastal waters, are governed by Commonwealth legislation and this, in part, is administered jointly with the States and Northern Territory. The 12 million or more square kilometres of ocean waters surrounding the continent are rich in natural living resources as well as overlying sedimentary basins with proven oil and gas potential.

The recent releases of vacant petroleum exploration areas for application under Commonwealth legislation (Release of Offshore Petroleum Exploration Areas, Release No 1 1992) have been accompanied by a list of special conditions. These special conditions require that successful exploration groups applying for the right to drill exploration wells during the course of a permit work program will have to supply to the Commonwealth with: firstly, a description of the environment, both within the permit and adjacent to it, which is likely to be affected by drilling and production - where there is written material already available, this has to be included; and, secondly, a description of the potential impact of drilling and production on the environment, a description of safeguards and standards for the protection of the environment intended to be adopted and applied in connection with the drilling of the well and future production.

In response to the demand for environmental baseline data, some of which has been collected by the petroleum exploration industry during the course of its exploration and production activities, the Bureau of Mineral Resources, Geology and Geophysics (BMR) has acquired and is interpreting a wide variety of data relating to baseline environmental conditions. Major regional surveys of marine geology of Australia's continental margins provide a unique insight into the nature of Australia's marine environment, its diversity and variability. Such surveys have been undertaken for the past thirty years by BMR.

The potential impact of petroleum exploration and production activity on Australia's marine environment has, over a 30 year period of major petroleum production, proved to be negligible with a total of 350 barrels of oil being accidentally released during the course of producing two and a half billion barrels of oil (Griffiths, 1991). Maritime shipping around Australia has been responsible for most of the oil spillage into the marine environment.

The specific requirements for descriptions of the environment surrounding sites on which petroleum exploration drilling is proposed have formalised a process that the petroleum industry has been undertaking for a considerable period of time. Site surveys, water temperature, current, wave, wind and tide patterns, and other oceanographic data have been evaluated as part of the process of petroleum exploration and development (Holloway, 1988). The special conditions, which now require formal documentation of such information in applications to drill exploration wells, have resulted in the research, interpretation and analysis of such information in the following form by BMR for use by government, the industry and the public.

The Van Diemen Rise (East Malita Graben Area) is likely to be included in Release 1 of 1992 and it overlies the Australian continental shelf between 9°30'0" and 10°0'0" south and 128°15'0" and 129°45'0" east (Figure 1). Water depths in the area increase to the north and northeast from less than 100 metres to over 400 metres. The central and southern parts of the area (Figure 1) comprise a complex series of relatively shallow flat top banks. Cutting through the banks is a series of sinuous channels and terraces which are the result of regional erosion (Figure 2). Cross correlation of such features allows for up to four base levels at which erosion and physical weathering processes have been active for short but significant periods.

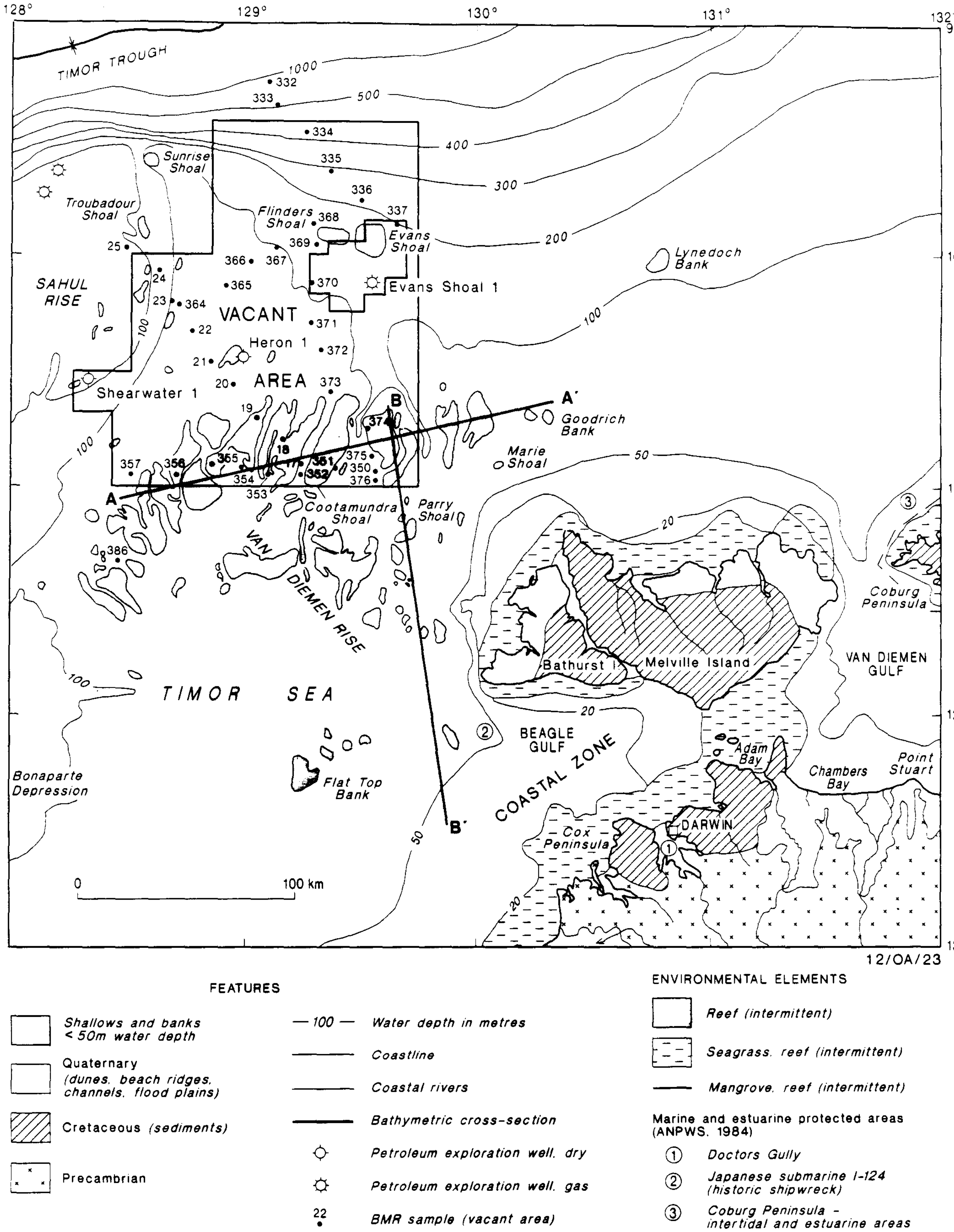

Figure 1 Location map, bathymetry and simplified geology/ geomorphology.

