Bureau of Mineral Resources, Geology & Geophysics

RECORD

Record 1990/17

Research Cruise Proposal : BMR Cruise 95

DISTRIBUTION OF TRIASSIC REEFS IN THE NORTHERN EXMOUTH PLATEAU AND OFFSHORE CANNING BASIN

Project 121.23
BMR Offshore Sedimentary Basins Program

by

N.F. Exon and D.C. Ramsay

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Schedule : April/May 1990

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SUMMARY

Petroleum exploration on the Exmouth Plateau has ceased, although the giant Scarborough Gas Field has been retained by Esso-BHP. Research cruises by BMR's vessel "Rig Seismic" and the associated assessment of other data, indicate that the plateau still has petroleum potential, but the combination of deep water and low oil prices militates against further exploration at present.

However, the Ocean Drilling Program (ODP) core drilling on the Wombat Plateau, in the far north of the Exmouth Plateau area, showed that Rhaetian (Latest Triassic) reefs are present there, one being drilled at Site 764 (Fig. 1). This discovery was the first of a Triassic reef in Australia, and indicates that suitable conditions for reefal development are likely to be widespread on the Northwest Shelf. The existence of Late Triassic reef complexes suggests a new petroleum exploration play, with the reefs forming traps, and lagoonal facies perhaps providing oil source potential. BMR has recently suggested that there is a 50% chance of Triassic reefs hosting 60 million barrels of undiscovered oil on the Northwest Shelf.

BMR's Marine Division intends to assess the potential of such reefs and other known Triassic and Jurassic shelf carbonates in two phases. The first is to map the known reef complexes on the Wombat Plateau, and to see how far they can be extended along the northern margin of the Exmouth Plateau and into the Canning Basin. The second is to take our knowledge of their seismic character, and the best seismic parameters for mapping them, into the outer Bonaparte Basin where Triassic carbonate sequences up to 1000 m thick have been drilled, but no reefs have yet been identified.

The present project makes up the first phase of work, on the northern Exmouth Plateau. It is proposed that a 34 day cruise of "Rig Seismic" be carried out in early 1990. This cruise should result in the acquisition of 2500 km of multichannel seismic profiles on the northern Exmouth Plateau, about 15 dredges aimed at Triassic and Jurassic carbonates, and up to 5 cores. The cruise and its post-cruise follow-up work aim to :

(i) Map the extent of and facies changes within the Triassic/Jurassic carbonates in and south of Wombat Plateau, and in the Rowley Sub-basin of the southwestern Canning Basin, using seismic profiling and dredging techniques.

(ii) Define the extent, character and petroleum potential of any Triassic or Jurassic reefs found.

(iii) Use the cruise results, along with other data, to help assess the petroleum prospects of Mesozoic reef plays elsewhere on the Northwest Shelf.

(iv) Better define the geological history of the northern Exmouth Plateau and the adjacent southwest Canning Basin.

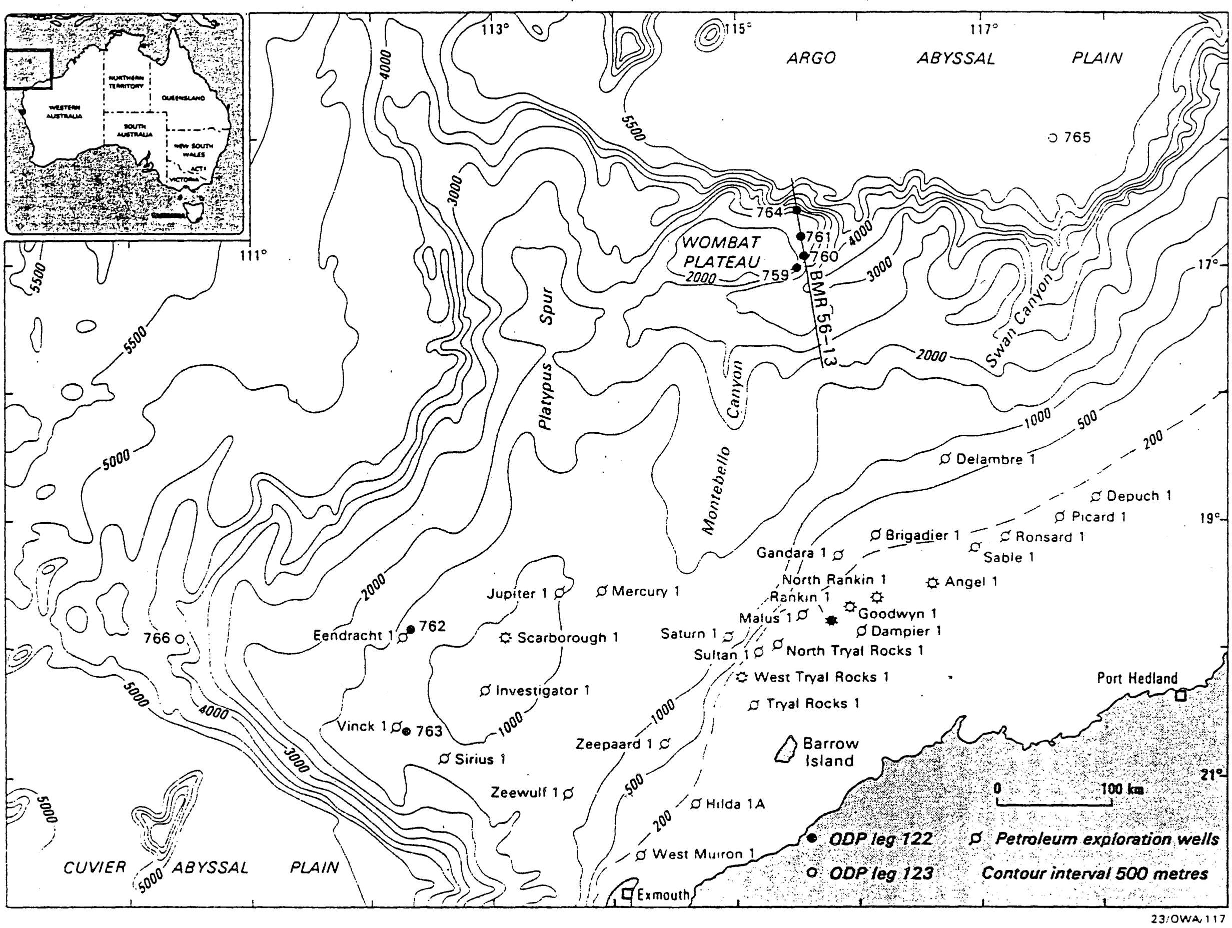


Fig. 1 Map of Exmouth Plateau with bathymetry, and exploration and ODP wells.

INTRODUCTION

The Exmouth Plateau is a marginal plateau lying off northwest Australia (Fig. 1). Water depths range from 800 m to 4000 m, and the area shallower than 2000 m is approximately 150,000 square kilometres. The plateau consists of rifted and deeply subsided continental crust, with a Phanerozoic sedimentary sequence about 10 km thick. It is separated from the Northwest Shelf by the Kangaroo Syncline, and is bounded to the north, west, and south by oceanic crust.

The plateau was first studied by BMR in the period 1974-1979, using 18,000 km of seismic profiles and some sample information, and results of the study were published, starting with Willcox & Exon (1976) and ending with von Rad & Exon (1983). The large fault blocks in the rifted Triassic and earliest Jurassic sequences, and the very large areal closures in the overlying Jurassic and Cretaceous sequences, encouraged petroleum exploration in the late 1970s and early 1980s. Some 30,000 km of high-quality multichannel seismic data were collected, and 14 exploration wells were drilled. The rifted section was shown to be largely gas-prone, and the overlying section to be largely immature. These results and the deep water over the plateau caused relinquishment of permits, except in the area surrounding the large Scarborough gas field discovered by Esso-BHP.

Because of the need to increase knowledge of this huge plateau, and to attempt to stimulate a second round of petroleum exploration over the plateau, BMR's Marine Division designed a three-phase research program for the plateau. The first phase was a short heatflow cruise, designed to ascertain present-day thermal gradients and hence maturation levels (Choi, Stagg et al., 1987). The second phase was a two-ship crustal structure study carried out with Lamont-Doherty Geological Observatory (Williamson, Falvey et al., 1988). The third phase was a study of the northern and western margins of the plateau, using conventional geophysical and sampling methods, and included site surveys for proposed Ocean Drilling Program (ODP) drill holes (Exon, Williamson et al., 1988).

ODP Leg 122 drilled six holes on the plateau (Haq, von Rad et al., 1988). Leg 123 drilled 2 holes, one on the Argo Abyssal Plain, and one on the lower slope of the western Exmouth Plateau (Gradstein, Ludden et al., 1989). The ODP Sites are located in Figure 1. A major discovery was that Triassic reefs are present in Rhaetian shelf carbonates on the Wombat Plateau (Williamson et al., 1988; Exon et al., 1989). This is the first time reefs of this age have been found in Australia, and potentially it adds a new petroleum exploration play on the Northwest Shelf. A recent BMR assessment of the petroleum potential of such reefs suggests that there is a 50% chance of there being 60 million barrels of undiscovered oil in Triassic reefs on the Northwest Shelf (BMR Research Newsletter 11).

This discovery is what has led us to plan the present cruise to the Wombat Plateau region, in order to better understand the nature of the reefs, and their extent, and to see whether they can be traced into shallower water to the south and east.

REGIONAL GEOLOGY

The regional setting and physiography of the Exmouth Plateau is shown in Fig. 1. The plateau is a continental block bounded on the north, west and south by oceanic crust forming the Argo, Gascoyne and Cuvier Abyssal Plains. The Canning and Carnarvon Basin sediments extend over the plateau from the east and abut the Pilbara Precambrian block. Pre-breakup, rift phase deposition has been identified on the plateau and beneath the shelf to the east. The known stratigraphic sequences in the region are summarized in Figure 2.

Tectonic Framework

The geological development of the Exmouth Plateau has been discussed by Falvey and Veevers (1974), Veevers and Johnstone (1974), Powell (1976), Willcox and Exon (1976), Exon and Willcox (1978, 1980), Veevers and Cotterill (1979), Wright and Wheatley (1979), von Stackelberg et al. (1980), von Rad and Exon (1983), Barber (1982, 1988), Exon, Williamson et al. (1988), and Haq, von Rad et al. (in press). The three margins abutting oceanic crust were compared and contrasted by Exon and others (1982).

The present structural configuration of the Exmouth Plateau region was initiated by rifting in Triassic to Middle Jurassic times prior to seafloor spreading. The western margin has a normal rifted structure and the southern margin has a transform dominated structure. The complex northern rifted margin contains at least one crustal block of post-breakup igneous origin.

The northern Exmouth-Wombat Plateau area experienced major deep crustal extension and thinning during the Permian, and this was followed by rifting in the Triassic (Carnian/Norian; ODP Sites 759, 760) and Jurassic time. Igneous intrusions and extrusions accompanied pre-Norian and post-Rhaetian deposition, and Jurassic block faulting separated the Wombat Plateau from the Exmouth Plateau by formation of steep south-facing escarpments. The results of ODP Leg 123 (Gradstein, Ludden et al., 1989) showed that the northern margin of the plateau (Figs. 1 & 3) formed in the Berriasian (140 m.y. ago), when seafloor spreading commenced in the Argo Abyssal Plain. The northeast-trending seafloor spreading anomaly pattern was initially described by Falvey (1972a), and magnetic lineations were most recently mapped by Fullerton et al. (1989).

Throughout the Triassic and Jurassic, pre-breakup rift tectonics affected the entire Australian western margin (Falvey and Mutter, 1981). Steady subsidence along the incipient northern Exmouth margin, north of an east-west hinge line, allowed several thousand metres of Upper Triassic deltaic sediments, Rhaetian carbonates, and Lower and Middle Jurassic carbonates and coal measures to accumulate before breakup (Exon et al., 1982; Haq, von Rad et al., in press). Breakup occurred along a series of rifted and sheared margin segments, complicated by northeast trending Jurassic horsts and grabens. The horsts were planed off in Late Jurassic and Early Cretaceous times, and the whole northern margin was covered by a few hundred metres of Upper Cretaceous and Cainozoic pelagic carbonates as it subsided steadily to its present average depth of 2000-5000 m. The history of the Rowley Sub-basin, east of the Swan Canyon, appears to have been very similar to that of the northern Exmouth margin.

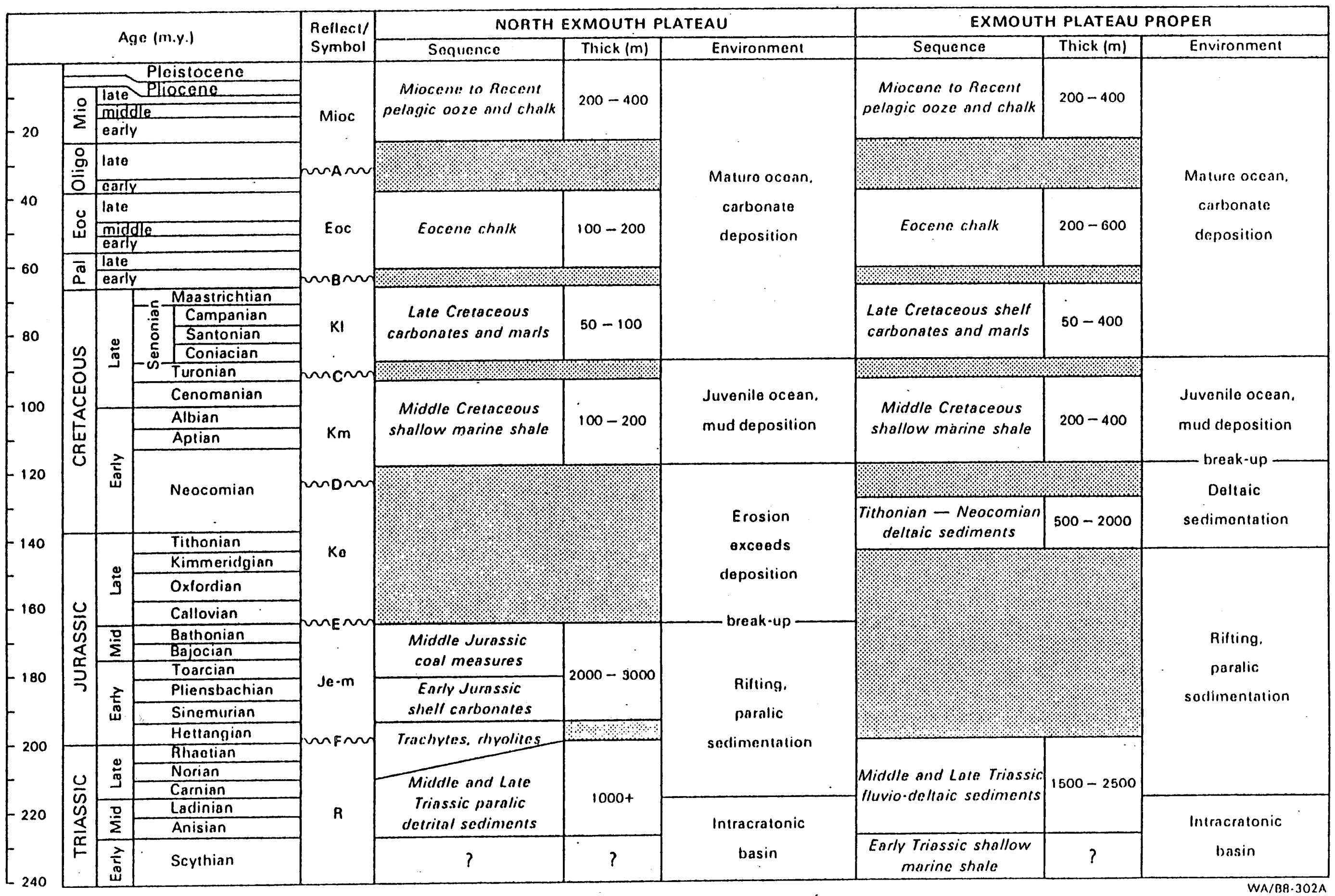


Figure 2. Simplified stratigraphy of the Exmouth Plateau.

