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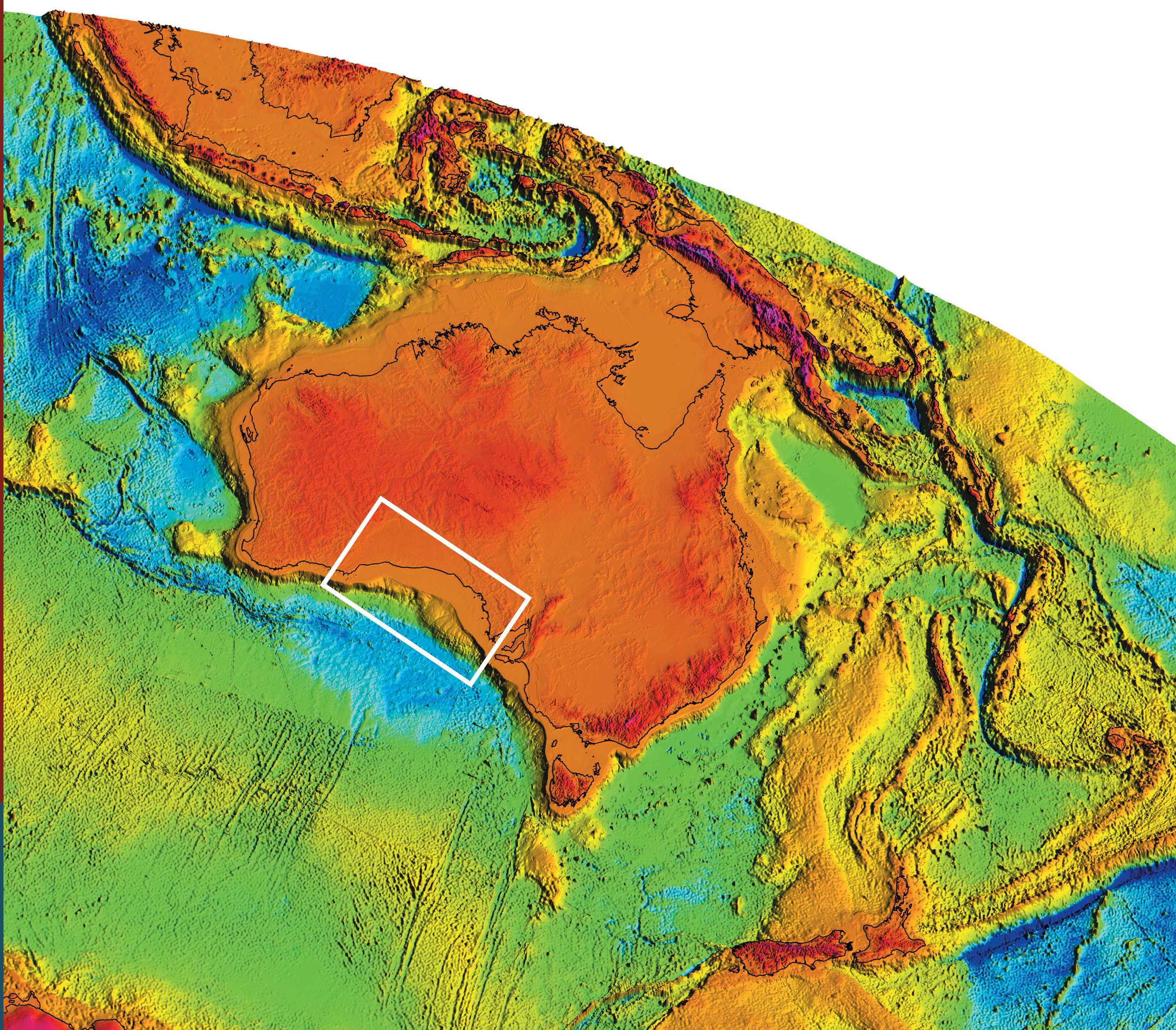

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Geoscience Australia Record 2003/02

SEQUENCE STRATIGRAPHIC CORRELATION OF ONSHORE AND OFFSHORE BIGHT BASIN SUCCESSIONS

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Southern Australia Regional Project

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ISSN: 1039-0073
ISBN: 0 642 46759 5

Bibliographic reference: Totterdell, J.M. and Krassay, A.A., 2003. Sequence stratigraphic correlation of onshore and offshore Bight Basin successions. Geoscience Australia, Record 2003/02.