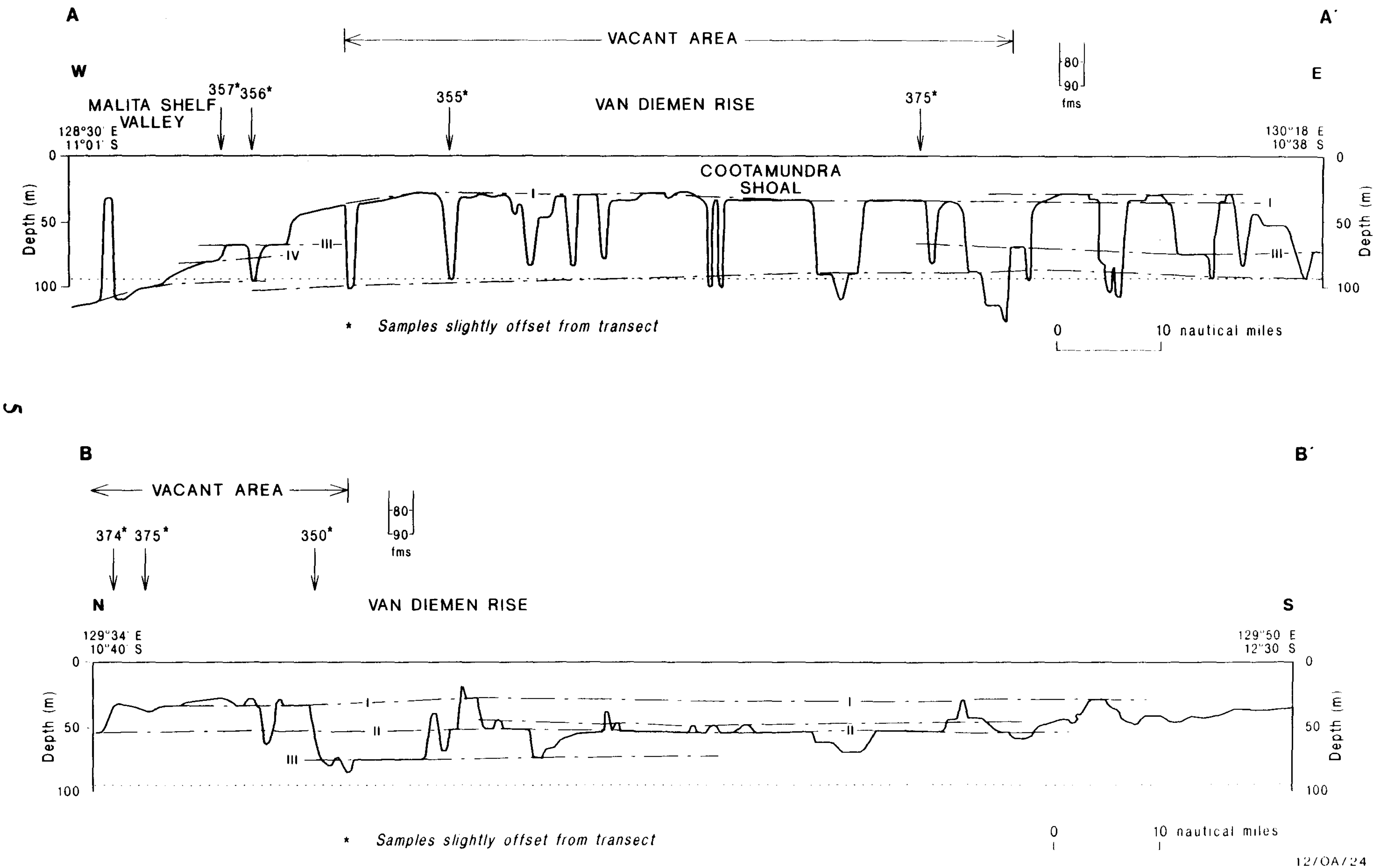

Figure 2 Cross sections of sea bottom topography

Although no specific means of correlating the offshore terraces and bank tops with the onshore erosion surfaces described by van Andel & Veevers (1967) are available, the general form of the coastal plain surface they describe is similar to Surface I outlined in their publication and shown in Figure 2 (Cross section AA') for the banks in the southern part of the vacant area. This (Surface 1) is younger than the onshore Wave Hill surface which has been identified broadly as Miocene in age. An extensive unconformity (S3) Veevers (1971), identified in seismic records of the Sahul Shelf, could correlate with the Wave Hill surface. In contrast, the coastal plain surface has several stages onshore and these appear compatible with the offshore Pleistocene stages shown in Figure 2. Two unconformities, identified by Veevers (1971), on the Sahul Shelf (S1 & S2) are Late Pliocene and Pleistocene and may correlate with development of an older part of the coastal plain surface. These surfaces have had a major influence on the form of the sea floor in and around the vacant area and the lithology and biofacies currently evident in the region.

Northern Territory coastal zone

Coastal areas of the Northern Territory, landwards of the waters covering the vacant area, are noted for their diverse and significant physical and biological resources. Those resources accordingly represent considerable economic, recreational and conservation values (NTDME, 1991).

For definition purposes only the 'coastal area' exists seawards to 25 nautical miles off-shore or the 50 m depth contour, whatever is greater from shore, and extends onshore to include all landforms which are subject to coastal processes, including mobile sand dunes and chenier beach ridges (NTDME, 1991) (Figure 1).