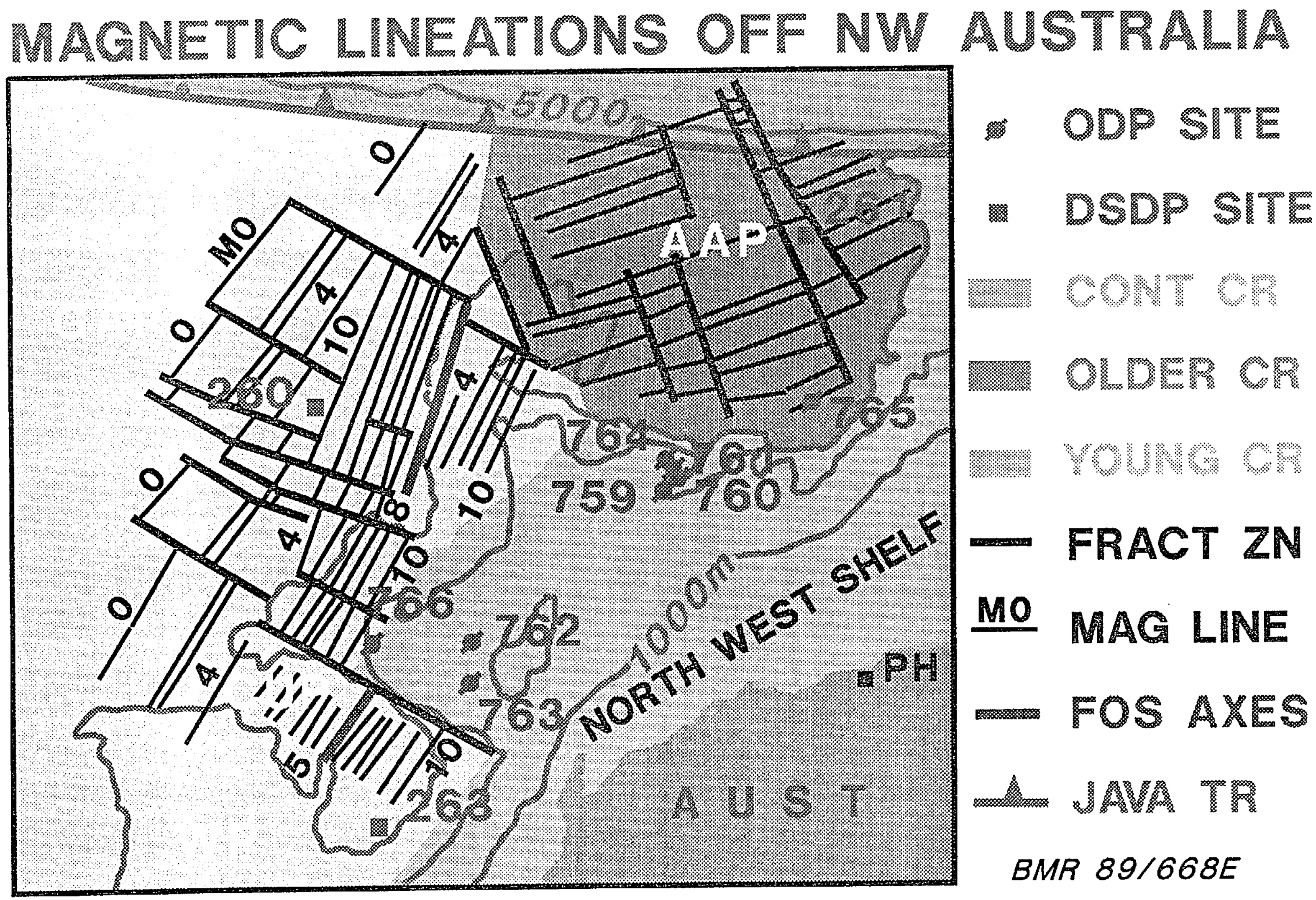


Fig. 3 Seafloor spreading lineations around the Exmouth Plateau, modified after Fullerton et al. (1989). Later ODP drilling indicates that seafloor spreading on the Argo Abyssal Plain began in the Berriasian, and in the Gascoyne Abyssal Plain in the late Valanginian. Thus, despite the different orientation of spreading, the age of breakup in the two basins may be as little as 5 m.y. different.

The northeast-trending western margin of the Plateau (Figs. 1 & 3) formed by breakup in the latest Valanginian approximately 134 m.y. ago, as "Greater India" moved off to the northwest, and seafloor spreading anomalies started to form in the Gascoyne Abyssal Plain (Gradstein, Ludden et al., 1989). The northeast trending seafloor spreading magnetic anomaly pattern of this and the Cuvier Abyssal Plain was recently described by Fullerton et al. (1989). On the western margin of the Exmouth Plateau, normal faults parallel the margin. A thick Triassic paralic sequence is unconformably overlain by a thin, Upper Jurassic marine sequence indicating that the area was high in the Early and Middle Jurassic. Thin Upper Cretaceous and Cainozoic pelagic carbonates cover the western margin, which now lies more than 2000 m below sealevel.

The northwest-trending southern margin of the Plateau (Figs. 1 & 3) formed along an incipient transform in the Neocomian, about the same time as the western margin (Exon et al., 1982). It is cut by northeast trending normal faults, which formed in the Late Triassic and Callovian, and is paralleled by Neocomian and later normal faults. A thick Triassic paralic sequence is unconformably overlain by a thick Upper Jurassic and Neocomian delta. This suggests that the area was high in the Early and Middle Jurassic, but a depocentre before and afterwards. There was thermal uplift of more than 1000 m during the Neocomian. Igneous intrusions buttress the margin. Later normal faulting lowered the outermost margin, and turned the uplift into a marginal anticline trending northwest. The anticline had sunk beneath the sea by late in the Cretaceous, and thereafter this margin was covered by a thin sequence of pelagic carbonates, which now lie at a water depth of 1500 m.

Stratigraphy

The stratigraphy of the Exmouth Plateau is sketched in Fig. 2. Sediment starvation has led to a greatly reduced post-breakup sequence. Thus, seismic profiling and drilling have been able to penetrate well into the pre-breakup sequence and resolve early stages of margin evolution (von Rad and Exon, 1983). Fourteen petroleum wells have been drilled and results from Phillips Jupiter No. 1, Saturn No. 1 and Mercury No. 1 have been published (Barber, 1982). Stratigraphic studies have been carried out by von Stackelberg and others (1980), Colwell and von Stackelberg (1981), Barber (1988), and von Rad and Exon (1983), and palaeontological studies by Quilty (1980, 1981, in press) and Zobel (1984). Seismic control consists of 12,000 km of data from the 1972 BMR continental margin survey, 9300 km of GSI seismic data collected in 1976 and 1977 (Wright and Wheatley, 1979), 30,000 kms of subsequent petroleum industry seismic data, 1450 km of wide angle common-depth-point data (Williamson and Falvey, 1988), and 2100 km of conventional seismic data (Exon, Williamson, et al., 1988).

Interpretation of seismic profiles indicates that up to 5000 m of Paleozoic strata and 5000 m of younger strata overlie basement. The sediments have been gently folded, and the pre-breakup section is affected by northeast trending faults.

The sediments beneath Exmouth Plateau are considered to have been deposited in an extension of the Carnarvon Basin, part of the Westralian Superbasin. This formed a north-facing Tethyan embayment in

Gondwanaland and received detrital sediments from the south until early Cretaceous time. In the central Plateau region, at least 3000 m of mainly paralic and shallow marine detrital sediments were deposited from Permian to Middle Jurassic times. After the Late Triassic rifting, about 1000 m of shallow marine and deltaic detrital sediments, derived from the south and east, covered the block-faulted surface in Late Jurassic and Early Cretaceous times. About 200 m of terrigenous marine sediment was deposited in the Middle Cretaceous, and 500 to 1000 m of carbonate sediment in the Late Cretaceous and Cainozoic. The Exmouth Plateau Arch and Kangaroo Syncline probably warped to their present form in the Miocene (Exon and Willcox, 1978, 1980), by which time the central Plateau had subsided to bathyal depths (Barber, 1982, 1988). On the northern margin there are Early Jurassic shelf carbonates and Middle Jurassic coal measure sequences in the Swan Canyon region, perhaps 2000-3000 m thick in total (von Stackelberg and others, 1981, Exon and Williamson, 1989). On the Wombat Plateau, ODP drilling showed that there is a thick Late Triassic deltaic and carbonate sequence (Haq, von Rad et al., in press).

The Rowley Sub-basin, which forms the southwestern corner of the Canning Basin, was reviewed by Stagg and Exon (1981). The sub-basin is an ENE trending, mainly Mesozoic basin connecting with the Beagle Sub-basin to the southwest. It is separated from the Bedout Sub-basin to the southeast by the Bedout High. The Sub-basin contains thick Cainozoic, Cretaceous, Jurassic and Triassic sedimentary sequences, with major unconformities of latest Triassic and approximately Callovian age. The central part of the sub-basin is structurally simple but its margins are complex, being both faulted and gently folded - especially beneath the Cretaceous sequence.

Petroleum Exploration

In the mid 1970's the Exmouth Plateau was regarded as having considerable petroleum potential. Reconnaissance surveys shot in the 1970's revealed the presence of large fault-bounded structures (Willcox and Exon, 1976; Exon and Willcox, 1978; Wright and Wheatley, 1979) and the close proximity of major hydrocarbon accumulations on the Northwest Shelf and at Barrow Island in the Carnarvon Basin encouraged optimism. Five exploration permits divided up the Plateau in 1977, much seismic data was recorded, and 14 exploration wells were drilled in the central and southern areas (Fig. 4). Several non-commercial gas shows were encountered as well as the Scarborough gas discovery that has been retained by Esso-BHP.

Early exploration concepts involved generation of oil from Upper Jurassic and Neocomian shales in the Kangaroo Syncline and subsequent migration into the Jurassic and Triassic tilted fault blocks on the Exmouth Plateau Arch. The lack of liquid hydrocarbons was attributed to unfavourable source rocks, unsuitable burial history and a low palaeo-thermal gradient. For three wells (Phillips Saturn No. 1 , Jupiter No. 1 and Mercury No. 1) Upper Triasssic, Jurassic and Cretaceous sections were found to be immature and incapable of generating hydrocarbons. Most hydrocarbons so far encountered on the Exmouth Plateau are thought to have originated from deep (5 km or more) overmature gas source rocks, probably Lower Triassic and Permian shales, by deep tapping of source beds along faults bounding the tilted block structures, enabling the gas to migrate upwards (Barber, 1982).

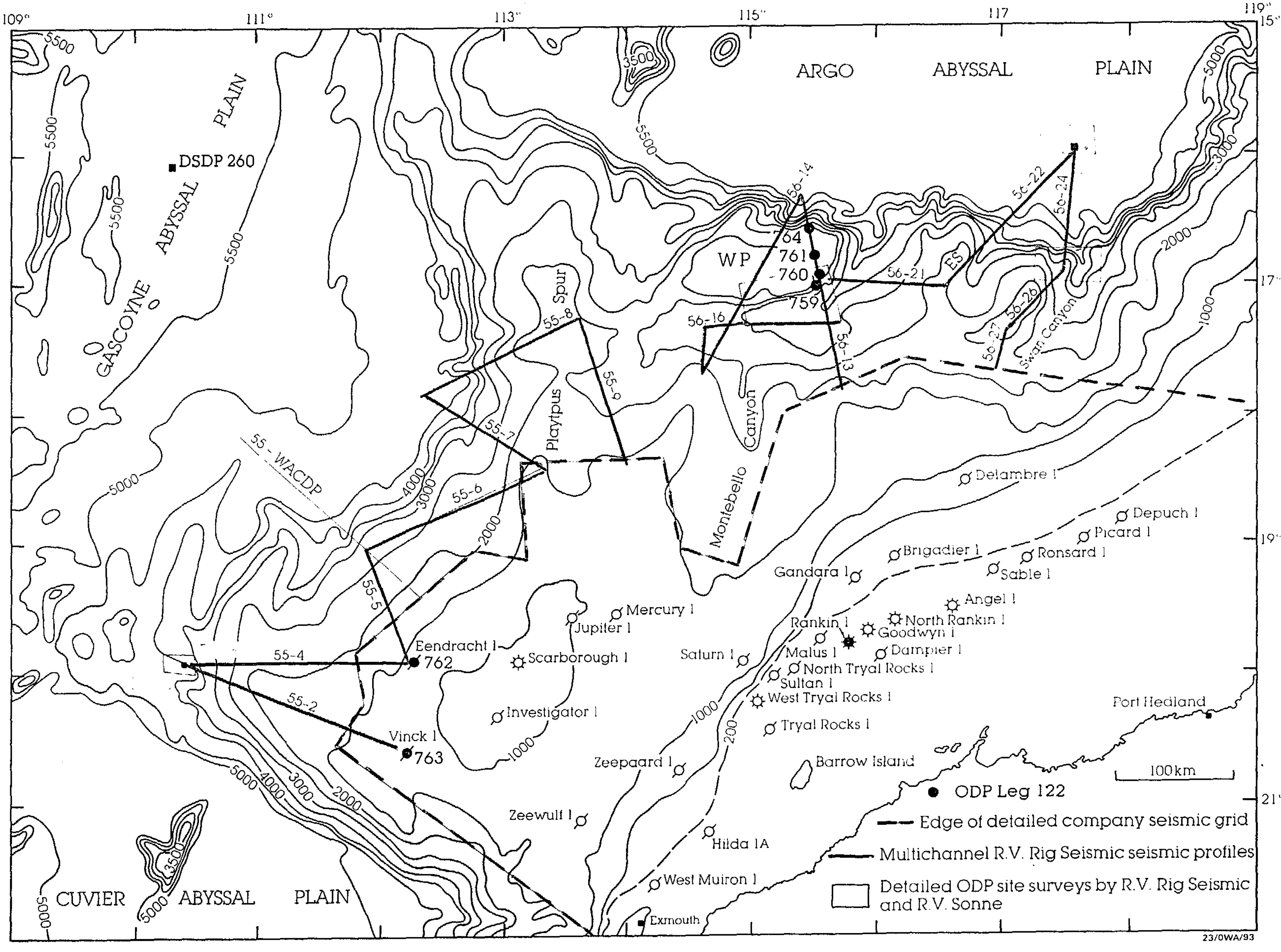


Fig. 4 Map of Exmouth Plateau showing area of detailed seismic coverage, and BMR tie lines to ODP sites. Bathymetry in metres.

The lack of success in finding oil in the major Exmouth Plateau structures has resulted in the dropping of all except part of one permit and the cessation of petroleum exploration on the plateau. Future petroleum exploration interest would appear to depend on demonstrating a marine oil-prone source at mature depths, either in Jurassic graben-fill sediments in the Kangaroo Syncline or local grabens, or in Triassic and Permian pre-rift sediments on the western or northern margins of the plateau, along with suitably located trapping structures.

Williamson et al. (1989) reported the discovery of a Triassic reef in ODP Site 764, the first found in Australia, and put together a Late Triassic palaeogeographic map (Fig. 5), which suggested that such reefs could be extensive on the outer Northwest Shelf. If they are, they could provide a new exploration play. BMR's resource assessment group has estimated since that there is a 50% chance of Triassic reefs hosting 60 million barrels of oil on the Northwest Shelf.

There has been little petroleum exploration in the Rowley Sub-basin, and the deepwater part of the sub-basin (northwest of the Rowley Shoals) is covered only sparsely by seismic surveys. Two wells have been drilled in the deepwater sub-basin, Shell East Mermaid No. 1 in 1973 and Woodside Barcoo No. 1 in 1980. East Mermaid No. 1 penetrated about 1250 m of Cainozoic carbonates, 120 m of Senonian-Maastrichtian shelf carbonates, 180 m of Albian-Cenomanian shelf mudstone and marl, 1000 m of Neocomian-Aptian shelf mudstone, and more than 1200 m of Jurassic deltaic mudstone and sandstone. Minor gas indications were present in the Jurassic sequence.

Barcoo No. 1 penetrated nearly 1600 m of Cainozoic carbonates, 300 m of Turonian-Maastrichtian shelf carbonates, 300 m of Turonian-Maastrichtian shelf carbonates, 800 m of Neocomian to Cenomanian shelf mudstone, 950 m of Jurassic deltaic mudstone, 100 m of Rhaetian deltaic mudstone, and 260 m of Rhaetian shelf limestone and mudstone. Minor gas indications were found in the Cretaceous, Jurassic and Triassic sequences. The well found several sandstone sequences with good porosity and permeability in the Mesozoic sequence, and thick Lower Jurassic claystones that are potential source rocks.

In 1987 and 1988, the Japanese National Oil Corporation carried out regional seismic surveys in the Canning Basin, shoreward of the Rowley Shoals, recording more than 11,000 km of seismic reflection profiles. These profiles tied most of the offshore wells in the Canning Basin, but not Barcoo No. 1.

THE NORTHERN EXMOUTH PLATEAU STUDY AREA

The discovery by ODP of the first Rhaetian reef facies in Australia (Williamson et al., 1989) points to the possibility of Late Triassic and Early Jurassic reef targets in shallower water. It was decided to limit the first survey for more reefs to the area defined by well data as being prospective (Fig. 5). A practical study area includes the known reef in Site 764, and extends eastward to 119° E, and southward to Delambre No. 1 well, which contains some Early Jurassic carbonates. The present survey will investigate Triassic/Jurassic carbonate facies by seismic profiling and sampling.

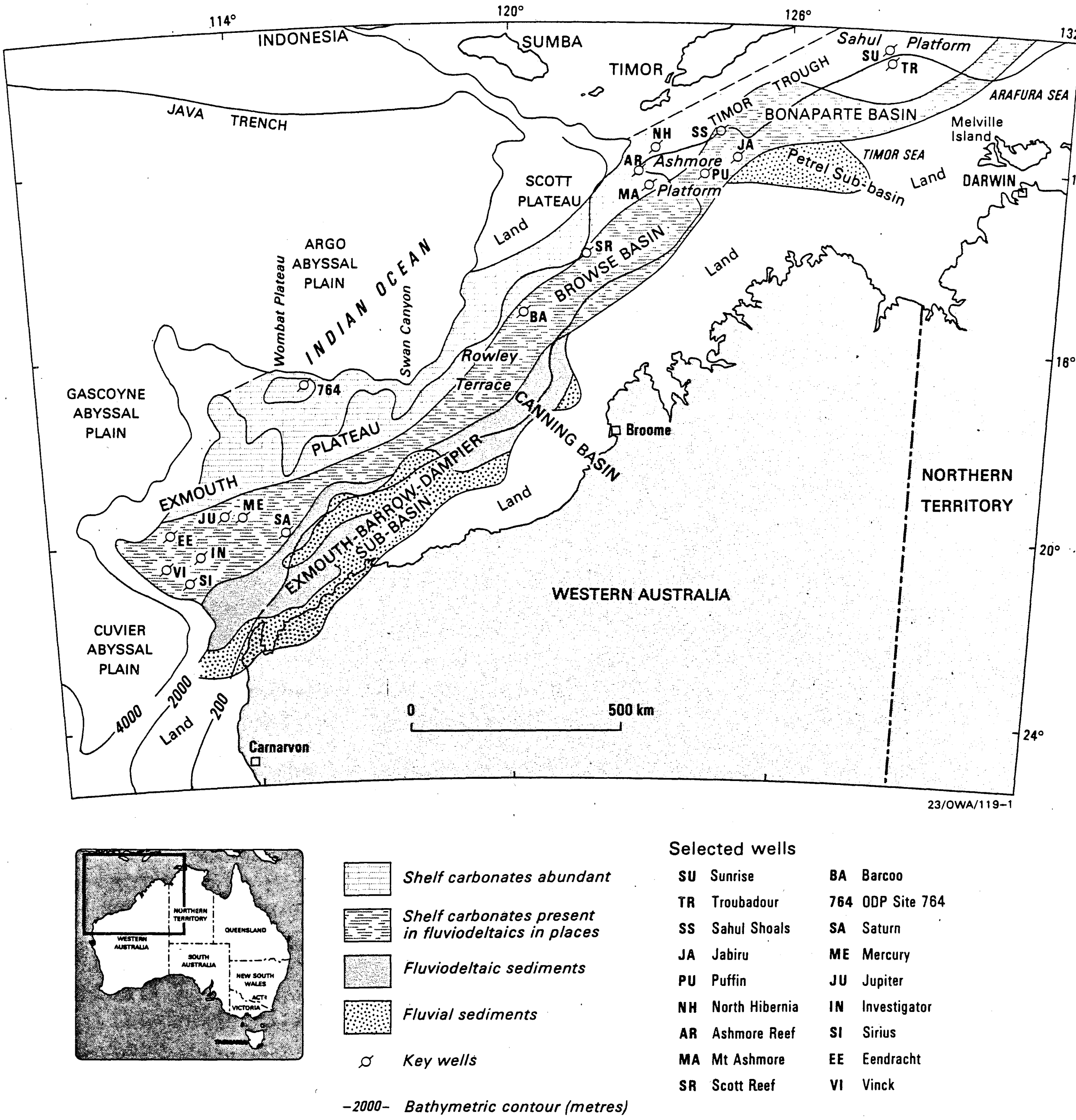


Fig. 5 Map of Northwest Shelf, showing Late Triassic sedimentation patterns derived from well information.