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EXECUTIVE SUMMARY

This Record presents a new stratigraphic interpretation of Cretaceous sedimentary rocks encountered in petroleum exploration wells, stratigraphic holes and water bores along the southern Australian coast in Western Australia and South Australia. The Cretaceous succession in these wells is interpreted within the Bight Basin sequence stratigraphic framework, and is correlated with the thicker section farther basinward. The correlation is based on existing and recently commissioned biostratigraphic data, and the interpretation of seismic data on the continental shelf. The onshore wells contain a sedimentary section ranging in age from Valanginian to Campanian, and attributable to the Bronze Whaler, Blue Whale–White Pointer, Tiger and Hammerhead supersequences. The succession reaches a maximum thickness of more than 357 m in the Madura 1 well. The section preserved in these wells records the evolution of depositional environments near the northern margin of the Bight Basin, from areally restricted non-marine deposition in the Early Cretaceous, through increasingly marine, although shallow and anoxic, conditions, to the local development of a small deltaic complex in the Late Cretaceous. Organic-rich non-marine shales of Early Cretaceous age, and Late Cretaceous organic-rich facies of marine affinity have been identified in wells in the study area., providing new information about the nature and extent of potential source rocks in the Bight Basin.

INTRODUCTION

The Jurassic–Cretaceous Bight Basin is a large, mainly offshore basin on the southern Australian passive margin. The basin is poorly explored, with only nine petroleum exploration wells drilled in the entire offshore portion. All offshore wells were drilled within relatively thin successions on the margins of the main depocentres and none encountered significant hydrocarbons. Recent integrated well and seismic based studies by Geoscience Australia have led to an improved understanding of the tectonostratigraphic development of the Bight Basin. These studies were initially restricted to the offshore portion of the basin and were based on the sequence stratigraphic analysis of 8 petroleum exploration wells from the Eyre, Ceduna and Duntroon sub-basins, and the sequence stratigraphic and structural interpretation of over 10,000 line kilometres of new and reprocessed seismic data. However, Mesozoic Bight Basin rocks have also been encountered in petroleum exploration wells, stratigraphic holes and water bores along the southern Australian coast in Western Australia and South Australia. This Record presents a new interpretation of the Mesozoic section in these wells, placing it within the Bight Basin sequence stratigraphic framework, and proposes a correlation with the thicker section farther basinward. The correlation is based on existing and recently commissioned biostratigraphic data, and the interpretation of seismic data on the continental shelf. New organic geochemical data are reviewed in light of this revised stratigraphic framework, and provide some interesting insights into the petroleum potential of the region.

REGIONAL GEOLOGICAL SETTING

The Bight Basin extends along much of the southern Australian margin, from the southern tip of Western Australia to the western tip of Kangaroo Island (Fig. 1; Bradshaw et al., in prep.). The basin contains a Middle Jurassic to Late Cretaceous sedimentary succession that accumulated within four main depocentres – the Ceduna, Duntroon, Eyre and Recherche sub-basins. Areas of thin platform cover are present along the northern and eastern margins (Madura and Couedic shelves). Two perched half-graben systems in the far western part of the basin correspond to the Denmark and Bremer sub-basins. The basin underlies the continental shelf and slope, which includes two broad bathymetric terraces, in water depths ranging from less than 200 to over 4000 m. The largest and thickest depocentre, the Ceduna Sub-basin, contains a sedimentary section in excess of 15 km thick. The wells included in this study are all situated within the Madura Shelf, to the north of the Eyre and Ceduna sub-basins. (Fig. 2)