Three basic divisions of the coastal area are readily made, based on the dominant sedimentological processes as well as the biofauna inhabiting each major geographical element (Figure 1) (NTDME, 1991).

The first division is the intertidal zone, which includes the areas between high and low tides levels. Elements, such as mangroves, salt marshes, some seagrass beds, mudflats, sand flats, with lesser sandy beaches and dune systems may be present.

Generally, the second division is landwards of the intertidal areas, and includes such features as dunes and chenier beach-ridges, as well as low-lying areas, which become water-logged during the monsoon season, paperbark swamps and monsoonal vine thickets. Such areas are the supratidal zone and comprise a buffer between the intertidal zone and non-marine environments *per se*.

The third division is the subtidal zone, which has marine or estuarine areas below low tide level. Elements in this group are major tidally-influenced channels, coastal lagoons, coral reefs, seagrass banks and shoals, as well as marine shelf areas.

A variety of cultural, social, biological, geological and geographical values are attributed to many of the coastal features of the Northern Territory (NTDME, 1991). Some features are considered likely to be sensitive to the impact of activities associated with petroleum exploration and development work that includes dredging, drilling and seismic exploration using explosive sources.

Other features which have been identified as being likely to be adversely affected by such activities include marine and estuarine protected areas, sacred sites, occupational reserve and fisheries reserves. Undeclared areas, such as seagrass, mangroves, turtle or bird breeding areas, shipwrecks, recreational sites and potential aquaculture development sites, are also the subject of considerable interest.

No declared protected areas are listed by the Australian National Parks and Wildlife Service (ANPWS, 1984) in the vacant East Malita Graben area.

Climate

All of northern Australia, including the coastal regions closest to the vacant area, are subject to a monsoon climate, with a wet season during the northwest monsoon (summer), from November to April, and a dry season during the southeast monsoon (winter), from May to October. Rainfall varies from 720 to 1920 millimetres (30 to 80 inches) per year. Mean temperatures in the wet season are in the high 20s and 30s degrees Celsius with high humidity, and in the dry season are down to 18 to 20 degrees Celsius with low humidity. Thunderstorms occur in summer, on average, 85 days per year in Darwin. The mean average evaporation rate is approximately twice the average annual rainfall (van Andel & Veevers, 1967).

The seasonality in temperature and wind regimes has a significant effect on the salinity levels in nearshore areas and water temperature. Nearshore waters can vary in temperature (by 10 degrees Celsius) and salinity (Poiner & others, 1987) but this variation is less marked in offshore areas. Much of the nearshore variation is related to the volume (and sediment load) of runoff from coastal river systems. The northern Arnhem Land coast is less affected by runoff than the Joseph Bonaparte, Van Diemen and Carpentaria Gulfs.

The Arafura Sea and Timor Sea areas are noted for a mean annual precipitation of 900 millimetres and a mean annual evaporation of 1716 millimetres. A southeast trade wind blows from May to October in the dry period, and a northwest trade wind blows from November to April in the wet season. Tropical cyclones lasting from 12 to 24 hours occur in the latter period. Wind velocities of 50 to over 90 knots, even as high as 140 knots, are developed during cyclonic conditions. Squalls in the dry season rarely last longer than three hours and develop winds of 30 to 100 knots (van Andel & Veevers, 1967).

The southeast trade winds can generate moderate to rough seas, the main swell being from the southeast. During much of the monsoon season, seas are calm and smooth except for the disturbance caused by tropical cyclones. Swells developed during cyclones come from the southwest, west and northwest.

Geomorphology

The East Malita Graben area overlies much of the northern extent of the Van Diemen Rise. The area is a bathymetric feature, comprising a complex array of relatively shallow banks cut by numerous narrow sinuous channels, some of which are bordered by terraces of varying inferred ages and are the result of regional erosion (Figure 2).

Quaternary history

In the Tertiary period, much of the present coastline of northern Australia, including the marine shelf underlying the vacant area, was elevated above sea level and subjected to subaerial erosion (Jongsma, 1974; Hughes, 1978). During the Pleistocene, several changes in sea level occurred and were followed by a final Holocene transgression. These processes were identified by Jongsma (1974) and are apparently reflected in the development of submarine terraces.

Jongsma (1974) identified a terrace at 200 metres subsea which he suggests formed 170 000 years B.P. (possibly Riss Glacial Stage). He also identified a transgression before 30 000 B.P., a lowering of sea level after 30 000 B.P., which formed terraces at minus 180 and minus 120 metres subsea (Wurm Glacial Stage), and a transgression from about minus 120 metres subsea at 15 000 years B.P. The latter terrace was formed before the Holocene transgression, which resulted in the inundation of river systems and the formation of chains of islands and straits typical of the present coastline.

Higher than present sea levels or local tectonic uplift are responsible for the development of chenier beach ridges and strandline features at higher levels and up to 3 kilometres inland of the present coastline (Hughes, 1978).

More detailed investigation by Lees & others (1990) and dating of such dune systems indicate that the dunes developed in an episodic fashion. The first period of dune and chenier building falls between 2600 and 1800 years B.P., the second period falls between 8500 and 7000 years B.P., and the third period falls between 81 000 and 171 000 years B.P. The last of these periods is similar to the oldest terrace identified offshore by Jongsma (1974).

Each of these three periods of dune building and development, identified by Lees & others (1990), coincides with drier climatic change, higher evaporation and lower precipitation. Reduced vegetation cover, resulting from the drier climate and seasonally persistent winds, has resulted in greater dune mobility. Rising sea levels further contribute by eroding foredunes, initiating blowouts and developing transgressive dune sequences (Lees & others, 1990).

Stabilisation of dune systems by vegetation halts the process and usually coincides with periods of increased rainfall. Past studies have highlighted the additional contribution of local sediment budgets, glacial low sea level stands, marine transgressions, cycles of storms and anthropogenic disturbances as the source(s) of processes leading to dune formation and emplacement (Lees & others, 1990).