Seismic and dredging studies

Key studies of the northern Exmouth Plateau area were carried out by :

1. BMR in the period 1974-1978, using regional seismic data and well ties (Willcox & Exon 1976; Exon & Willcox, 1978, 1980).

2. BGR and BMR in the period 1979-1983, using new dredge and core information gathered by R.V. "Sonne" to upgrade the earlier interpretations (von Stackelberg et al., 1980; Exon et al., 1982; von Rad & Exon, 1983).

3. BMR in 1986-1988, using new dredge and multichannel seismic data gathered by R.V. "Rig Seismic" in 1986 (Exon, Williamson et al., 1988).

The 1974-1978 studies indicated that :

Adjacent to the northern margin of the Exmouth Plateau is a complex of horsts and grabens produced by vertical movements along northeast and east-striking faults. Displacements on individual faults of either trend exceed 1000 m in places. Closely-spaced faults have caused a total displacement of the order of 2500 m down the lower continental slope. Gravity modelling indicates that the crust thins abruptly under the lower continental slope, which is consistent with the interpretation that it developed by transform faulting.

Several small subplateaux in water depths of 1600 to 2300 m coincide with the horst blocks and were once part of the Exmouth Plateau. The largest, the Wombat Plateau (Fig. 1), covers an area of about 3500 km^2. Identification of seismic horizons in the northern area is impeded by lack of continuity between the subplateaux across the grabens which separate them, and between the subplateaux and the Exmouth Plateau proper.

In general, the northern margin of the plateau is downwarped along the extensively faulted North Exmouth Hinge Zone, which is made up of numerous blocks down-faulted northward or northwestward into a series of half-grabens. The subplateaux which separate the half-grabens from Argo Abyssal Plain were believed to be largely composed of west-dipping Triassic and Palaeozoic strata (pre-Horizon F), beneath nearly horizontal Mesozoic and Cainozoic strata, and buttressed against collapse by igneous intrusions along their northern edges.

The deepest reflector identified on the seismic profiles, Horizon G, was correlated with the Late Permian. It is an extensively faulted horizon which on Echidna Spur lies 4000 m below sea level beneath an overburden of about 1800 m, and in the adjacent graben lies 6600 m below sea level beneath an overburden of about 3600 m.

On Emu and Echidna Spurs, west of the Swan Canyon, Mesozoic strata appeared to lie beneath a wavecut platform upon which post-Miocene carbonates had been deposited. This area was thought to have been structurally high throughout the Cretaceous and Early Cainozoic, or to have been uplifted and stripped of sediment during final formation of the Exmouth Plateau Arch in the early Miocene. A well-defined magnetic anomaly trough corresponds with the half-graben south of the Wombat

Plateau and extends eastwards along the northern margin of the Exmouth Plateau. The trough is due in part to the negative anomalies of large dipolar fields associated with elevated basement blocks to the north, but its linearity suggests that there may also be a contribution from a deepseated structural trough. This trough could be a westerly extension of the Fitzroy Trough in the northern Canning Basin. North-south offsets of the magnetic anomaly trough on meridians $115^{\circ}30'$, $116^{\circ}30'$, and $117^{\circ}00'$E are reminiscent of transcurrent faults.

The 1979-1983 studies led to some changes in the above ideas. Von Stackelberg et al. (1980) reported the results of 18 dredge hauls from the outer slopes of the northern margin. More than half contained Jurassic and Triassic prebreakup shallow water sediments. Four dredges from the north also contained intermediate to acid volcanics dated at about the time of rift onset (Triassic-Jurassic boundary). This suggests limited continental crustal anatexis very near to the incipient continent-ocean boundary. These data also indicate that it is not valid to interpret the occurrence of volcanics on a marginal plateau slope as definitive evidence of non-continental crustal structure, either in whole or in part (Falvey and Mutter, 1981).

The main results of these studies were to provide the vital rocks with which the interpretations of seismic profiles could be controlled, and a firmly-based geological history was developed. In the Swan Canyon area in the northeast (Figs. 1, 6 and 7), the "Sonne" results showed that a thick, dipping Jurassic sequence underlaid the almost planar main unconformity in the Emu Spur and Echidna Spur regions. This consisted largely of Early and Middle Jurassic shelf carbonates and coal measures. A thin sequence of younger rocks rested on the unconformity, and thin Cretaceous rocks were probably below it in places.

In the Wombat Plateau region (Figs. 1, 8 & 9), the same main unconformity was apparently underlaid by thick Late Triassic detrital sediments, Early Jurassic shelf carbonates, and Triassic/Jurassic volcanics. It was mistakenly assumed that a thick Jurassic sequence rested on the Triassic sequence (as was indeed the case in the Emu and Echidna Spurs), and that a Cretaceous sequence also underlaid the main unconformity in places. A thin Cainozoic sequence rested on the unconformity.

The 1986-88 studies built on the earlier results, but led to no major changes in ideas. In the northern part of the plateau a series of regional multichannel seismic profiles were run by "Rig Seismic", as well as ODP site surveys, and 16 dredge hauls were obtained (Fig. 10A). The dredge hauls are located more accurately in Figures 6 and 8, and the results are summarized in Figures 7 and 9.

Petroleum exploration activities

Petroleum exploration started on the Exmouth Plateau with GSI multichannel seismic group shoots in 1976 and 1977, some of which were interpreted by Wright and Wheatley (1979). The northern limit of these data is indicated in Figure 4. A lease in the northern part of the plateau was held by a consortium headed by Hudbay Exploration Co., and one in the central Exmouth Plateau by Phillips Petroleum Co. Six wells were drilled of relevance to the present study : Delambre, Brigadier,

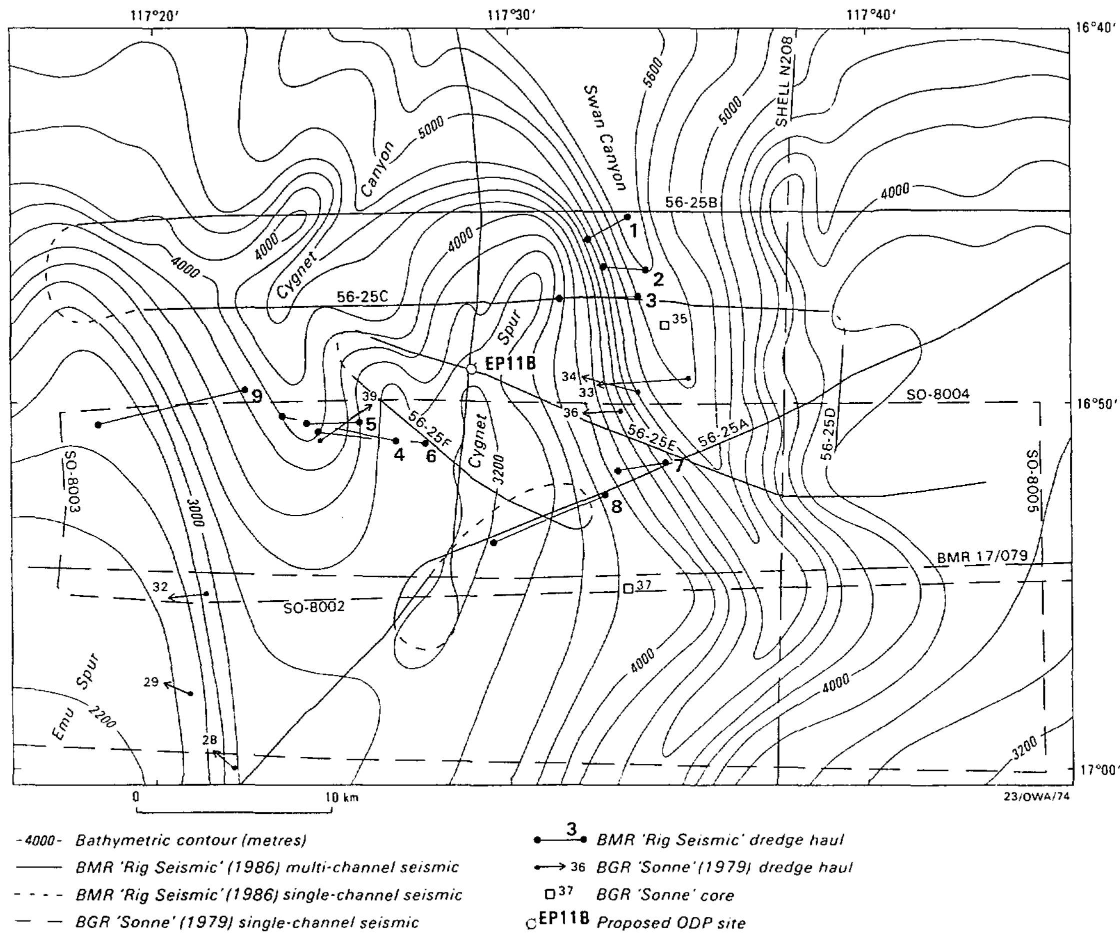
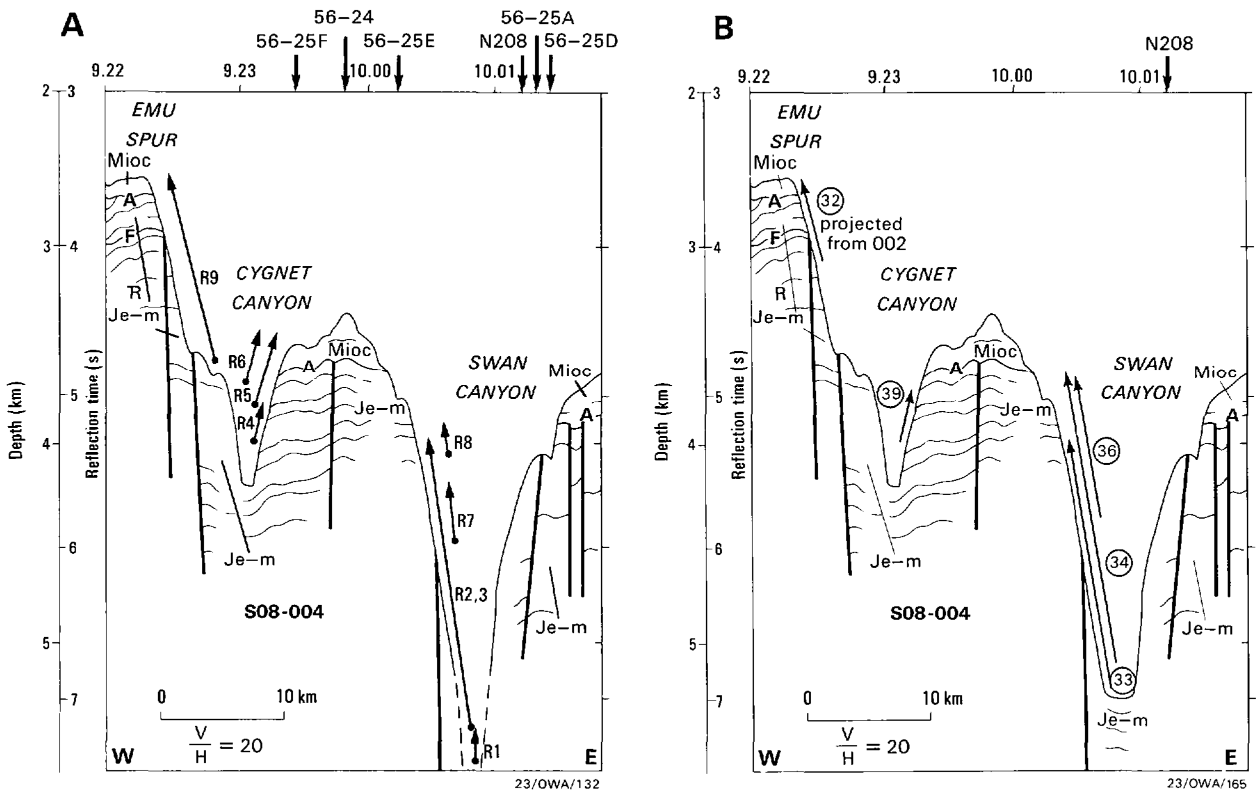


Fig. 6 Map of Swan Canyon area on northeastern margin of Exmouth Plateau, showing bathymetry and "Sonne" and "Rig Seismic" sampling locations.

Fig. 7 Dredge locations in the Swan Canyon area transposed onto "Sonne" seismic profile 8-004, east-west across the region. Summarizes pre-Cainozoic rock types recovered. Seismic reflectors as in Figure 2.



Swan Canyon

R1: ? Jurassic coal measures (A2,3,4); ? Cretaceous marine clay (D3)
R2: Callovian coal measures (A2,3,4); ? Cretaceous marly clay (D2)
R3: ? Jurassic coal measures (A2,3,4)
R7: ? Early Cretaceous marine shale, sandstone (D3,4,6)
R8: ? Jurassic ironstone (B1,2,5); ? Cretaceous marine claystone, sandstone (D3,4,6)

Cygnet Canyon

R4: Callovian shelf carbonates (C2,3,4,8); ? Jurassic coal measures (A2) and ironstone (B1,2,3); ? Cretaceous marine claystone (D5)
R5: ? Jurassic coal measures (A2) and ironstone (B3)
R6: ? Jurassic ironstone (B3); Late Aptian and Cenomanian marine mudstone, sandstone, conglomerate (D2,4,6)
R9: ? Oxfordian shelf carbonates (C1,3,4); ? Cretaceous marine sandstone, mudstone (D2,4,6,7)

32 E1 (Middle Miocene chalk): A2,3 (? Jurassic coal measures); C1,2 (? Jurassic shelf carbonates)

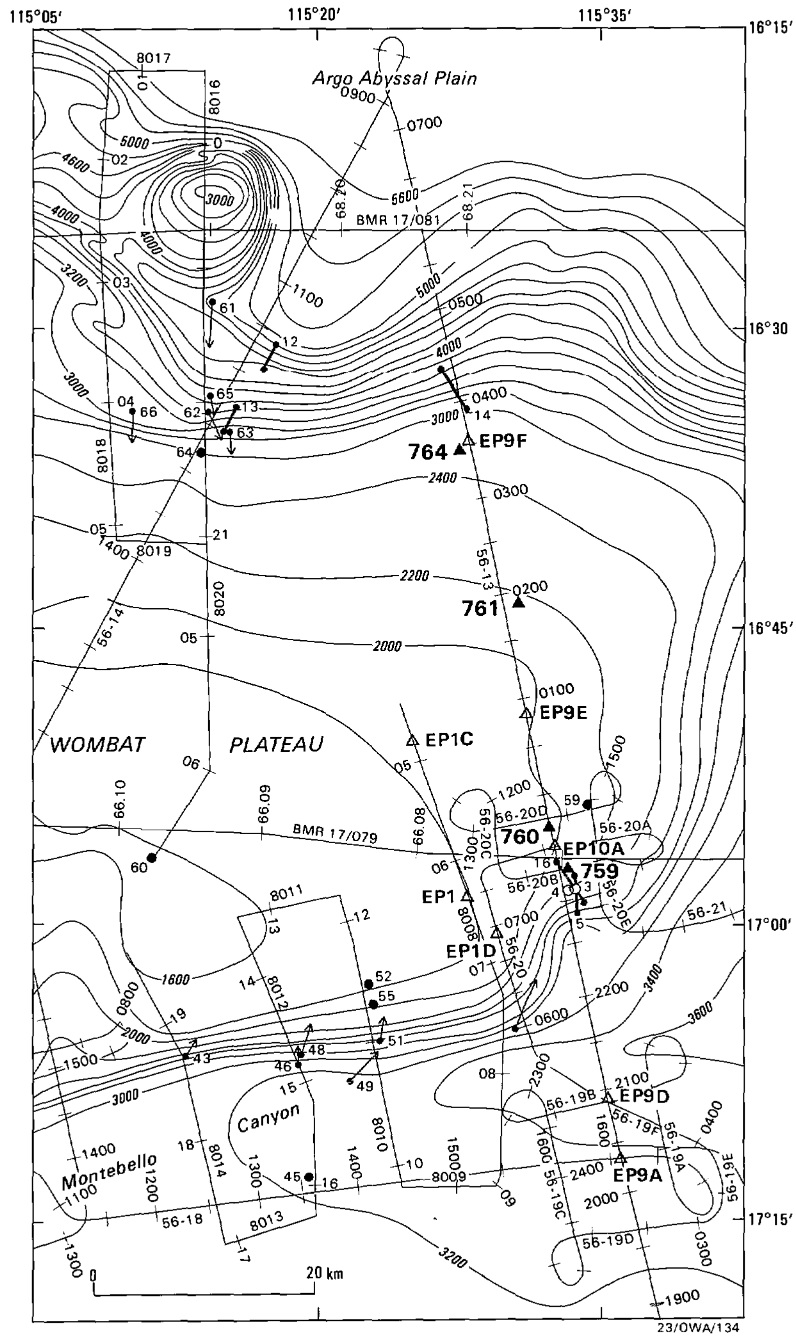
33 E3,4 (Early Aptian chalk); A2,3 (Middle Jurassic coal measures)

34 A1–4 (Middle Jurassic coal measures)

36 E2 (Late Miocene–Early Pliocene chalk); D2 (Late Albian–Early Cenomanian shelf claystone); A1–4 and B1,2 (Middle Jurassic coal measures, some weathered)

39 D1 (? Cretaceous/Tertiary claystone); D2 (Late Albian–Early Cenomanian shelf claystone); B1–4 (? Jurassic terrest/littoral sediments); A4,5 (? Jurassic coal measures); C1,2,4,5 (? Early Jurassic shelf carbonates)

Fig. 8 Map of the eastern Wombat Plateau on northern margin of the Exmouth Plateau, showing bathymetry, "Sonne" and "Rig Seismic" sampling locations, and ODP drill sites.