The Bight Basin is one of a series of Mesozoic to Cainozoic depocentres that developed along Australia's southern margin during a period of extension and passive margin evolution that commenced in the Middle–Late Jurassic (Fraser and Tilbury, 1979; Bein and Taylor, 1981; Willcox and Stagg, 1990; Stagg et al., 1990; Hill, 1995; Totterdell et al., 2000; Norvick and Smith, 2001). The basin was initiated during a period of Middle–Late Jurassic to Early Cretaceous upper crustal extension. A northwest–southeast to north–south extension direction superimposed on east–west and northwest–southeast oriented basement structures resulted in oblique to strongly oblique extension and the formation of *en echelon* half graben in the Eyre, inner Recherche, eastern Ceduna and Duntroon sub-basins. The extent of early extensional structures beneath the thick Ceduna Sub-basin cannot be determined at present, however, the anomalously thick nature of the sub-basin may indicate that Jurassic–Early Cretaceous rifts are present at depth. Post-rift thermal subsidence was followed by a phase of accelerated subsidence, which commenced in the Late Albian and continued until continental break-up in the Late Santonian–Early Campanian. During this phase of enhanced subsidence, the dominant structural feature was a system of gravity-driven detached extensional and contractional structures, which formed in the Cenomanian as a result of deltaic progradation. Evidence for upper crustal extension during this period is limited to Turonian–Santonian extensional faulting in the Ceduna Sub-basin and the reactivation and propagation of Cenomanian growth faults. The commencement of seafloor spreading at about 83 Ma (Sayers et al., 2001) was followed by a further period of thermal subsidence and the establishment of a passive margin.

Stratigraphic studies carried out in Western Australia have traditionally assigned Mesozoic rocks penetrated by drilling in the southeastern corner of the state to the Eucla Basin. The Eucla Basin was interpreted to encompass both Cainozoic and Mesozoic rocks and to extend southwards across the continental shelf to include the succession within the Eyre Sub-basin (e.g., Lowry, 1970). By comparison, the basin definition used in South Australia restricted the Eucla Basin to the Cainozoic section, and assigned Mesozoic rocks to the Bight Basin (Benbow et al., 1995). Geoscience Australia follows a modified South Australian usage in referring all Mesozoic rocks in the Denmark, Bremer, Eyre, Recherche, Ceduna and Duntroon sub-basins, and adjacent shelfal areas, including the onshore region, to the Bight Basin (Bradshaw et al., in prep; Fig. 1). The Eucla Sub-basin is restricted to the unconformably overlying Cainozoic sedimentary rocks, which extend from onshore regions south to approximately the foot of slope, where they are onlapped by sediments of the Australian–Antarctic Basin.

DATA AND METHODOLOGY

This study is based on the examination of six onshore and one offshore petroleum exploration and stratigraphic wells – Gambanga 1, Eyre 1, Madura 1, Eucla 1, Mallabie 1, Denman 1 and Apollo 1 – as well as eight water bores – Albala-Karoo bore, Nullarbor 5, 6, 7 and 8, Guinewarra bore (Nullarbor 1), Muddaugana bore, and Roberts bore (Table 1; Figs 2 and 3). Data availability for these wells varies considerably; well completion reports exist for wells drilled for petroleum exploration purposes, but only limited information is available for the water bores, some of which were drilled in the late 1800s.

Limited biostratigraphic information was available for a few of the wells. Palynological investigations of three wells – Gambanga 1, Eyre 1 and Madura 1 – were carried out by Ingram (1968) and Cookson and

Eisenack (1970, 1971). Micropalaeontological studies by N. H. Ludbrook accompanied the Gambanga 1 and Eyre 1 well completion reports (Exoil, 1960; Shiels, 1960), and studies of Madura 1 and adjacent water bores were included in Ludbrook (1958). In addition, a recent palynological review of wells from the Bight Basin (Morgan, 1999) includes assessments of both Mallabie 1 and Denman 1.