A specific examination, by Lees (1987), of the strandline units at Point Stuart, approximately 15 kilometres east of the mouth of the Mary River on the coast of Van Diemen Gulf east of Darwin, has identified at least five chenier ridges which have formed in the last 1270 years. Major storms over an 80 to 200 year frequency appear to have built the five ridges closest to the coast. A further five ridges, landwards of this set, have a much lower proportion of carbonate and shelly material, and differences between the two sets are explained by a major change in the pattern of sediment supply (Lees, 1987). The switching of the Adelaide River system from Chambers Bay to Adam Bay and the abandonment of a single channel for the Mary River to several discharge channels may be the cause of the differences between the two sets of chenier systems.

The beach ridges at Point Stuart and others around the coastal fringes of northern Australia are formed by storm waves where wave base reaches deeper and further offshore than normal. Wave-winnowing can excavate shelly material and remove fine grained sediments, allowing coarse-grained sediments and shell debris to accumulate on the strandline or at storm-surge level landwards of the normal strandline.

Recent sedimentation

Each of the major coastal features identified above is noted for the development of a suite of sediment types such as fluvial channel and floodplain sequences landwards of the coastal system. These comprise silt, fine sand, mud, minor gravel and alluvium up to a total of 5 metres in thickness in meander channels, swamp depressions and even cut-off meanders. Towards the hinterland and in between such units are red sandy and mottled grey to yellow sandy soils up to 10 metres thick which form in colluvial and eluvial environments (Hughes, 1978). The latter are generally developed as a result of the erosion and dissection of Tertiary and possibly older consolidated sequences.

In coastal and offshore areas, littoral, aeolian, intertidal deltaic and estuarine sand, shell and coral debris, organic rich mud and silt are being deposited in sequences up to 20 metres thick. Beach and littoral strandline sands are evident on present coastlines and as low vegetated ridges. Along some shoreline and other areas, Pleistocene coquina, calcarenite and conglomerate have formed in sequences up to 8 metres thick (Hughes, 1978). The extensive estuarine systems are evident at the mouths of major river systems developed where marine inundation drowned existing river valleys.

The modern sediments of the Timor and Arafura Seas are most extensive in the nearshore areas of less than 50 metres in water depth. Within these areas, sediment distribution is irregular, being controlled by the proximity to sediment sources and the degree of exposure to tidal and wind generated activity. The current pattern of modern sedimentation and older Quaternary units is thought to be the combined effect of sea-level fluctuations, relict deposits and subaerial, fluvial, lacustrine and marine conditions (Jones, 1987). During the past 6000 years, sea level is thought to have been relatively stable at or near its present level (Thom & Chappell, 1978).

Fluvial sediments are the major input into the Timor and Arafura Seas from the coastline and hinterland, more so where major river systems empty into sheltered bays and estuaries, such as those in the Joseph Bonaparte and Van Diemen Gulfs. Where wind and wave energy are sufficient, fine-grained terrigenous sediment, transported down river systems in the wet season, are prevented from being deposited in nearshore areas and are deposited offshore over older Late Pleistocene continental and marine sequences.

Carbonate comprises much of the offshore sediments deposited in the vacant area at present, but is mixed with a significant amount of fine clastic material to form calcarenite with some silty calcilutite (Figure 3). The sequence is part of a broad