BMR seismic line (17 or 56) or "Sonne" (8009) seismic line with hourly positions

48 → *Successful 'Sonne' dredging locality*

13 —• *Successful 'Rig Seismic' dredging locality*

•60 *Successful 'Sonne' coring locality*

o3 *Successful 'Rig Seismic' coring locality*

▲ *ODP site*

△ *Proposed ODP site*

-3200- *Bathymetric contour (metres)*

Gandara, Saturn, Mercury and Jupiter (Fig. 4). Results for the latter three wells have been published by Barber (1982, 1988). Those for the former three wells have not been published in any detail, but are summarized briefly in Figure 11. Results from the critical well, Woodside Delambre No.1, are tabulated in Figure 12.

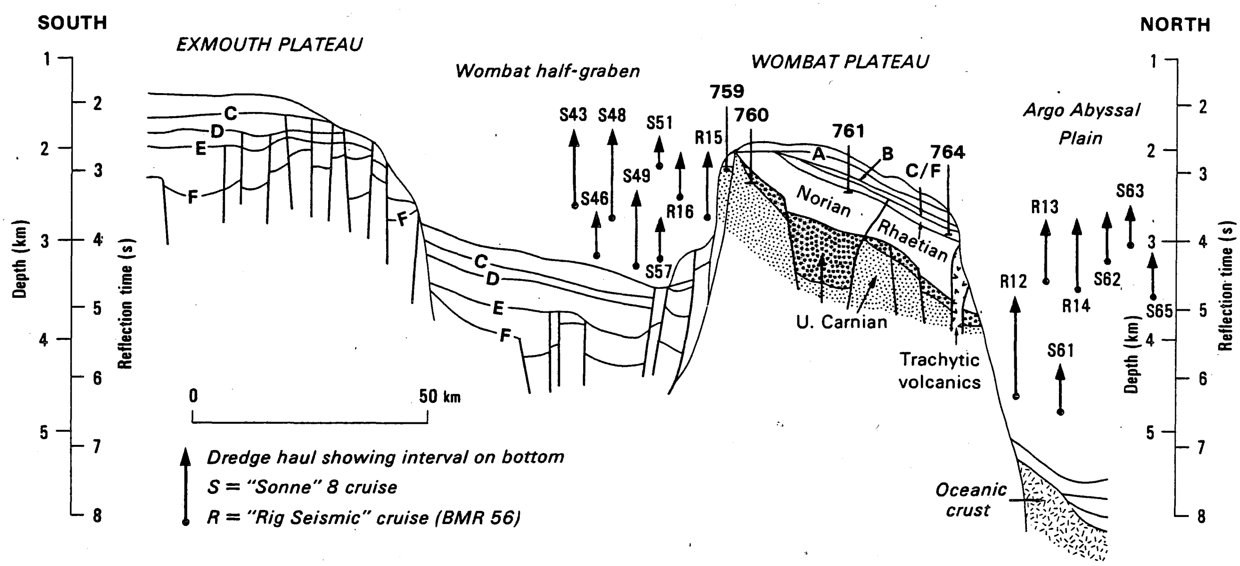
In general terms, Triassic sedimentary rocks are thick and omnipresent, whereas Jurassic rocks are thin in the central and southern Exmouth Plateau, but thicker in the Delambre-Gandara region. Dredge and seismic results indicate that thick Jurassic rocks extend to the northeastern margin of the plateau.

<u>Ocean Drilling Program results</u>

During ODP Leg 122, four continuously cored holes were drilled on the Wombat Plateau, a northern subplateau of the Exmouth Plateau : Sites 759, 760, 761 and 764 (Figs. 1 & 13). These four holes all intersected Late Triassic sediments directly beneath the main unconformity, with a composite thickness of 750 m (Fig. 13), of which 30% are carbonates, and the remainder low-energy paralic to fluviodeltaic facies. Haq, von Rad et al. (in press) state : "Carbonate rocks were first deposited on the Wombat Plateau during late Carnian time, in a southern embayment of a shallow Tethys sea where marginal marine clastics were succeeded by alternating shallow-water carbonates and deltaic siliciclastics. In the Norian, a more than 300 m thick, shallowing-upwards sequence began to be deposited, resulting in shallow-marine limestones interbedded with fluviodeltaic silty claystone, grading upwards to a deltaic coastal plain facies with algal mats, coal seams and root-mottled zones that indicate periodic emergence. The Wombat Plateau developed a fully marine carbonate platform sequence, with a deeper water shelf limestone/marlstone section, overlaid by an over 200 m thick reef complex and related perireefal facies dating from the Rhaetian. These carbonates resemble their coeval strata in the western Tethys region of the Alps. Northward tilting and uplift of the Wombat Plateau resulted in Jurassic emergence and subaerial erosion that removed Jurassic sequences at the onset of Argo Abyssal Plain seafloor spreading. During early Neocomian time the Wombat Plateau sank below sea level and, coupled with the adjacent Argo Abyssal Plain, subsided to bathyal water depths. A condensed sequence of upper Berriasian to lower Valanginian sandstone, belemnite sand, and hemipelagic calcisphere/nannofossil chalk interbedded with bentonite layers documents rapid subsidence from littoral to bathyal depths during the 'juvenile ocean stage'. The Turonian marks the onset of the 'mature ocean stage' and purely pelagic carbonate sedimentation."

<u>Triassic and Jurassic shelf carbonates</u>

Shelf carbonates of Triassic and Jurassic age are common on the Exmouth Plateau. Barber (1988) stated that in the central plateau, a shallow sea transgressed over the fluvio-deltaic sequence of the Mungaroo Formation during late Rhaetian to Hettangian time, depositing an interbedded sequence of calcareous sands, siltstones and occasional limestones. The total thickness of this sequence is about 100-300 m. Further shoreward to the southeast, at the intersection of the prograding fluvial-deltaic regime with the marine transgressive front, a north-northeast-trending beach-barrier bar and back-lagoonal complex developed. As deltaic input diminished, carbonate deposition



South of Wombat Plateau

S43: Triassic/Jurassic shelf carbonates (C3,4) and claystone (A4)
S46: Triassic brackish sandstone (A3)
S48: L. Triassic paralic siltstone (A2)
S49: Triassic brackish siltstone (A2,3);
Triassic/Jurassic shelf carbonates (C5,6) and ironstone (B1)
S51: E. Cretaceous shelf mudstone (D2)
S57: Triassic/Jurassic paralic shale, sandstone (A4,6)
R15: Triassic/Jurassic redbeds (D6), coal measures (D4), carbonates (C6)
R16: E. Cretaceous marine sandstone (D4);
L. Triassic shelf carbonates (C2,4); Triassic/Jurassic ironstone (B1,3)

North of Wombat Plateau

S61: L. Triassic/E. Jurassic shelf carbonates and "trachyte" (H4)
S62: E. Jurassic shallow marine carbonates (C2)
S63: Triassic/Jurassic sandstone and mudstone (A2,3,4)
and ironstone (B1,2); L. Triassic/E. Jurassic "trachyte" (H4,7)
S65: L. Triassic "trachyte" (H4); ? Cretaceous bryozoan limestone (C7)
R12: Triassic/Jurassic "trachyte" (H4,8)
R13: Triassic/Jurassic "trachyte" (H1,4,7,8), shelf carbonates (C2),
ironstone (B2,3); ? E. Cretaceous marine mudstone (D2,6)
R14: L. Triassic shelf carbonates (C2,4,6)

23/OWA/131

Fig. 9 Dredge locations on the Wombat Plateau transposed onto "Rig Seismic" seismic profile 56-13. Seismic reflectors as in Figure 2. ODP drill holes on Wombat Plateau have provided accurate definition of sequences there.

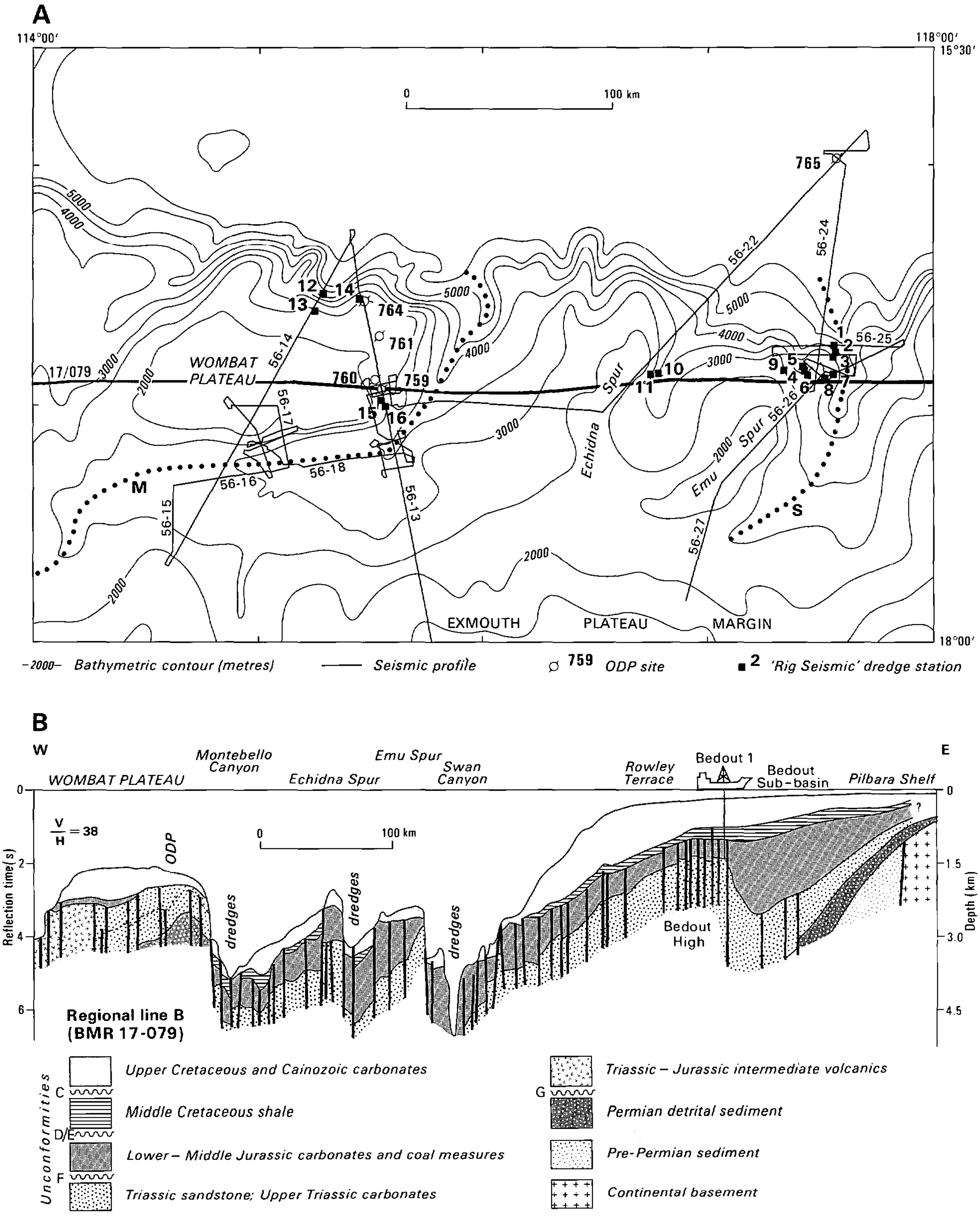


Fig. 10 Northern Exmouth margin. A) General map showing "Rig Seismic" profiles and dredge sites, and ODP drill holes

B) Schematic east-west profile from Pilbara Shelf across northern margin of Exmouth Plateau. Western part based on BMR seismic profile 17/079 (see A).

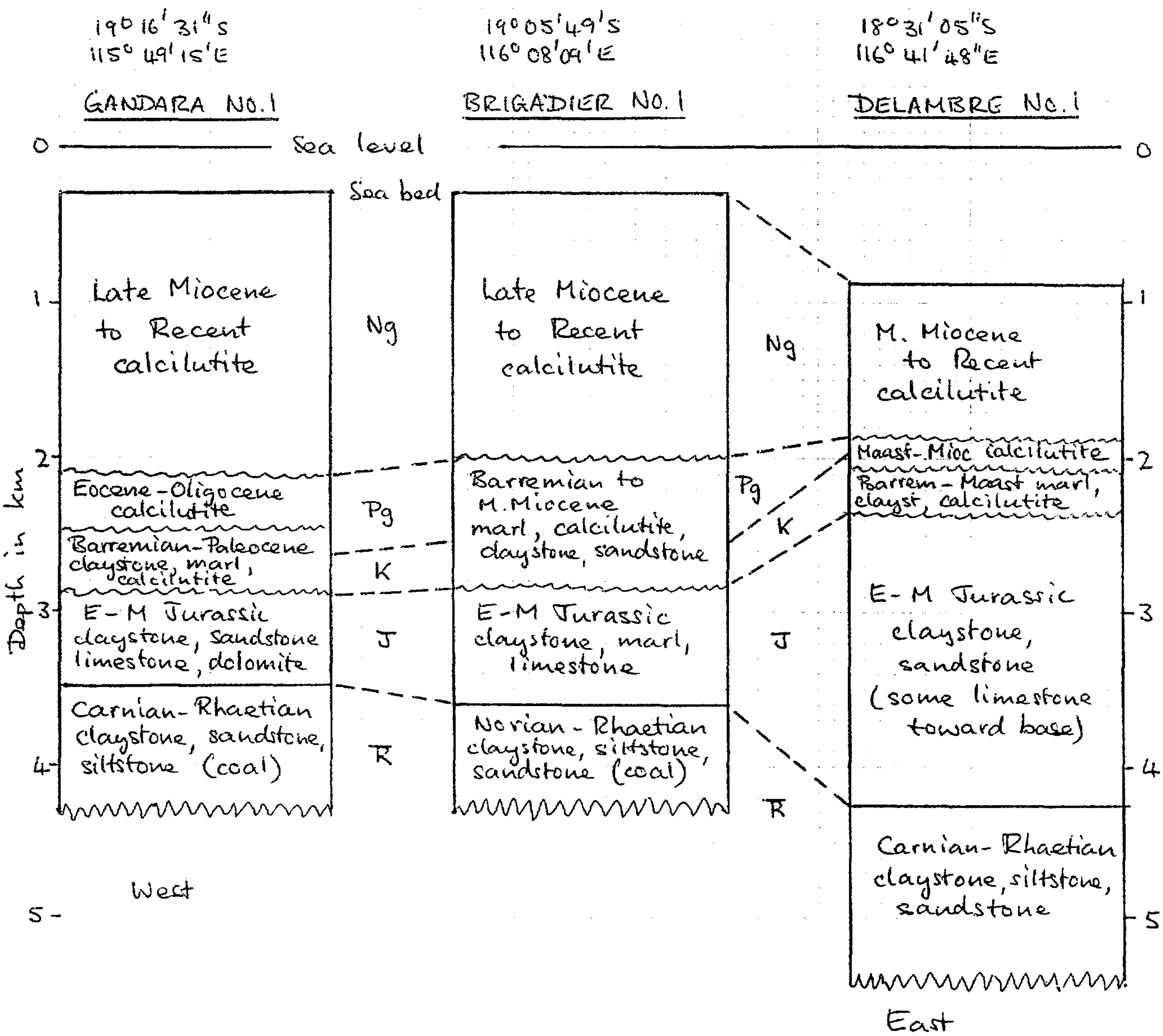


Fig. 11 Summary of logs of Gandara, Brigadier and Delambre wells (location in Fig. 1). Note thick Jurassic sequence in Delambre well, with some shelf limestone in Pliensbachian to Hettangian rocks.

Fig. 12. Lithological log of Woodside Delambre No. 1 well.