All available lithological, biostratigraphic and well log data was used to make an initial stratigraphic interpretation. In the case of the water bores, this required an interpretation of the rather meagre driller's records. The preservation of Madura 1 core materials presented some unique interpretation problems. Only representative sections of the core and cuttings have been kept, so existing core material represents only a fraction of the original material. These remnant cores represent well intervals ranging from 0.3 to 92.5 m. A sampling program was devised for all available wells, based, where possible, on a sequence stratigraphic assessment of those intervals likely to contain good source rock and/or favourable biostratigraphic facies.

Samples were taken from core, sidewall core and cuttings materials held by Geoscience Australia, Western Australian Department of Minerals and Energy, and Primary Industries and Resources South Australia, and were split for organic geochemical and biostratigraphic analysis. Palynological investigations were undertaken by Robin Helby (Helby, 2001; Appendix 1) and Eric Monteil, Geoscience Australia (Appendix 2), and the samples were assessed for foraminiferal assemblages by David Haig at the University of Western Australia (unpublished data). The results of these analyses allowed further refinement of the stratigraphic interpretation and enabled these wells to be placed within the sequence stratigraphic framework previously established in the offshore part of the basin (Totterdell, 2000). While seismic data is not available onshore, offshore seismic data sets extend well onto the Madura Shelf. High resolution seismic data, acquired in 1998–1999 by Fugro and Geoscience Australia, were used to correlate the thick Ceduna Sub-basin succession with the section at Apollo 1. In addition, seismic data from the Eyre Sub-basin and the adjacent shelf, acquired by JNOC in the early 1990s, allowed the onshore wells to be placed in a regional seismic stratigraphic context and provided some constraints on the interpretation.

The Cretaceous succession studied herein has previously been referred to the Loongana, Madura, Toondi and Nurina formations (see e.g., Cockbain and Hocking, 1989; Hocking, 1990; Hill, 1995)

SEQUENCE STRATIGRAPHIC FRAMEWORK

A new sequence stratigraphic scheme for the basins of the Great Australian Bight was proposed by Totterdell et al. (2000). This scheme is based on the identification of four megasequences, each related to a different basin phase, and their component 2nd-order supersequences (Fig. 4). Basin Phase 1 (BP1) records the initiation of sedimentation during the Middle–Late Jurassic period of intracontinental extension. The formation of a series of extensional and transtensional half graben appears to have been focused along pre-existing west–east and northwest–southeast striking basement trends, although the extent of Jurassic age extensional structures beneath the thick Ceduna Sub-basin succession is difficult to determine. Two rift-related depositional units have been identified – the Sea Lion and Minke supersequences (Fig. 5). These units consist of fluvial–lacustrine sandstone, siltstone and shale, with minor coal. The extensional phase was followed by a period of slow thermal subsidence throughout most of the Early Cretaceous (BP2). Deposition during this time was largely non-marine. The Berriasian Southern Right Supersequence consists mainly of fluvial–lacustrine sandstone and claystone, while the Valanginian to mid-Albian Bronze Whaler Supersequence is a thick dominantly fine-grained lacustrine succession. Some marine influence is evident within the upper, Aptian–Albian part of the Bronze Whaler Supersequence. An abrupt increase in subsidence rate in the mid-Albian signalled the start of the third basin phase (BP3). This period of accelerated subsidence coincided with a period of rising global sea level This combination of factors resulted in a high rate of creation of accommodation, the first major marine flooding event in the basin and the widespread deposition of marine silts and shales of the mid-Albian to early Cenomanian Blue Whale Supersequence (Figs. 5 and 6). The present-day distribution of the supersequence indicates that the seaway at that time extended along the southern margin from the open sea in the west (Fig. 7). Progradation of deltaic sediments into this seaway (White Pointer Supersequence) commenced in the Cenomanian, following uplift and erosion along the eastern margin of the continent. Deposition of the White Pointer Supersequence was followed by the accumulation of the marine–marginal marine mixed clastic sediments of the Turonian–Santonian Tiger Supersequence. Continental break-up in the Late Santonian was followed by a period of thermal subsidence and the establishment of the southern Australian passive margin (BP4). It was during this phase that a second large progradational delta developed, represented by the sand-rich fluvial, deltaic and marine sediments of the Hammerhead Supersequence (Krassay and Totterdell, in press; Fig. 6). A dramatic reduction in sediment supply at the end of the Cretaceous saw the abandonment of deltaic deposition and the development of a cool-water carbonate margin.