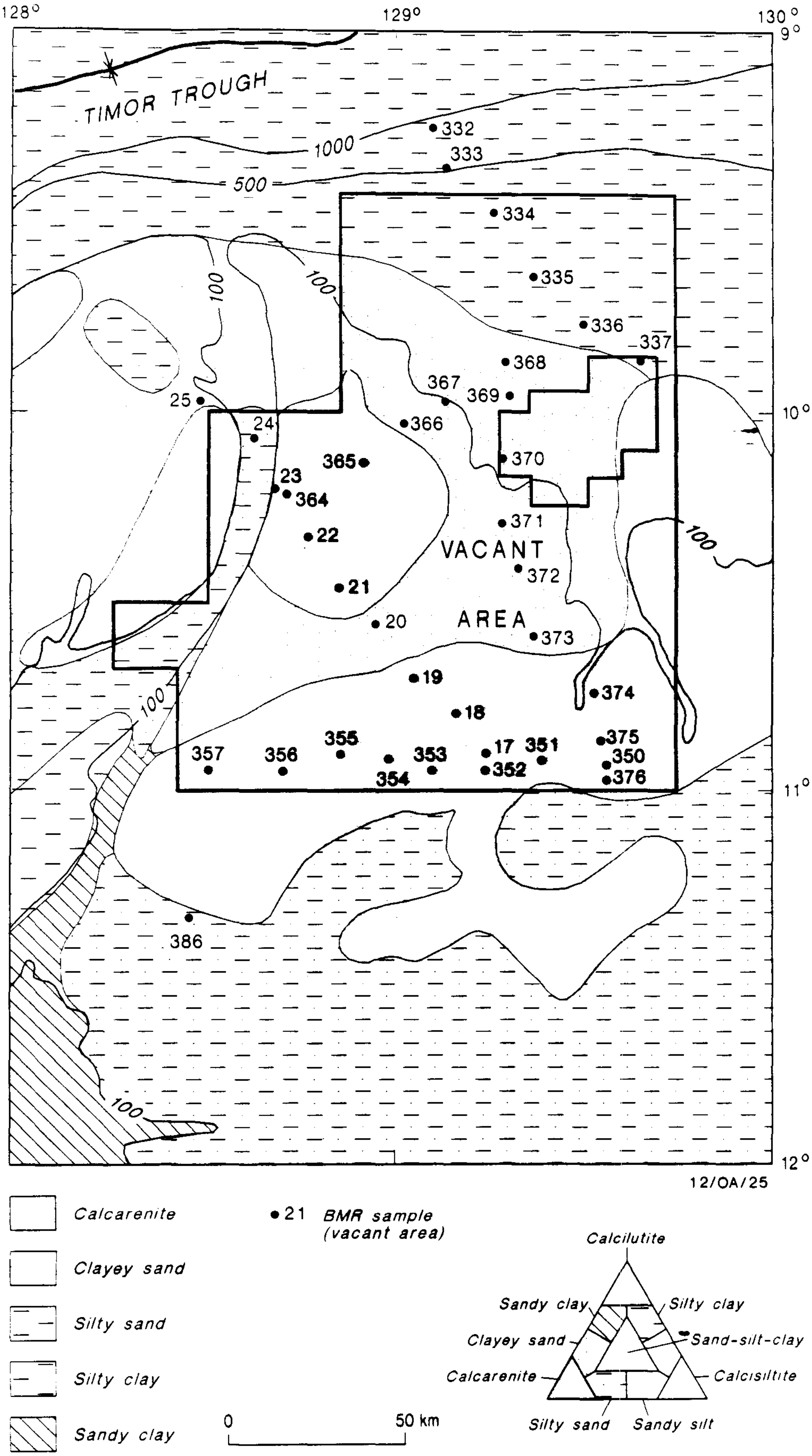

Figure 3 Lithofacies map

suite of calcarenite and calcilutite which are a significant feature of the outer continental shelf in the Timor Sea and parts of the Arafura Sea. The calcarenite is derived from the breakdown of skeletal and algal carbonate material deposited on the shallower and more turbulent banks and rises of the outer shelf. Although such areas are now covered by water depths of the order of 50 metres, the latter feature is due to a Holocene rise in sea level and/or additional local subsidence. Prior to the sea level rise, the shelf area was much narrower and the banks and shoals of the outer shelf were part of an active reef and carbonate bank system which fringed the shelf edge.

Some fine clastic (clay grade) material is deposited from suspension as a result of plumes derived from major river systems which are most active in the monsoon wet season. Analyses of the clay fraction in sediments of the region in which the vacant area is located are reported by van Andel & Veevers (1967). They indicate that the clay fraction is predominantly kaolinite derived from an onshore deeply weathered lateritic hinterland. Organic carbon content in the clay fraction in the region of the vacant area is between 0.75 and 1.00 per cent and may reflect the input from both terrestrial and marine sources. Heavy minerals present in the minor sand fraction of sediments in the region are largely tourmaline and zircon derived from a deeply weathered sedimentary terrain onshore (van Andel & Veevers, 1967).

The coarse fraction of recent sediments deposited in the vacant area is largely skeletal material derived from organisms and processes developed *in situ*, except for remnant features derived from older sequences (van Andel & Veevers, 1967). Smaller foraminifera, algal and coral colonies provide a major source for the remainder of the skeletal remains on the shallowest banks on the Van Diemen Rise and Evans Shoal.

Side scan sonar records obtained prior to drilling of the Evans Shoal No. 1 well (WMC, 1988) indicate that in the vicinity of the vacant area the sea bottom is of the order of 102 to 118 metres deep and comprises unconsolidated carbonate sands. The topography of the sea bottom proximal to the well site is notable for its circular depressions in the order of 10 to 30 metres diameter and 1 to 2 metres deep which are readily evident. In some cases, the edge of these features exhibits a raised outer lip. The interpretation of the origin is subject to conjecture because of the lack of specific information. Fluid release, in the form of biogenic or thermogenic gas, is a possible reason for the development of such features, as is subsurface dewatering of semi-consolidated sediments.

Lithofacies

Sampling from the vacant area was undertaken by van Andel & Veevers (1967) as part of a major regional study of the Timor Sea (Figure 3). The results from approximately 35 sea bottom samples collected and analysed from within and adjacent to the vacant area are graphically displayed in Figure 3.

While the sea bottom sediments of the vacant area are predominantly of sand grade material, much of these are derived from skeletal material. Calcarenites and clayey and silty calcarenites cover the banks, rises and channels of most of the vacant area. The coarsest calcarenites are found on the tops of banks and shelf edge banks. Beyond shelf edge banks, such as Evans Shoal towards the Timor Trough, clay and silt grade material is dominant and is derived from planktonic foraminifera.

Some silty sand is also present on the extensive number of banks landward of (shallower than) the 200 metre depth contour.

Biofacies

Samples of sea bottom sediments were subjected to detailed analysis by van Andel & Veevers (1967). The coarse fraction of all samples in the Timor Sea region, including those collected in and around the vacant area, were examined and classified into major components (particles coarser than 0.062 millimetres). As most of these components are skeletal material, they reflect the remnants of living organisms. Their distribution may reflect the impact of transporting agents as well as the living habitats of the organisms. The major components identified by van Andel & Veevers (1967) are as follows (Figures 4 & 5).

Halimedia were tabulated separately, all other calcareous algae, such as *Lithothamnium* and *Amphipora*, are combined. Larger foraminifera include *Marginopora*, *Heterostegina*, *Amphistogina*, *Cycloclypeus*, *Aveolinella*, *Calcarina*, *Sorites*, Peneroplids, and large Miliolids (van Andel & Veevers, 1967). Smaller foraminifera comprise the remainder. Minor components, such as ostracods, pteropods and crustaceans, are not significant. Lithoclasts comprise calcareous and terrigenous fragments cemented by calcite.

Using the end members identified in the analysis of all samples in the Timor Sea, including those in the vacant area, van Andel & Veevers (1967) used a correlation coefficient to measure positive and negative covariance between the various components (Figure 4). The essential groupings reflect those components which are likely to be found in similar habitats and locations: corals/bryozoans,