Woodside Offshore Petroleum Pty Ltd

DELAMBRE Nº 1

STRATIGRAPHIC TABLE

Latitude: 18° 31′ 05″ S   Longitude: 116° 41′ 48″ E   R.T. 10m

AGE				LITHOLOGY	DEPTH (m)	THICKNESS	
						10	
				Sea Level	10	884	
				Sea Bed	894		
			NOT SAMPLED			343	
CAINOZOIC	NEOGENE		LATE PLIOCENE	FORAMININFERAL ARGILLACEOUS CALCILUTITE	1237	59	
			EARLY PLIOCENE		1296	174	
			LATE MIOCENE	CLAYSTONE AND CALCISILTITE	1470	251	
			MIDDLE MIOCENE	CALCAREOUS CLAYSTONE, MARL AND CALCILUTITE	1721	139	
			EARLY MIOCENE	CALCILUTITE	1850	7	
	PALAEOGENE		LATE OLIGOCENE		1857	12	
			MIDDLE EOCENE	CALCILUTITE AND CALCISILTITE	1869	47	A 2.15s
			EARLY EOCENE		1916	75	
			LATE PALAEOCENE	CALCILUTITE AND CALCISILTITE	1991	69	
			PALAEOCENE UNDIFF.		2060	6	
			EARLY PALAEOCENE	CLAYSTONE	2066	3	
MESOZOIC	CRETACEOUS	LATE	LATE MAASTRICHTIAN	MARL	2069	32	B 2.35s
			EARLY MAASTRICHTIAN	MARL	2101	19	
			LATE CAMPANIAN		? 2120	36	
			INDETERMINABLE	MARL AND CALCILUTITE	2156	13	
			LATE SANTONIAN		2169	24	
			EARLY SANTONIAN		? 2193	7	
			CONIACIAN		2200	22	
			? TURONIAN	CALCILUTITE	2222	18	
			LATE CENOMANIAN	MARL AND CALCILUTITE	2240	5	C 2.50s
		EARLY	EARLIEST CENOMANIAN TO LATE ALBIAN	MARL	? 2245	8	
			MIDDLE TO EARLY ALBIAN	MARL AND CALCILUTITE	2253	33	
			INDETERMINABLE	CLAYSTONE	2286	2	
			BARREMIAN		2288	30	
			BERRIASIAN	CLAYSTONE AND SANDSTONE	2318	28	D 2.57s
	JURASSIC	MID	BATHONIAN TO BAJOCIAN	SANDSTONE, SILTSTONE AND CLAYSTONE	2346	1007	E 2.60s
		EARLY	AALENIAN TO TOARCIAN	CLAYSTONE	3353	611	
			PLIENSBACHIAN TO HETTANGIAN	CLAYSTONE, LIMESTONE AND SANDSTONE	3964	323	
	TRIASSIC	LATE	RHAETIAN	CLAYSTONE AND SANDSTONE	4287	317	F 3.75s
			NORIAN		4604	61	
			NORIAN TO CARNIAN	CLAYSTONE, SANDSTONE AND SILTSTONE	4665	599	
			CARNIAN		5264	231	
					T.D. 5495		

Compiled: R. Malcolm   Drawn: J. Boshart   Date: April, 1981   400 - 7323s predominated, and the base of the Jurassic Dingo Claystone is largely carbonate.

The Ocean Drilling Program holes from the Wombat Plateau are summarized in Figures 13 and 14, and wireline logs from ODP Site 764, showing the reefal facies, are illustrated in Figure 15. Williamson et al. (1989) described the Wombat Plateau Late Triassic sequences. The sequence is more than 100 m thick, and consists of pro-delta mudstones, overlain by deltaic marginal marine mudstone and associated carbonate banks. The Norian sediments are 330 m thick, and consist of a number of shallowing-upward sequences deposited in a variety of shallow marine, paralic and coastal plain environments. Mudstones predominate, both marine and non-marine, and associated lithologies include shelfal carbonates, sandstone and coal, with soil profiles near the top.

The Rhaetian sequence consists predominantly of shelf carbonates, including reef complexes. Only in Site 764 (Fig. 14) was a reef complex drilled, and there the sequence was 300 m thick. It consisted of outer shelf mudstone, overlain by cycles of outer shelf limestone and marl, overlaid by a thick sequence of alternating reefal, peri-reefal and back-reefal deposits including oolite shoals and fore-reef talus, and capped by shallow open-marine limestone and marl.

The oldest sediments recovered at Site 764 consist of 14 m of very dark, clayey, partly recrystallised marlstone to wackestone. These rocks are interbedded with light-grey carbonate mudstone containing clay. Palynomorphs indicate a Rhaetian age. Crinoid fragments are common in the clayey carbonate mudstone, which may indicate an open-marine, deeper-water (lower photic zone) environment. The extensive bioturbation suggests a nutrient-rich substratum and/or slow sedimentation rates, and possibly a lagoonal to back-reef mud-flat environment. The environment was certainly open marine and low energy : lagoonal (back reef) or deeper marine (deeper fore-reef slope, indicated by the presence of crinoids).

The 210 m thick reefal to peri-reefal sequence, of which less than 10 per cent was recovered, is white to pale brown in colour. It consists of a great variety of shallow-water platform limestones and related lithologies, with well-preserved reefal framework structures and many macrofossils. Major lithologies include wackestone, packstone, grainstone, rudstone and boundstone. *In situ* sessile benthic fossils, such as colonial corals and green algae, are prevalent, as is characteristic in Tethyan Upper Triassic reefs (Flugel & Stanley, 1984). Bryozoans, brachiopods, echinoderms, gastropods and bivalves are also present. Coralgal limestone indicates that deposition was in the tropical or subtropical belt of the Tethyan Ocean. Oolitic and oncolitic grainstone and coquinas point to a Bahaman-type, high-energy environment. Most limestones are highly porous, with vugs filled partly by dog-tooth calcite and partly by several generations of micrite and haematite-goethite.

These microfacies types signify either a highly agitated, well-oxidised carbonate bank environment or a reefal (back-reef/fore-reef/reef platform) environment. The lower part of the sequence consists of bioclastic rudstone and floatstone interbedded with wackestone and mudstone. This is interpreted as talus material on a fore-reef or back-reef slope or ramp. At least six cycles can be identified, from the bottom upward : packstone/wackestone (in situ

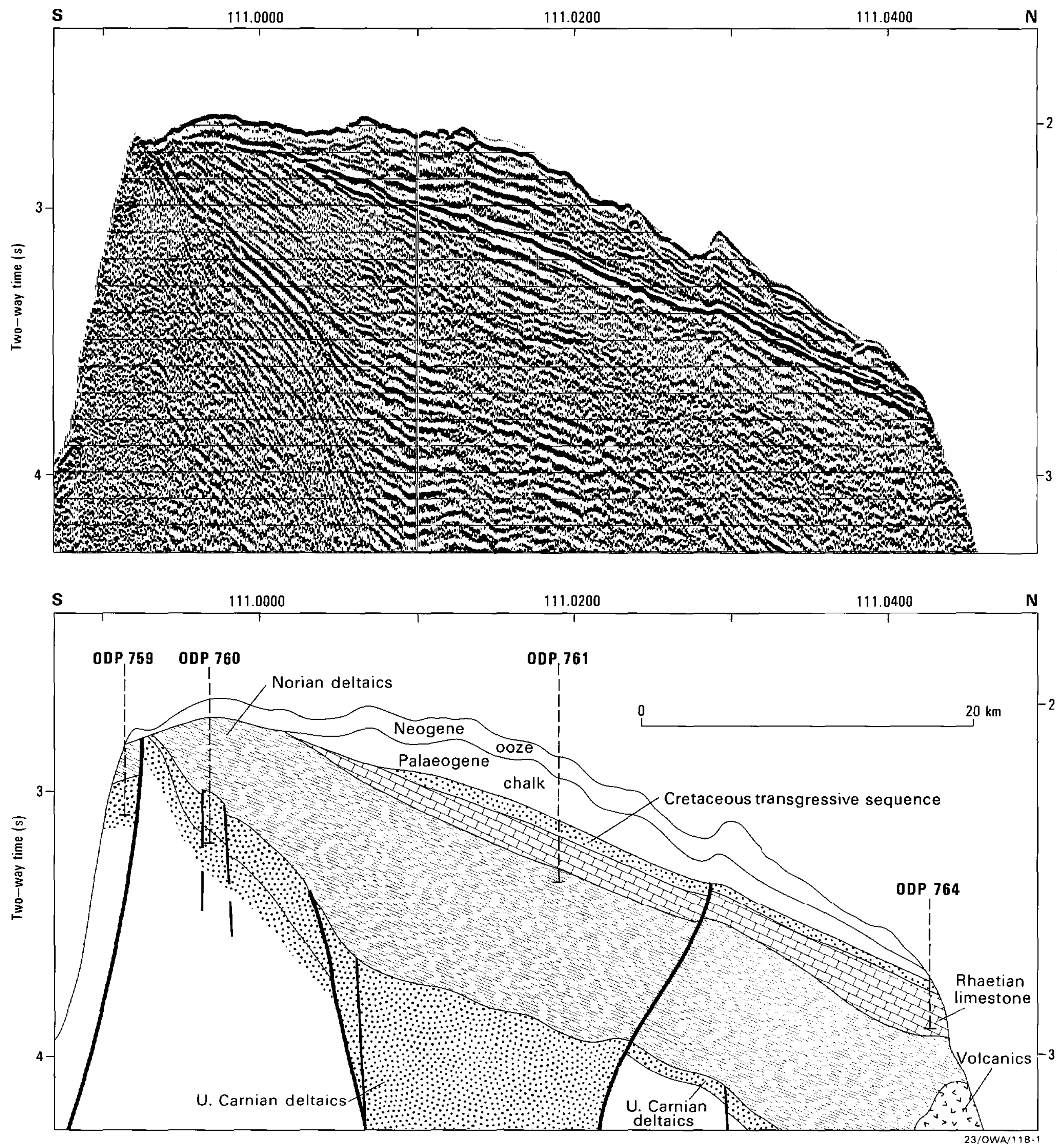


Fig. 13. BMR seismic profile 56-13 across Wombat Plateau, with ODP drill holes shown on it, and a summary of their results. ODP holes located in Figures 8 & 10A.

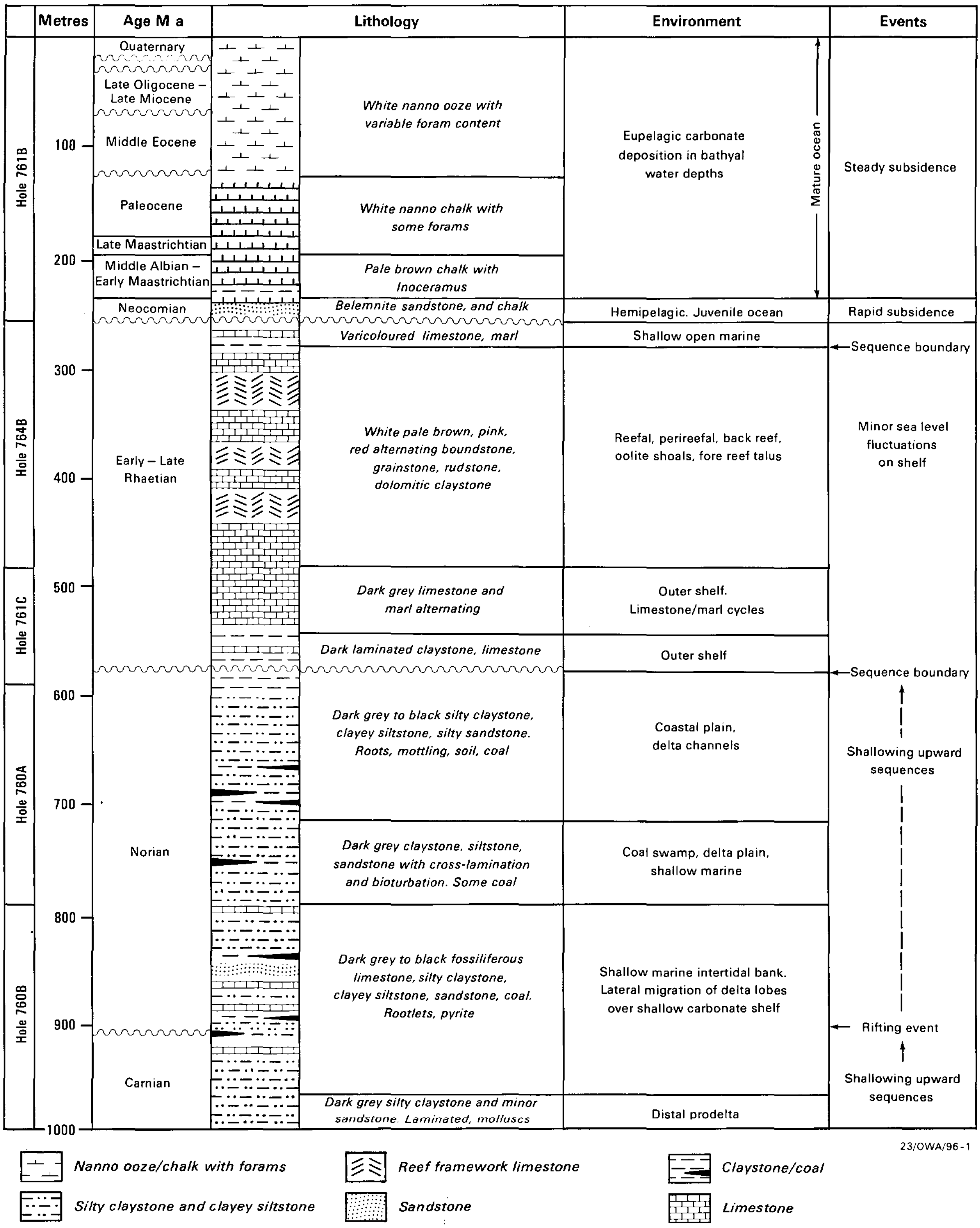


Fig. 14. Stratigraphic composite diagram summarizing the results of Wombat Plateau ODP drilling. Note deltaic and reefal sequences of Late Triassic age.

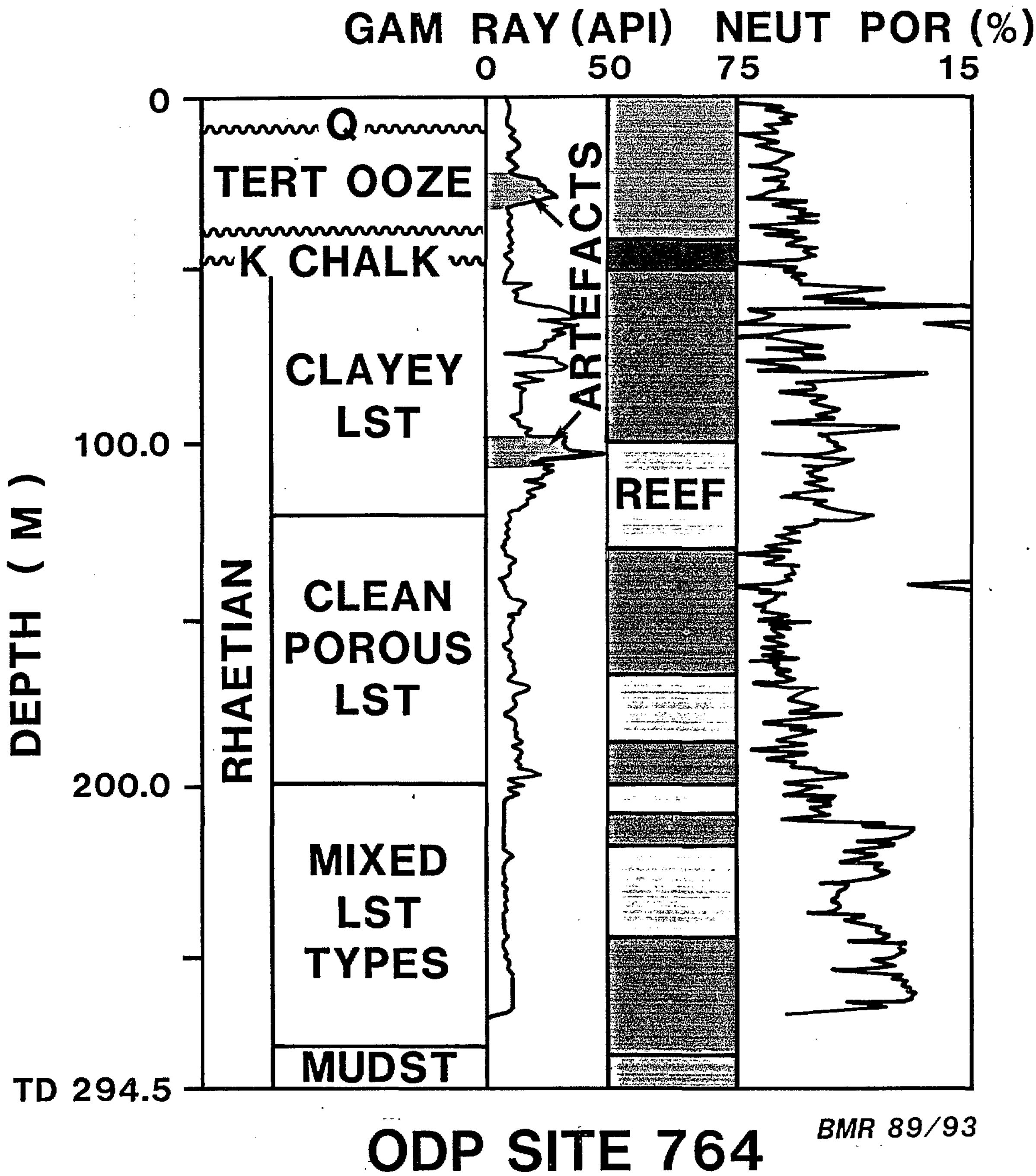


Fig. 15. Wireline logs of Late Triassic sequences in ODP Site 764, showing homogeneous character of reefal sequence.

deeper marine fore-reef or ramp environment); rudstone/carbonate breccia (gravity mass-flow deposits, possibly fore-reef talus); white oolite grainstones (Bahaman-bank-type deposit, highly agitated); reefal boundstone/bafflestone (central coral-reef build-up); grainstone, packstone, wackestone (possibly back-reef, intertidal); and carbonate mudstone (intertidal, lagoonal, quiet water).