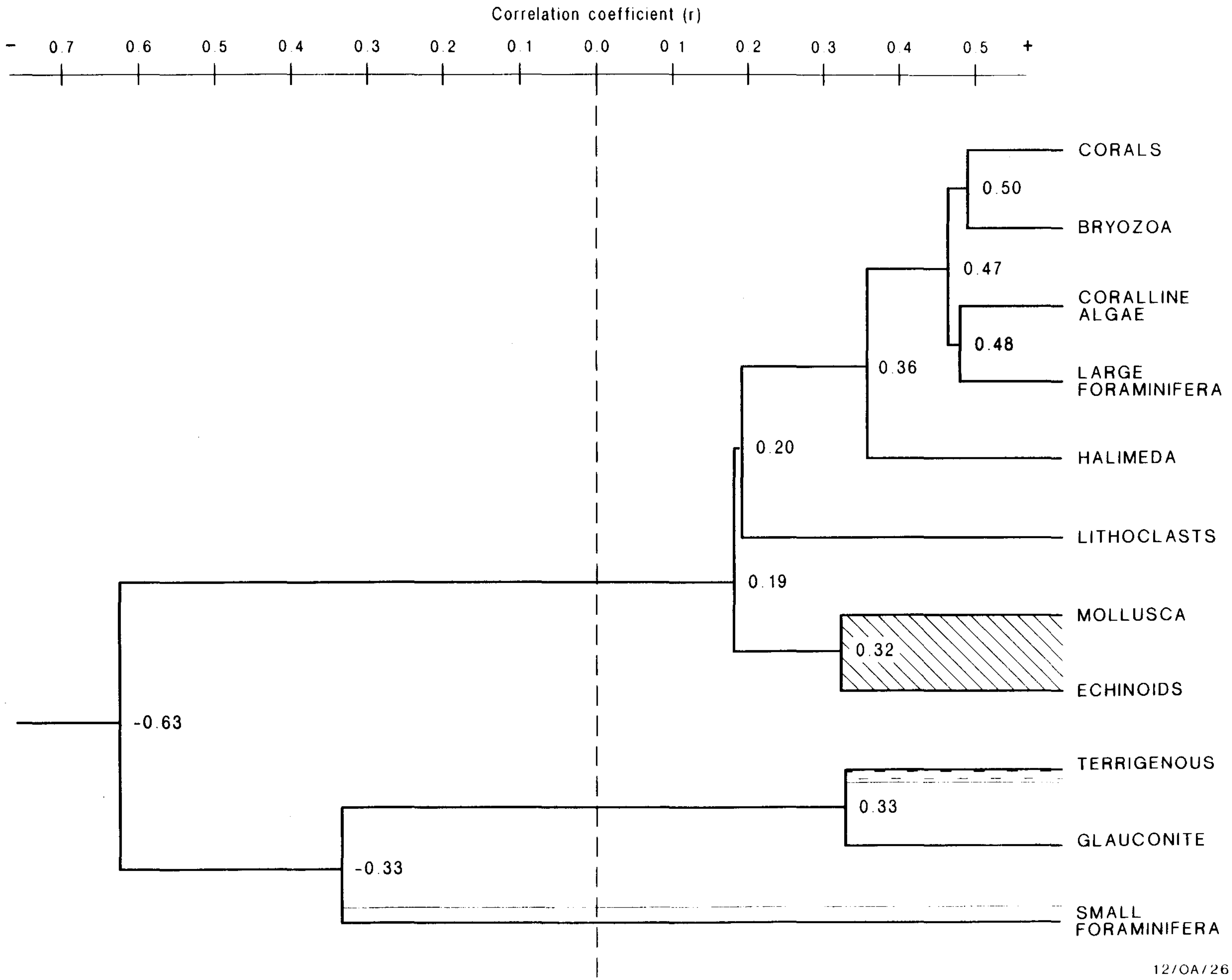

Figure 4 Dendrograph of biofacies associations

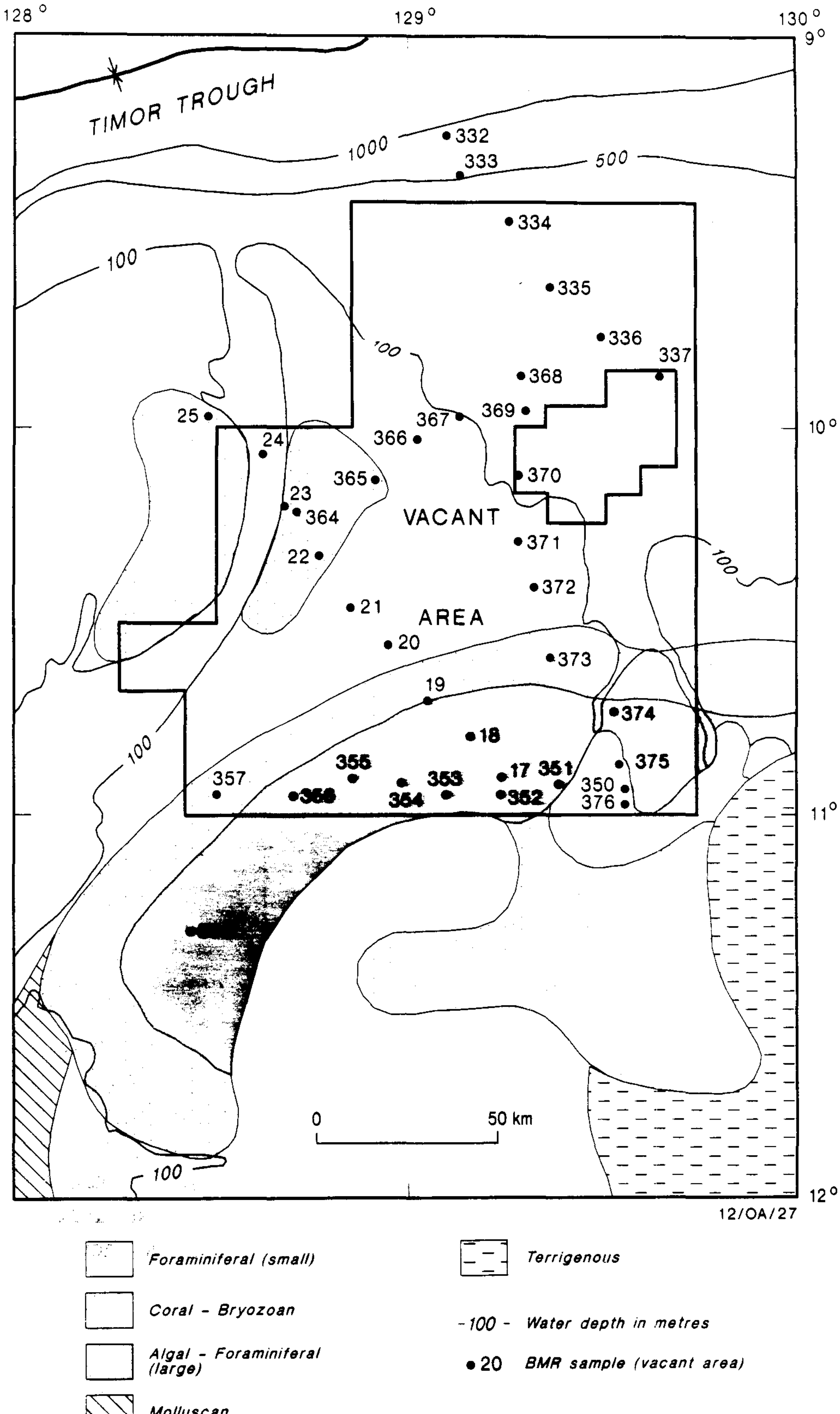

Figure 5 Biofacies map

algae/forams, molluscs/echinoids. In addition, they show those which are not cohabitants, for example, small foraminifera and glauconite/terrigenous versus the remainder. Only the groups with a positive correlation of greater than 0.01 are statistically significant.

The small foraminifera are a regional 'background' biofacies (Figure 5) on which others are superimposed. With increasing distance from shore, there is an increase in the proportion of planktonic forms in this group and they are dominant in the deep waters of the Timor Trough. The molluscan group is dominant in and around the Bonaparte Depression, which was the location of a major Quaternary marine estuarine embayment.

The coral/bryozoan group is present on the banks and rises of the western Sahul Rise (Figure 5) and the Van Diemen Rise although it is limited to the seaward edge of the major groups of banks in the vacant area. The algal/foraminifera (large) group is present on the shallowest and broadest banks of the Van Diemen Rise. The terrigenous end member is limited to an area closest to the coast and it has developed as a result of the input of clastic material from major river systems during the wet season.

In addition to the biofacies evident on the sea floor, other major ecological associations are developed within the terrigenous biofacies including seagrasses and mangroves.

Major ecological features

Mangrove

These are essentially marine tidal forests and are adapted to colonising loose wet soil types which are subject to periodic tidal submergence. On the Northern Territory coastline, conditions favourable to their development are widespread, particularly around coastlines in bays, tidal channels and estuaries. The overall control on the occurrence of mangrove forests is the minimum air temperature, although they are known to range into temperate parts of the Australian coastline (Hatcher & others, 1989). Locally, conditions such as soil salinity, frequency of tidal inundation, sedimentation, rainfall variation and frequency of tropical cyclones, contribute to the richness of tree species in mangroves (Smith & Duke, 1987). There is some debate over whether mangroves are the cause of sediment aggradation and accumulation or the opportunistic consequence of existing sedimentation processes. They are generally regarded as the means of stabilising sediments deposited by the prevailing physical forces rather than the cause of sedimentation.

Optimal conditions for mangrove development are generally present in brackish water areas. The theory that mangroves are important sources of outwelled dissolved nutrients has been challenged by Boto & Wellington (1988) who suggest that no net annual exchange of organic or inorganic nutrients occur in mangroves and that they require a significant import of dissolved phosphorus for growth. They are however important areas for the development of juvenile fish and prawns (*Penaeus merguiensis* in particular) (Staples & others, 1985). Mangroves in Northern Australia have been demonstrated to contain, in order of magnitude, a greater number of juvenile fish and prawn species than adjacent seagrass, bay and estuarine areas (Robertson & Duke, 1987).

Major causes of disturbance to mangroves from human activities are generally those which result in reclamation of intertidal areas for industrial or other uses. The presence of iron pyrite (FeS_2) in the anaerobic subsoil of such areas can render them unsuitable for use in agriculture and aquaculture (Hatcher & others, 1989). There is a very close correlation between the areal extent of mangroves on the Carpentaria coast of the Northern Territory and the size of commercial prawn catches in adjacent coastal waters (Kirkwood & Somers, 1984).

While spillages of crude oil are very rare, and mainly occur as a consequence of maritime transportation mishaps, they can have a significant impact. The effects of these spillages can be cumulative for mangroves exposed to the side effects of high-density maritime traffic. The presence of 2.4 per cent crude oil by weight in the sediments of mangroves has been shown to be sufficient to prove fatal within two months, resulting from the interruption of water supply to the leaves (Allaway, 1987). The speed of recovery is potentially related to the period required to degrade the crude oil.

Seagrass

Seagrass communities develop below the low tide zone and in estuaries, bays and the open ocean into water depths of up to 30 metres. Water clarity is the factor which controls the depths of seagrass development. In turbid water, they grow in very shallow depths due to a low level of light penetration. Their significant effect on the substrate is in binding sediment particles together by means of a fine mat of roots, thus stabilising it. Widely vegetated substrates can reduce the height of storm surges and provide a physical baffle against tidal and current flows (Hatcher & others, 1989). The latter development can encourage the settlement of benthic larvae in areas of sheltered water and thus significantly increase local species diversity. Seagrass communities are known to be present on the coastal fringes of the Timor Sea, Bathurst and Melville Islands, the coastline of the Cox Peninsula and the western part of the Gulf of Carpentaria (Figure 1).

Seagrass communities are also important nursery grounds for juvenile tiger and endeavour prawns which are of major importance in the prawn catch from northern Australia (Poiner & others, 1987). The seagrass communities of the Northern Territory coastline contain similar species to those in the Gulf of Carpentaria and inhabit intertidal to shallow subtidal areas. Species of *Cymodocea*, *Halodule*, *Enhalus*, *Thalassia*, *Syringodidium* and *Halophila* are most commonly present (Poiner & others, 1987). The seagrass assemblages evidently occur in both depth-limited associations along open coastlines as well as mixed-species associations from the intertidal zone. The depth-limited communities tend to be dominated by a single species such as *Syrinodium* sp., *Thalassia testudium* and or *Cyodocea serrulata* (Poiner & others, 1987).

On open coastline areas, monospecific stands of *Halophila ovalis* and *H. uninervis* dominate the intertidal zone, whereas *C. serulata* and *S. isoetifolium* are the major species in the subtidal areas (Poiner, & others, 1987).