The 23 m thick transgressive facies at Site 764, which overlies the reefal facies, consists of grey to dark grey alternating clayey recrystallised limestone and calcareous claystone. The depositional environment was probably open marine and below wave-base, possibly a protected lagoon on the mid-shelf. The overlying unit consists of lighter coloured fossiliferous wackestone, packstone and grainstone with Triasina hantkeni, a typical latest Triassic foraminifer; the wackestone and packstone are partly dolomitised. The grainstone fines upward into wackestone and carbonate mudstone. These sediments were probably deposited in a well-oxygenated, quiet- to moderate-energy environment, with periodic current redeposition. Crinoids found in the wackestone and carbonate mudstone might indicate a deeper-marine environment.

The interpretation of seismic profiles, combined with the well data, suggests that there is a series of reefal bodies on the eastern Wombat Plateau, surrounded by detrital carbonate fore-reef and back-reef wedges (Fig. 16, 17, 18). The reefal complexes are interbedded with non-reefal lagoonal and shelf carbonates of various types. Deltaic sediments like those in the Carnian and Norian are not present in the Rhaetian.

On the Exmouth Plateau as a whole, shelf carbonates have been penetrated in 12 wells (Table 1). The aim of the present study is to establish their distribution and facies on the most carbonate-rich part of the plateau, the northeast.

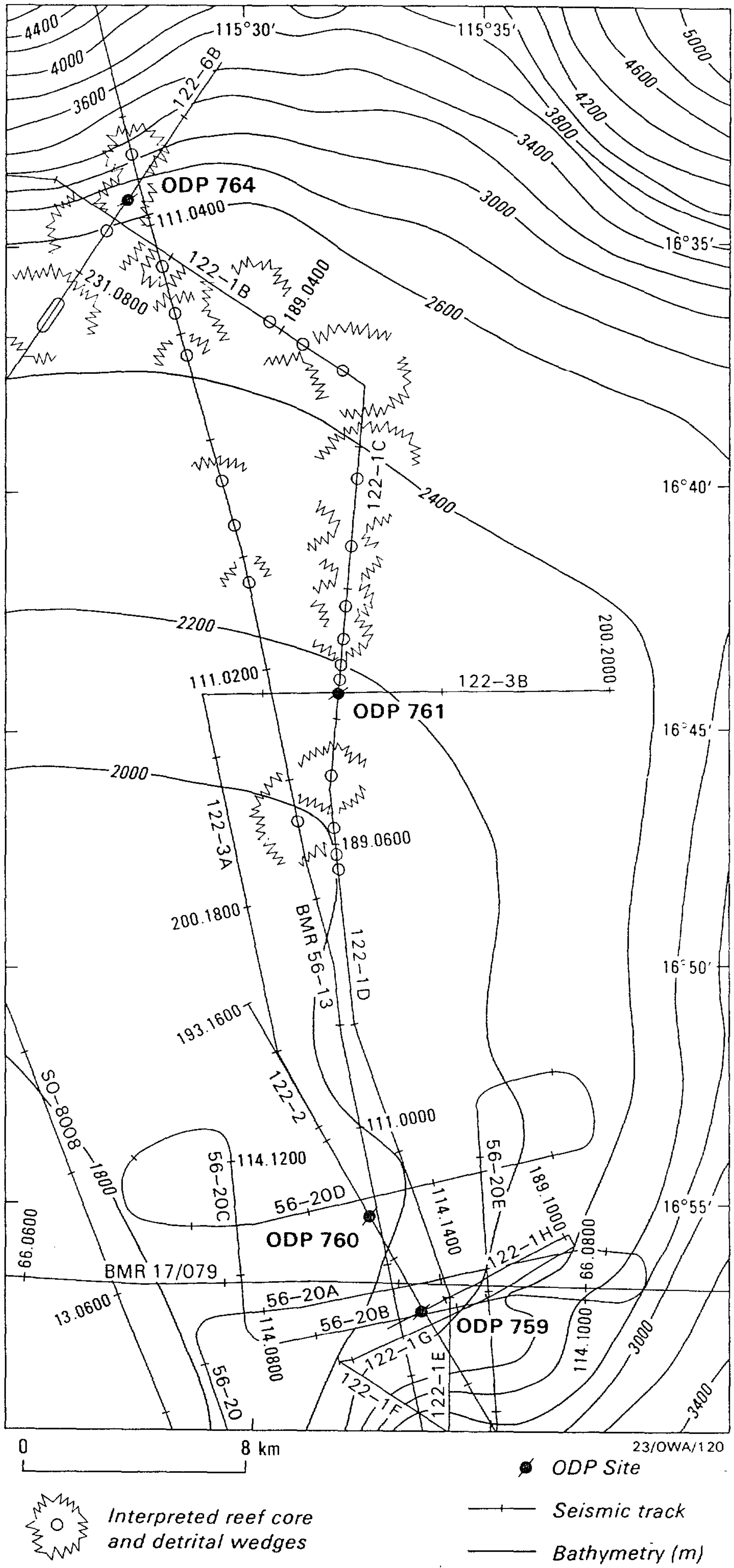


Fig. 16. Map of eastern Wombat Plateau showing BMR and ODP seismic profiles, ODP drill holes, and reefal bodies interpreted from seismic profiles (a reef was drilled at ODP Site 764).

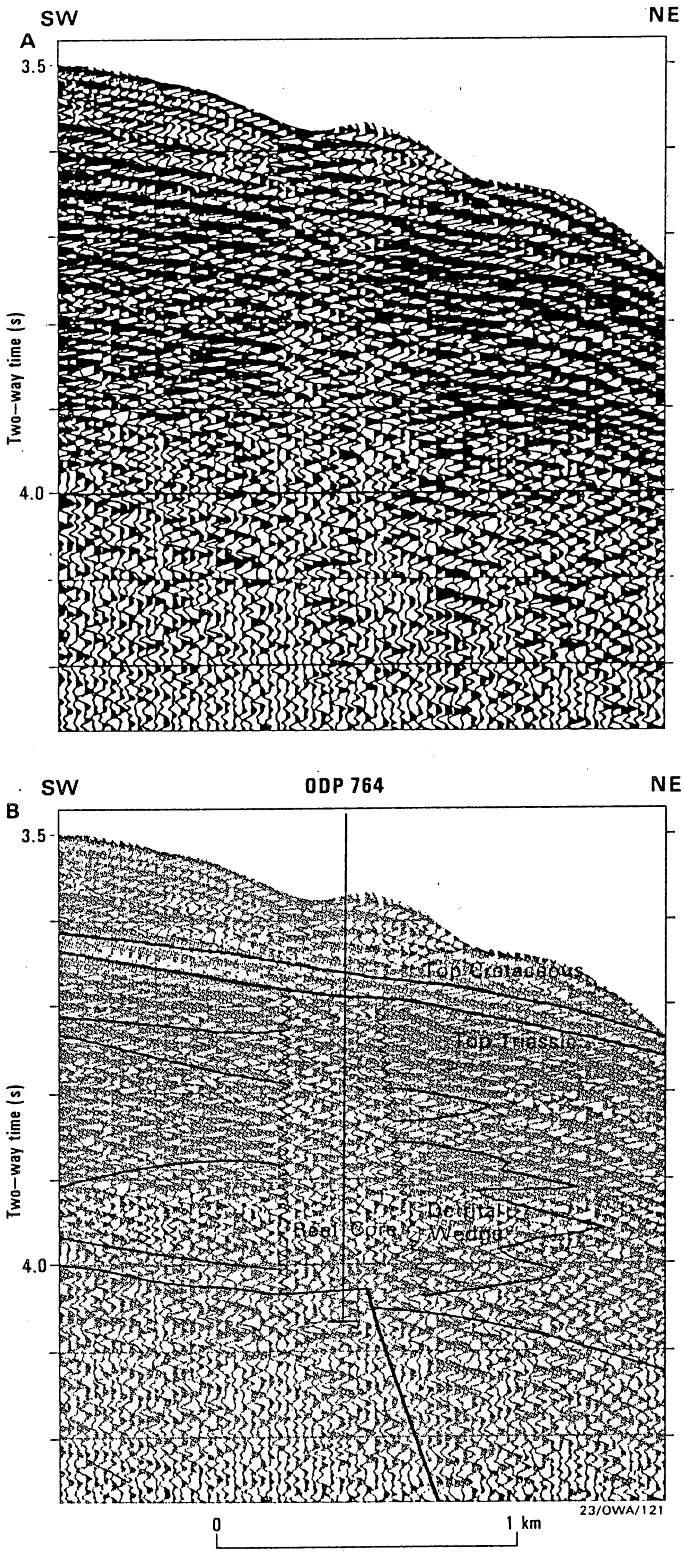


Fig. 17. Segment of ODP seismic profiles 122-6 showing ODP Site 764 which drilled a Rhaetian reef. Reef core corresponds to a zone of poor reflections, and a downlapping seismic facies around the core is interpreted as reef-derived talus. After Williamson et al. (1989). Location in Figure 15.

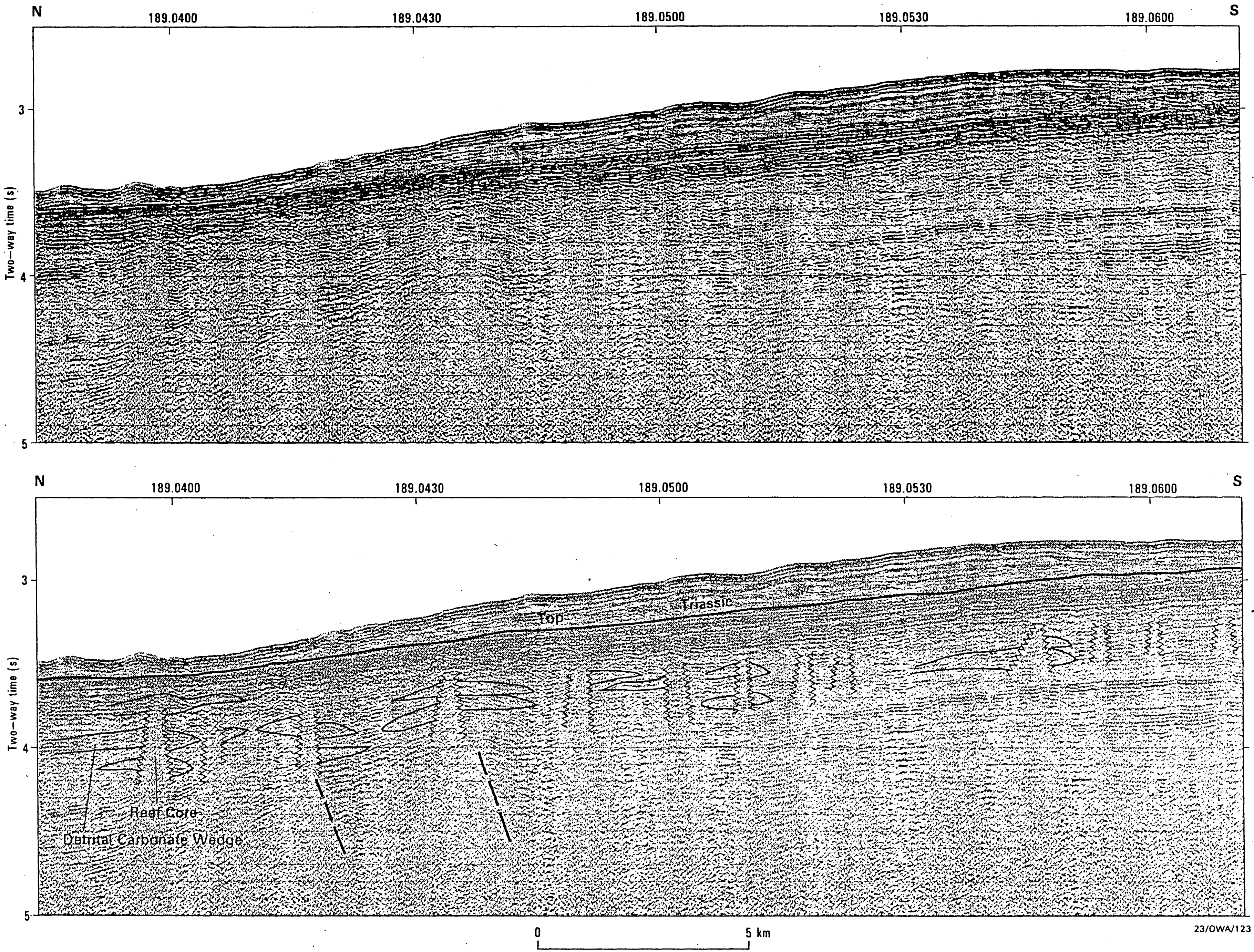


Fig. 18. ODP seismic profile 122-1B showing interpreted reef complexes like that in Figure 16. After Williamson et al. (1989). Location in Figure 15.

Table 1. Late Triassic to Early Jurassic carbonates on Exmouth Plateau.

Well	Location	Description Carbonate	Carbonate Thickness (m)
ODP Site 764	NE Wombat	Rhaetian shelf limestone	230
ODP Site 761	E Wombat	Late Norian to Rhaetian shelf limestone	140
ODP Site 760	SE Wombat	Thin Late Carnian to Norian limestone in deltaic sediments	30
ODP Site 759	SE Wombat	Thick Norian shelf limestones and thin Middle Carnian limestones in deltaic sediments	45
Woodside Delambre	NE Exmouth	Pliensbachian to Hettangian shelf limestones in deltaic sediments	323
Phillips Saturn	Central Exmouth	Hettangian shelf limestone	40
Phillips Mercury	Central Exmouth	Norian shelf limestone	Ca.20
Phillips Jupiter	Central Exmouth	Norian shelf limestone	3
Esso Eendracht	Western Exmouth	Rhaetian marl	47
Esso Vinck	Western Exmouth	Rhaetian marl	45
Esso Investigator	Southern Exmouth	Rhaetian marl	65
Esso Sirius	Southern Exmouth	Rhaetian marl	11

CRUISE OBJECTIVES

The objectives of the planned cruise are :

- To map the extent and seismic character of reef complexes discovered by the ODP holes on the Wombat Plateau, in order to characterize them and to be able to identify them elsewhere.

- To study the facies of Late Triassic and Early Jurassic deltaic and shelf carbonate rocks, and to map the extent of such rocks to the west, south and east away from the holes in which they were fully cored. This study would make use of all suitable data, including the regional GSI grid on the northern Exmouth Plateau and the Japanese National Oil Corporation (JNOC) grid in the Rowley Sub-basin. Well ties to Barcoo, East Mermaid and Delambre wells are planned.

- To use the cruise results, in conjunction with existing data, to assess the significance of Triassic and Jurassic shelf carbonates to petroleum exploration on the Northwest Shelf.

- To better define the geological history of the northern Exmouth Plateau, and the Rowley Sub-basin of the Canning Basin.

CRUISE PLAN

The cruise is tentatively scheduled for 34 days, Darwin-Perth, starting in April 1990. Excluding transit time and some work in the Vulcan Sub-basin, this leaves 25 working days in the Exmouth-Canning area. Figure 19 is a summary track map. The scientific activities have five components:

1. Experimental seismic line in Vulcan Sub-basin
   (Estimated working time 2 days)

An experimental high-resolution watergun seismic line about 70km long will be run SE across the Vulcan Sub-graben, as a test for the proposed high-resolution seismic survey there late in 1990. Location about 275 km northwest of Cape Leveque.

2. Conventional seismic tie lines
   (Estimated working time 9-10 days)

It is intended to use a conventional 2400m, 96 channel seismic cable and a single airgun array, to provide critical tie lines between our areas of detailed study (outer Rowley Terrace and Wombat Plateau) and key exploration company wells in shelf water depths. These data will also be useful in mapping the shoreward extension of Triassic-Jurassic shelf carbonates and reefal buildups from their known development in deep water.

The total amount of profiling (Figure 19) is nearly 1000 nautical miles, which amounts to approximately 8 days of continuous profiling at 5 knots. Allowing two days for deployment and retrieval of equipment, and minor breakdowns, 10 days of working time should be allowed. The layout of the proposed tracks is detailed in Figures 20 and 21.

The tracks in the Rowley Sub-basin (Figures 20 and 21) provide for ties (A&C) from Barcoo No 1 and East Mermaid No 1 wells and the JNOC seismic grid to the lower continental slope in the outer part of the sub-basin, where Triassic and Jurassic rocks are believed to be exposed. They also provide one along-slope line (B) to complete the tie, and also to help delineate sample sites.

Water depths along the seismic lines in the Rowley Sub-basin will range from 720m at Barcoo No 1 and 400m at East Mermaid No 1, to 5500m on the Argo Abyssal Plain. The top of the Middle Jurassic (E reflector) lies at 3.02 s (TWT) at Barcoo No 1 and 2.19 s at East Mermaid No 1; the top Triassic reflector (F) lies at 3.57 s in Barcoo No 1 (Figures 22 and 23).

A long line (D) will extend westward from East Mermaid No 1 to the northern Exmouth Plateau (Figures 19, 20 and 21) to tie the two regions together in an area of shallow Triassic subcrop (along the North Exmouth Hinge Zone). Two lines across the Wombat Plateau (E&F) will tie existing seismic data and delineate possible Triassic-Jurassic dredge sites (Figures 24 and 25). A final regional tie line (G) will tie ODP Sites 764 and 761 to the regional GSI data grid and Delambre No 1, and complete the regional tie to the Rowley Sub-basin.