The western part of the Gulf of Carpentaria has been closely investigated for the interaction between prawn populations and seagrass communities (Poiner & others, 1987) and the results appear to be applicable to other parts of the Northern Territory coastline. Of the four types of seagrass community in reef-flat, open coastline, sheltered embayment and river mouth areas, juvenile prawns were least well represented in the river mouth area, were most prevalent in the sheltered embayment and were of intermediate numbers in the reef-flat and open coastline areas (Poiner & others, 1987).

Human activities which can most seriously impact on seagrass communities are the dredging and infilling habitat areas. Significant side effects can also develop without direct disturbance because of turbidity or the resuspension of unconsolidated sediments (Hatcher & others, 1989). Increased nutrient levels in runoff from the land surface can also lead to widespread mortality and habitat loss. Even with only mild disturbance habitat, changes can occur and be sufficient to cause a turnover from the more diverse subtidal species assemblage to the hardier intertidal forms.

Reef

In the Arafura and Timor Seas, reefs are evident on shallow banks and the outer shelf edge (van Andel & Veevers, 1967). Coralline algae are the dominant component of these assemblages along with larger formanifera. The dominant coral components are *Halimedia* and the algae *Lithothamnium.*

The dominant feature of both the Timor Sea and Arafura Sea reefs is the remnant nature of reef-related carbonate formation on the outer shelf edge, the site of significant reef-building activity during the Quaternary (lower sea level). As sea level rose during the last 20 000 years B.P., reef-like growth on the outer shelf has generally been unable to keep pace with the rise in sea level, and the focus of reef growth spread landwards onto banks and shoals back towards the present coastline as the influx of clastic material in these areas decreased with greater marine inundation.

Reef development is also patchy because of the additional impact regional subsidence has had causing inundation and the submergence of most sites on the outer shelf edge. Despite the presence of mangrove, seagrass and reef communities in coastal zone and outer shelf areas of the Arafura and Timor Seas, most of the sea bottom on the extensive marine shelf areas consists of unconsolidated sediment inhabited by a limited epifauna and infauna which have been classified into the biofacies shown in Figure 5.

Other elements

Northern Territory coastal waters also support significant commercial and recreational fishing activities including pearl, prawn, fish and algal cultures. While potential disturbance of such activities by petroleum exploration activity to date is not readily evident, future disturbance could readily be avoided. Other significant biological elements such as dugongs, Irrawaddy River dolphins and turtles may be present in areas of the coastal zone where future exploration activity could be located.

Potential effects

Seismic

The initial type of exploration activity likely to occur in any potential release area comprises seismic surveying work. This activity is generally undertaken by the towing of surveying equipment, in the form of a receiver cable and acoustic signal source, along a grid of survey lines sufficient to determine the subsurface geological structure of the region. As the activity is brief and coverage of the region is generally sparse, limited if any environmental effect occurs. The impact of the periodic acoustic signal on fish and invertebrate populations is minimal unless they are within a metre or so of the signal source (Neff & others, 1987). Some concerns have been raised about the disturbance effects of such signals on larger marine mammals at close range (less than 1 kilometre) even though the noise from a seismic source is less than that generated by mammals during periods of vigorous activity.

Noise appears to be the only factor causing any disturbance to normal marine habitats as a result of petroleum industry activity. Under most circumstances, according to Geraci & St. Aubin (1987), marine mammals and vertebrates habituate to low level background noise. The most significant disturbance effects have occurred around the world where such activities are of part of a widespread disturbance of the environment, resulting in subtle changes in environment and habitat (Geraci & St. Aubin, 1987).

Drilling

Exploration drilling involves drilling of a subsurface bore into geological sequences which may contain natural accumulations of petroleum. Purpose-designed vessels are used for drilling. Their anchoring and limited operation provide no long-term impact and only slight local disturbance within a small area. Less than 40 days of operation are generally involved in the drilling of exploration wells and the main initial activity involves the installation of subsurface tubing and associated cementation.

Excavation of the well bore generates cuttings of subsurface rock which are size-sorted and washed prior to discharge to the sea bed where ultimate dispersal by local currents readily occurs. Drilling fluids used to lubricate drill bits, maintain and clean out the well bore generally comprise a mixture of sea water and naturally-occurring clay minerals. Limited amounts of the clay mineral component may be present on the rock cuttings discharged to the sea bed. Limited quantities of fluids such as treated sanitary wastes are also discharged to the sea during such operations, as would take place during any normal maritime operation.

Production

Should the results of exploratory drilling warrant it, fixed or floating structures could be installed to commercially develop any potential hydrocarbon accumulation(s). Development of such accumulations could involve drilling of a number of development wells from drilling/production facilities. Production will usually, in the case of crude oil production, involve the discharge of subsurface water separated from the crude oil into the sea after processing. If full processing is undertaken onboard the offshore facility offloading and transportation are required, otherwise a pipeline connection to shore-based facilities will be installed. The functioning and effects of such operations are beyond the scope of this analysis and the most relevant local guide to their long term effects are production platforms and facilities of the Gippsland Basin in Bass Strait.

Major studies of the ecological impact of production facilities are available for a range of marine habitats. Some ecological changes do occur and these are largely related to artificial reef effects or changes due to the presence on the sea bottom of cuttings. Other changes are subtle and not readily detectable without great sampling effort (Spies, 1987).

Conclusions

The baseline data for environmental conditions in the Timor Sea, including the vacant area in the East Malita Graben area, can be assessed from the BMR study undertaken by van Andel & Veevers (1967). The pattern of lithofacies, biofacies and oceanographic data from the region, collected in 1960-61 before the first seismic (1963+) and drilling (petroleum exploration) activities were undertaken in region (1969-70), provides a usefull reference frame with which any post-exploration patterns can be compared.

From available data, it is evident that the transitory nature of exploration operations is likely to cause minimal localised disturbance from seismic and drilling activities. Cuttings generated during drilling operations are the only significant traces of such work and these are rapidly reworked and removed by normal marine processes.

No visible long-term disturbance effects are anticipated from seismic and drilling activities if the environmental work record of the petroleum industry elsewhere in Australia is maintained in the release area.

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