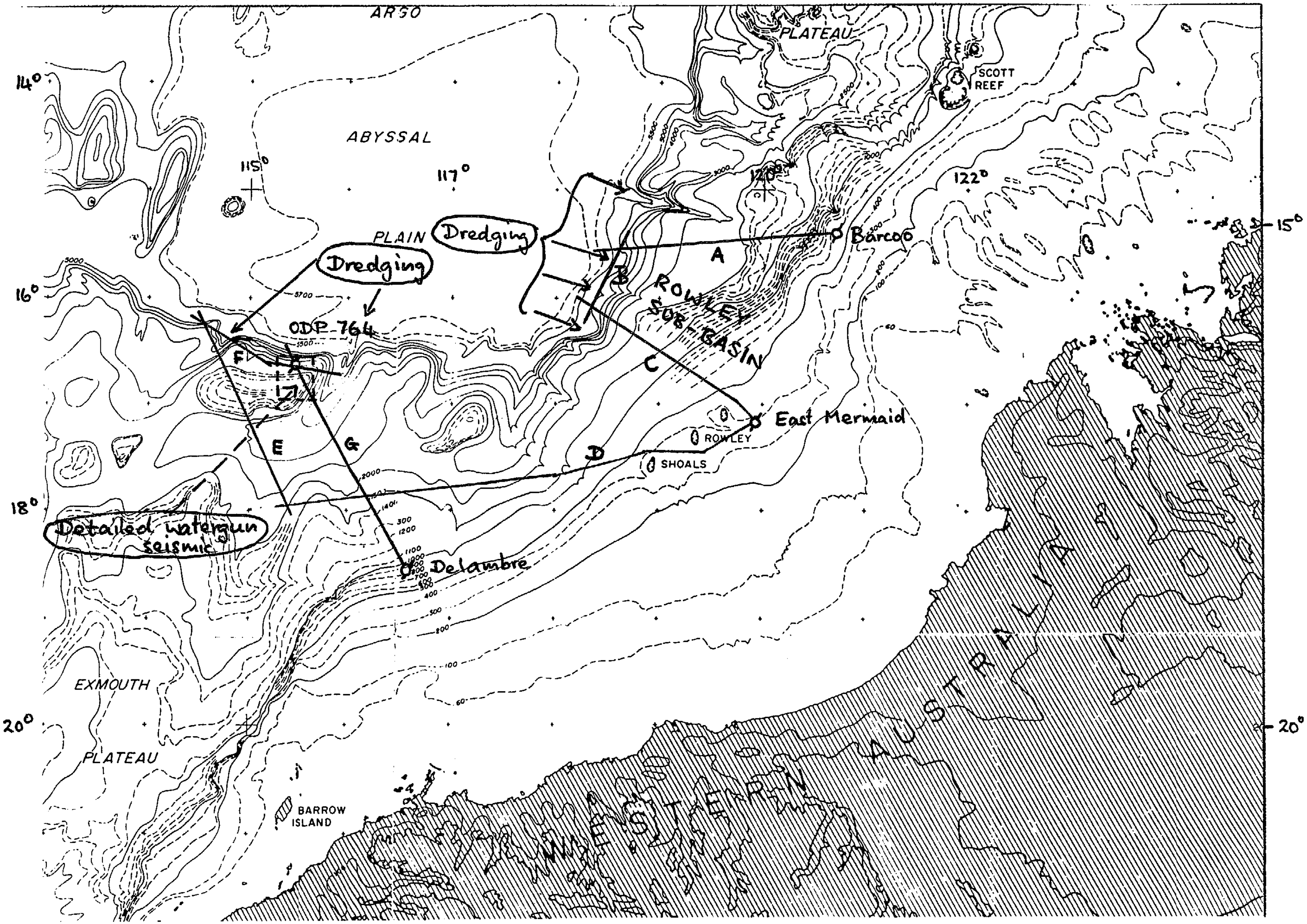


Fig. 19. Summary map of proposed cruise program.

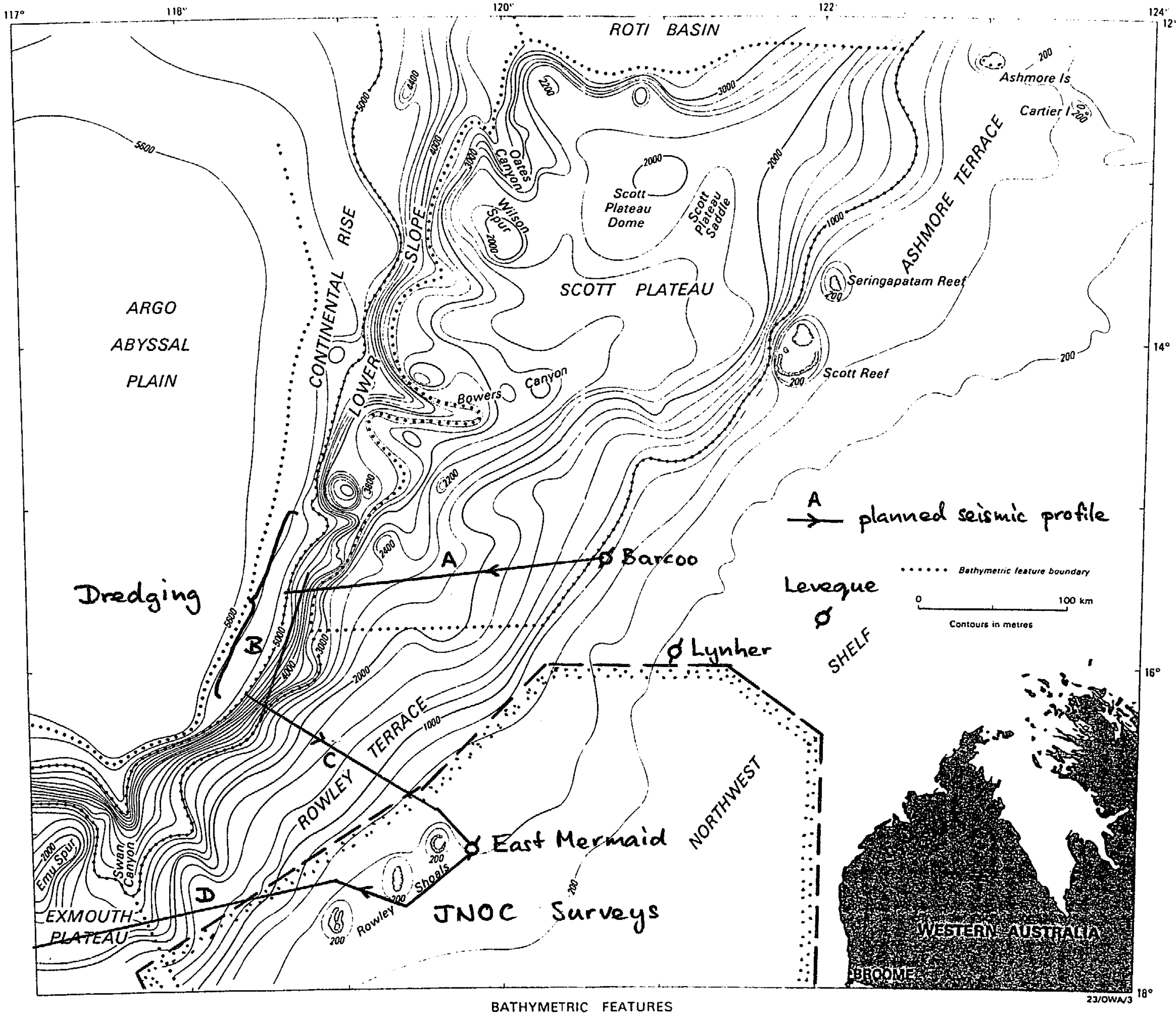


Fig. 20. Map of proposed reflection seismic profiles and dredge locations in Rowley Sub-basin of Canning Basin, related to bathymetry, petroleum exploration wells, and areas of JNOC regional seismic grids.

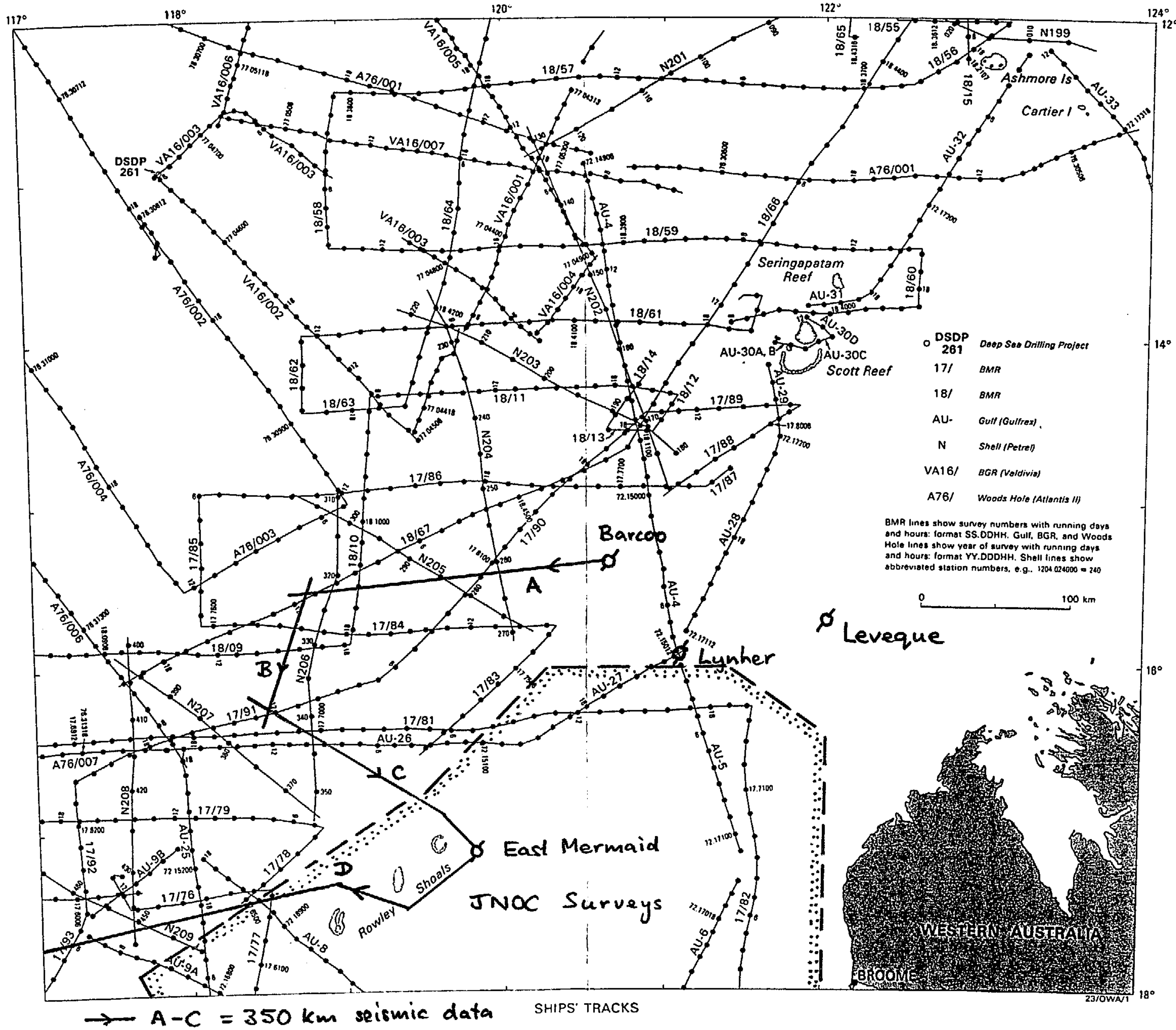


Fig. 21. Map of proposed reflection seismic profiles in Rowley Sub-basin related to deepwater seismic grid.

Fig. 22 Lithological log of Woodside Barcoo No. 1 well in Rowley Sub-basin (location in Fig. 20).

Figure 2.

Woodside Petroleum Development Pty Ltd

BARCOO Nº1

STRATIGRAPHIC TABLE

Latitude 15° 20' 37·0" S Longitude: 120° 38' 12·2" E R.T 11m

ERA	PERIOD	AGE	LITHOLOGY	DEPTH (m)	THICKNESS (m)	
					11	
			Sea Level	11	720	
			Sea Bed	731	394	
		NOT SAMPLED		1125	580	
CAINOZOIC	NEOGENE	MIDDLE MIOCENE	CALCARENITE, SKELETAL, MINOR CALCISILTITE	1125	580	
		UPPERMOST EARLY MIOCENE	CALCARENITE, CALCISILTITE AND CALCILUTITE	1705	517	
		EARLY MIOCENE	MARL AND CALCILUTITE	2222	63	
	PALAEOGENE	LATE OLIGOCENE		? 2285	58	
		LATE EOCENE	CALCILUTITE AND MARL	2343	12	
		INDETERMINABLE	CALCILUTITE	2355	45	
		MIDDLE EOCENE	CALCILUTITE, PARTLY RECRYSTALLISED	2400	30	
		INDETERMINABLE	CALCILUTITE, PARTLY RECRYSTALLISED, AND MINOR SILTSTONE	2430	27	
		EARLY EOCENE	CALCILUTITE AND CLAYSTONE	2457	73	
		LATE PALAEOCENE		2530	12	
		LATE PALAEOCENE	ARGILLACEOUS CALCILUTITE, CLAYSTONE AND MARL	2538	100	
		MIDDLE PALAEOCENE	ARGILLACEOUS CALCILUTITE	?2638	37	
		EARLY PALAEOCENE	MARL, MINOR CALCILUTITE	2675	27	
MESOZOIC	CRETACEOUS	LATE MAASTRICHTIAN	MARL, CALCILUTITE, MINOR CLAYSTONE	2702	47	B 2.28s
		LATE CAMPANIAN	MARL, MINOR CALCILUTITE	2749	217	
		EARLY CAMPANIAN		2966	1	
		SANTONIAN	CALCILUTITE, MARL AND CLAYSTONE	2967	34	
		CONIACIAN	CLAYSTONE AND MINOR CALCILUTITE	3001	5	
		TURONIAN	CALCILUTITE	3006	1	
		PROBABLE MIDDLE CENOMANIAN	CLAYSTONE	3007	47	C 2.47s
		EARLIEST CENOMANIAN TO LATEST ALBIAN	CLAYSTONE, MINOR CALCILUTITE	3054	83	
		LATE TO MIDDLE ALBIAN	CLAYSTONE	3137	37	
		ALBIAN UNDIFF.		3174	156	
		EARLY ALBIAN TO LATE APTIAN	CLAYSTONE, SILTSTONE AND LIMESTONE	3330	323	
		EARLY APTIAN TO LATE BARREMIAN	CLAYSTONE	3653	59	
		BARREMIAN TO BERRIASIAN	CLAYSTONE AND MARL	?3712	84	
	JURASSIC	OXFORDIAN TO LATE CALLOVIAN	CLAYSTONE, MINOR SANDSTONE	3796	20	
		CALLOVIAN	CLAYSTONE, MINOR CALCILUTITE	3816	13	
		BAJOCIAN TO AALENIAN	SANDSTONE, CLAYSTONE, MINOR SILTSTONE	3829	276	E 3.02S
		TOARCIAN	CLAYSTONE, SANDSTONE, MINOR SILTSTONE	4105	178	
		PLIENSBACHIAN TO HETTANGIAN	CLAYSTONE, SANDSTONE, SILTSTONE, RECRYSTALLISED LIMESTONE	4283	465	
	TRIASSIC	RHAETIAN	CLAYSTONE, MINOR SANDSTONE AND SILTSTONE	? 4748	97	
		RHAETIAN TO NORIAN	CLAYSTONE, RECRYSTALLISED LIMESTONE, SANDSTONE, SILTSTONE, MINOR ACID INTRUSIVES	~ 4845	264	F 3.57s
				T.D. 5109 m		

Compiled S.J. Robinson Drawn T. Wood Date: September, 1980 400-7188 s

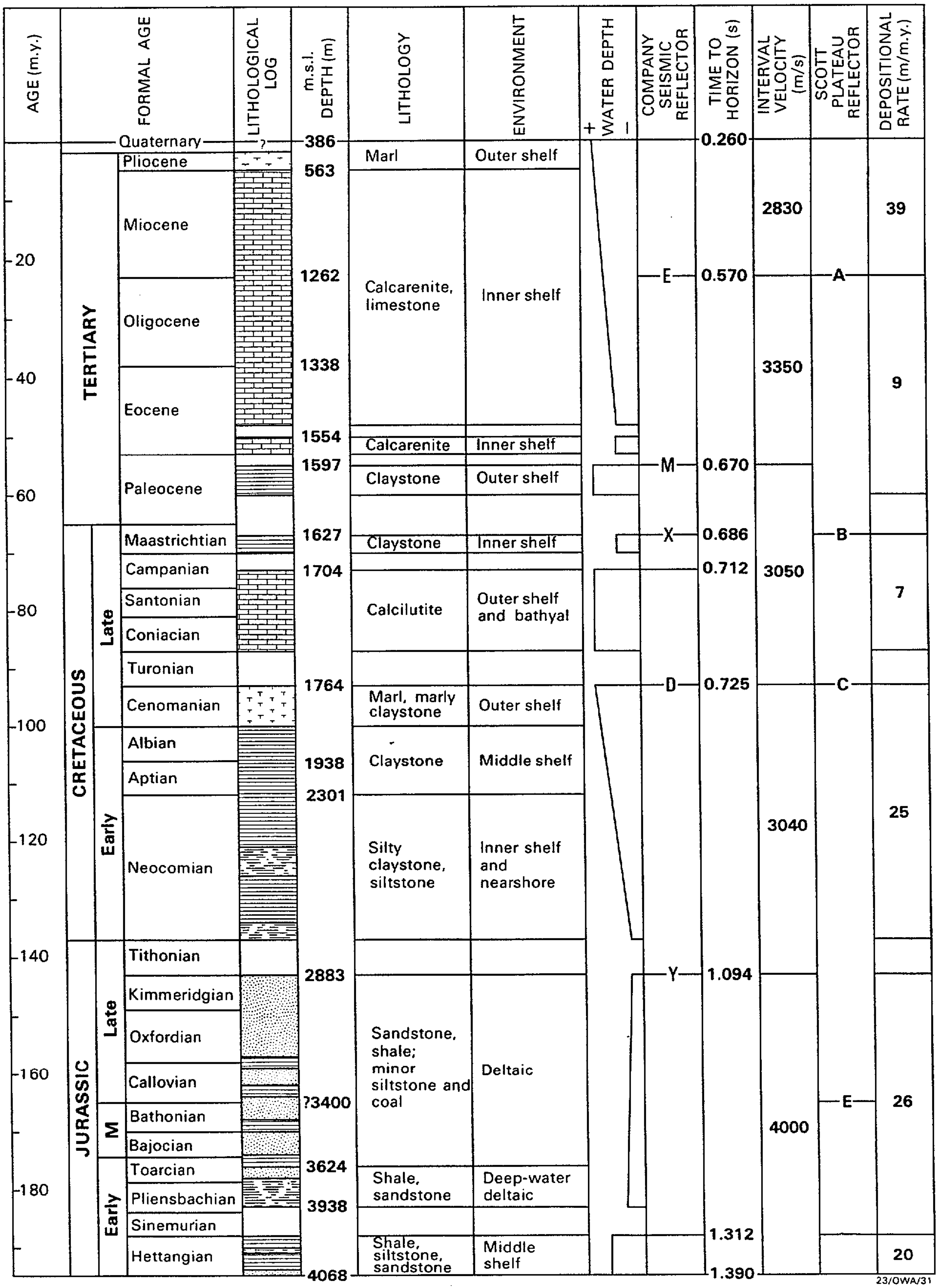
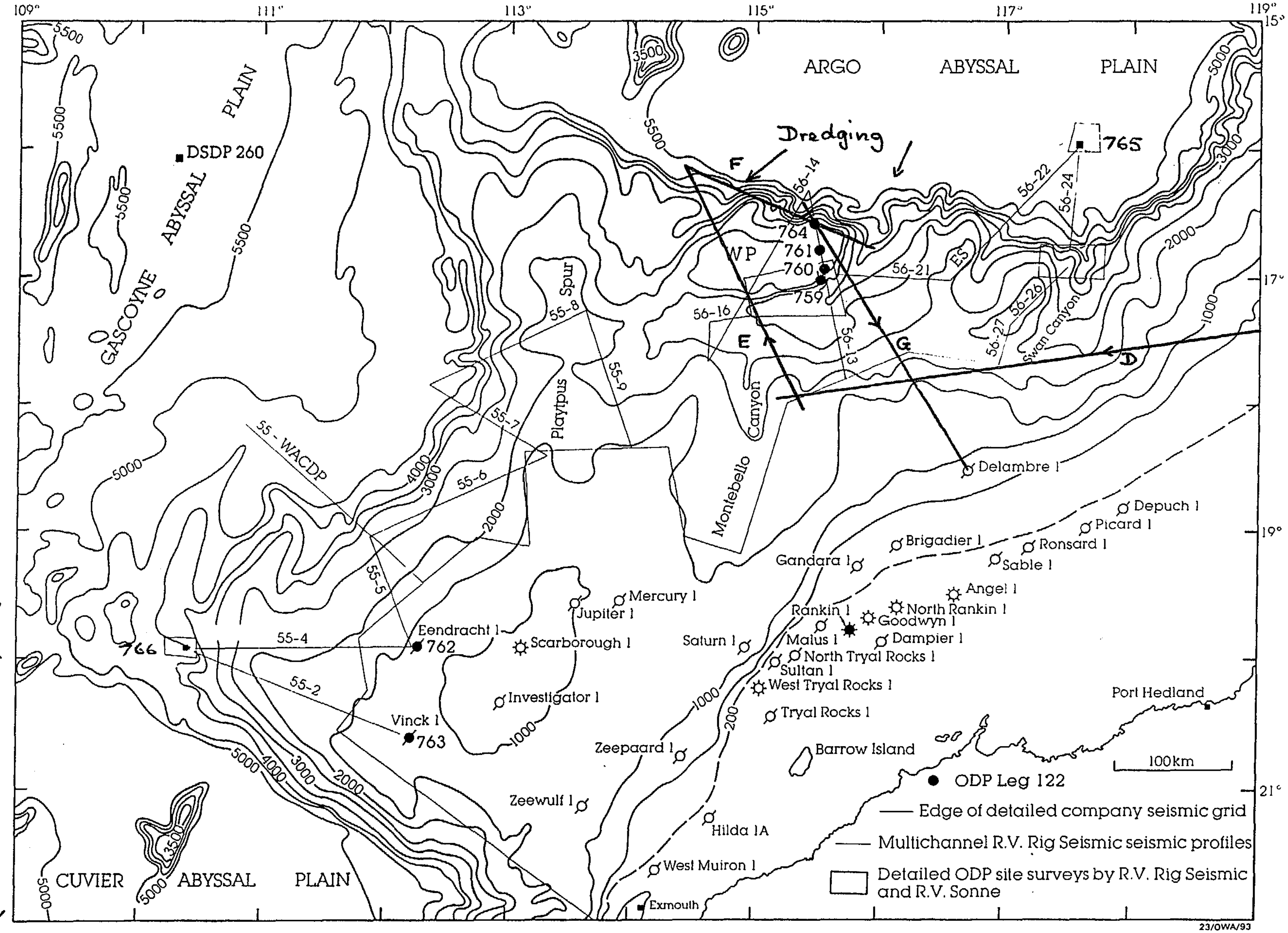


Fig. 23. Lithological log of Shell East Mermaid No. 1 well in Rowley Sub-basin (location in Fig. 20).

Fig. 24. Map of proposed regional seismic grid and dredge locations in northern Exmouth Plateau area, related to bathymetry.

D-G = 1300 km seismic profiles (from East Mermaid No. 1)



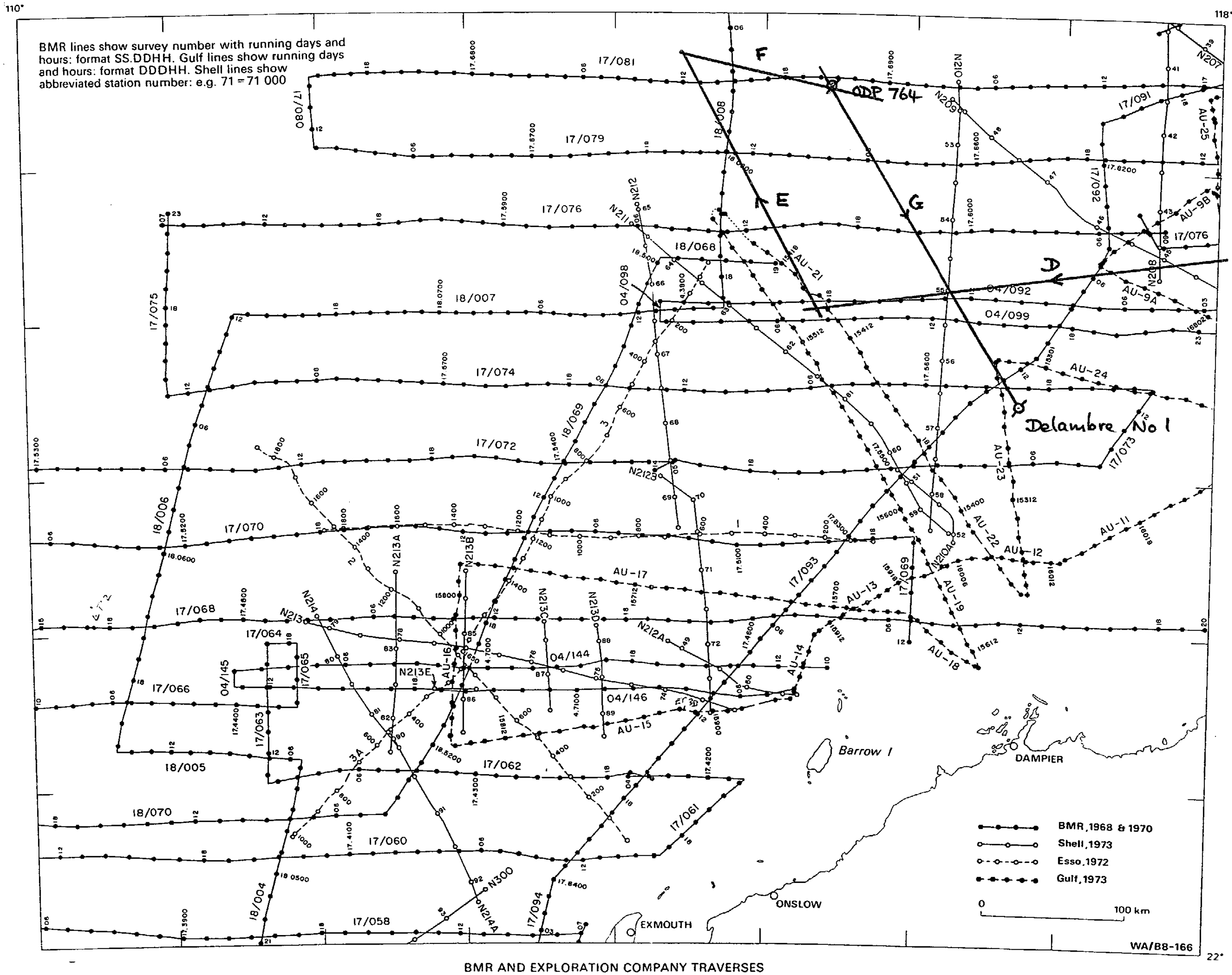


Fig. 25. Map of proposed regional seismic grid in northern Exmouth Plateau related to some existing data.

3. High-resolution seismic lines across ODP sites
(Estimated working time 4-5 days)

It is proposed to run 600km of detailed high-resolution seismic profiles, using a 1200m, 96 channel seismic cable and a watergun array, in the vicinity of ODP Sites 761 and 764, to delineate the shape and extent of the Triassic reefs found in Site 764 (Figures 19 and 26). If there is time available, this work will be preceded by an experimental line, using the same equipment, back along Line G from Delambre No 1 to ODP Site 764 (140km). The detailed survey will consist of an initial grid spaced 4km apart, with a follow-up grid in areas where reefs are clearly widespread, to reduce the line spacing to 2km. Including deployment and retrieval, and assuming a speed of 5 knots, 600km of seismic profiling should take 4 days, and 740km should take 5 days.

4. Dredging and coring on outer Rowley Terrace
(Estimated working time 5 days)

It is proposed to extensively dredge (and perhaps core) the walls of the canyons which cut the outer margin of the Rowley Terrace (Figures 19 and 20) in an endeavour to recover the Triassic, Jurassic and basement rocks that appear to crop out, on the evidence of existing seismic profiles. A transit of 180km from the Wombat Plateau will precede this work, which will also involve some bathymetric surveying. There are 3 major canyons and several subsidiary ones, and the structure is complex. At least 10 dredge hauls will be needed to address the known problems, which will take 5 days in these water depths with some preliminary surveying.

5. Dredging and coring on northern Exmouth Plateau
(Estimated working time 4 days)

It is proposed to dredge the eastern and western margins of the Wombat Plateau in the search for Triassic and Jurassic carbonates (Figures 19 and 24). Should suitable targets be apparent along the North Exmouth Hinge Line south of the Montebello Canyon, more dredging could be appropriate there. In total 6 dredges would be necessary. In addition, Quaternary cores should be taken at ODP Sites 760 and 761, as a complement to the ODP data. Including the transit from the Rowley Sub-basin the work should take up to 4 days.

EQUIPMENT REQUIREMENTS

High-resolution seismic reflection equipment

The aim of the high-resolution seismic program on the northern Exmouth Plateau is to define subtle structures in Late Triassic sequences, in water depths generally around 2000-2500 m, with overburden of 100-1000 m, and with total subsea penetration averaging 2 seconds. This clearly needs a high-resolution seismic system. In general the configuration will be :

- Source - watergun array.

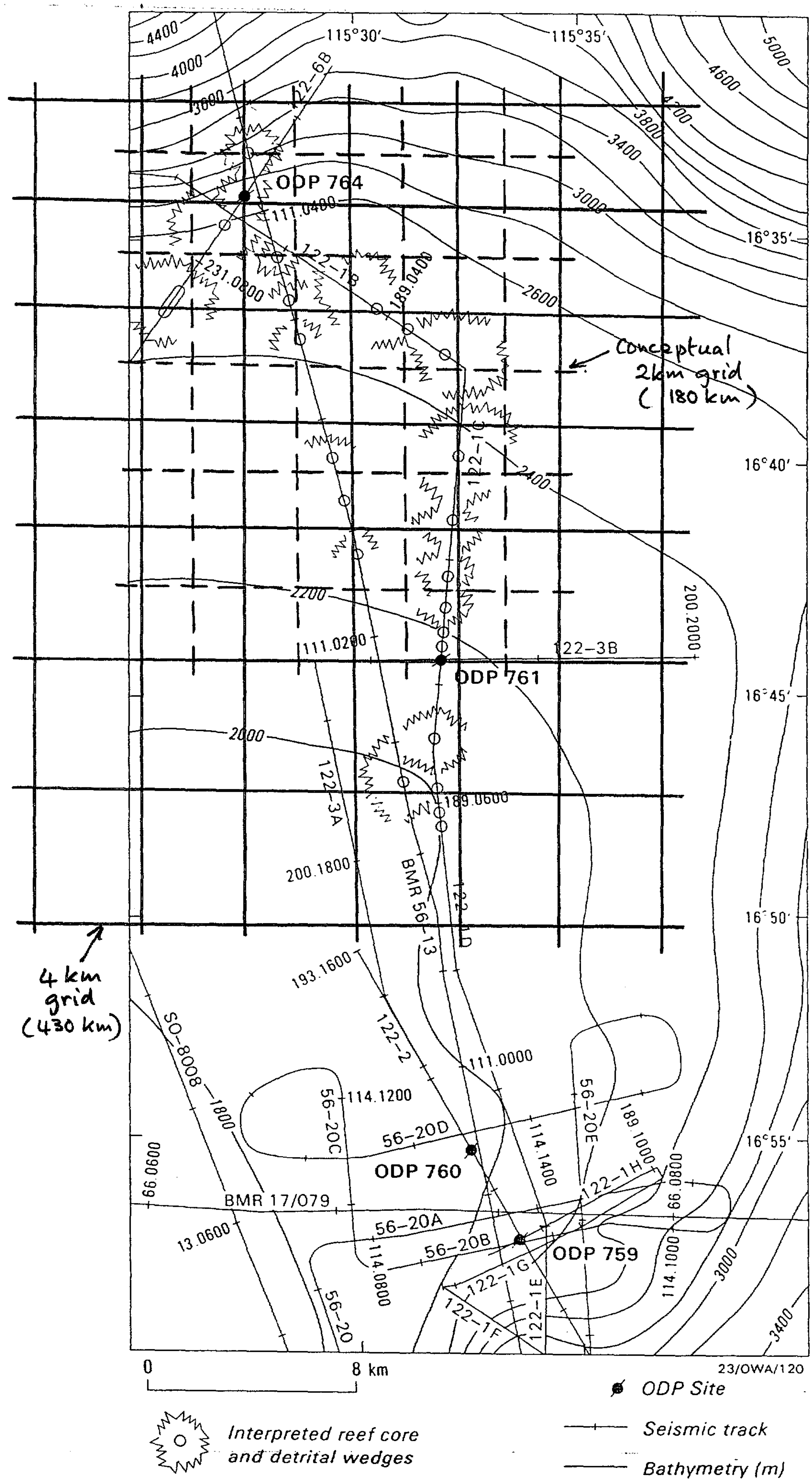


Fig. 26. Map of proposed detailed high-resolution seismic survey of the known area of Triassic reefs on the eastern Wombat Plateau.

. Cable - 1200 m active section
  - large offset, perhaps as much as 300 m.
  - 96 channel, 24 fold
  - 12.5 m groups
  - 25 m shot interval, i.e. 10 s shot rate
  - 2 ms recording
  - 5-6 second records

. Recording requires aboard-ship identification of features, and hence :

  - Direct display on quality EPC recorder
  - Playback facilities, either to give a brute stack, or failing that a filtered single channel display.

Conventional seismic reflection equipment

For the regional seismic ties, including those to Barcoo, East Mermaid and Delambre wells, relatively deep penetration will be needed, with target horizons in the Upper Triassic sequences deepening landward to up to 3.5 s (TWT). Because reasonable resolution will be required to identify reefal structures, a fairly high shot rate is necessary. In some cases 2 arrays may be necessary, but generally the configuration will be:

. Source - single airgun array

. Cable - 2400 m active section
  - offset 200 m
  - 96 channel, 48 fold
  - 25 m groups
  - 25 m shot interval, i.e. 10 s shot rate
  - 2 ms recording
  - 6 second records

Geological sampling equipment

. 4 heavy chain bag dredges, ideally with solid bridges, and appropriate weak links for water depths of 2000-5000 m (ca. 3000-8000 m cable out).

. At least 4 small pipe dredges for attachment to chain bag dredges.

. Appropriate shackles, steel rope, slings etc.

. Coring equipment for 5 gravity cores (10 m), and 2 piston cores (10 m).

Navigation

. Although, for much of the survey, conventional navigation would be satisfactory, it is clear that some form of real-time radio-navigation is almost essential for the 2 km-spacing seismic survey on the Wombat Plateau, where variable surface currents of up to 2 knots are known.

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