The geoseismic sections presented in Figures 5, 6, 8 and 9 illustrate the stratigraphic and structural architecture of the offshore Bight Basin. These sections clearly show the distribution of the early extensional structures in the Eyre and Recherche sub-basins and the geometry of the thick Ceduna Sub-basin succession. Figure 9 illustrates the thin nature of the sedimentary section on the Madura Shelf.

SEQUENCE STRATIGRAPHIC INTERPRETATION OF ONSHORE WELLS

BRONZE WHALER SUPERSEQUENCE

The oldest Mesozoic sedimentary rocks identified in this study are the sandstone, siltstone, shale and minor coal of the Bronze Whaler Supersequence (Figs 4, 10 and 11). This unit is relatively widespread and directly overlies basement in the westernmost part of the study area (Fig. 10). Palynological assemblages of Valanginian to Aptian age (*B. limbata*) have been identified in Gambanga 1, and a poorly-dated sandstone-dominated section of possibly Barremian to Aptian age occurs at the base of Madura 1. The Aptian to Early Albian dinocyst zones *O. operculatum*, *D. davidii* and lower *M.tetracantha* have been identified in Gambanga 1, Madura 1, Mallabie 1 and Denman 1 (Appendix 1). In addition, foraminifera of Barremian to Early Aptian age were identified in mudstones near the base of Madura 1 (D. Haig, University of Western Australia, pers. comm.). The presence of dinocyst and foraminifera assemblages indicates there was a significant, and increasing, marine influence during deposition of upper Bronze Whaler Supersequence.

In water bores east of Eucla 1, an undated fine-grained succession unconformably underlies the Cainozoic Eucla Basin succession (Fig. 10). These rocks are assigned to the Bronze Whaler Supersequence due to their similarity to the well-dated section in Mallabie 1. There, the Bronze Whaler Supersequence is 154 m thick and consists of a sandstone dominated unit overlain by a mudstone unit of equivalent thickness. The supersequence unconformably overlies Permian glacial sedimentary rocks and is directly overlain by an Eocene sandstone. In the Mallabie 1 well, a thin conglomeratic interval directly overlies the Permian section. Similar conglomeratic rocks occur at the base of the fine-grained section in several water bores to the east and west of Mallabie 1, namely Guinewarra bore, Nullarbor 8, Roberts bore, Nullarbor 5 and Nullarbor 6.

Geochemical sampling of the Bronze Whaler Supersequence identified one interval containing organic-rich rocks in Gambanga 1 (Fig. 12). Samples from a core at 366–369 m yielded total organic carbon

(TOC) values of 8.8–10.1%. These readings came from a highly carbonaceous black–brown shale of waxy appearance, which was classified as a terrestrial oil shale. Geochemical analyses indicate a strong non-marine signature (Boreham et al., 2001).

The available lithological and biostratigraphic data indicate that initial deposition of the Bronze Whaler Supersequence was in non-marine environments in the western part of the study area. The presence of a terrestrial oil shale, and limited seismic evidence of small rift structures in the adjacent offshore area (Fig. 13), suggest that lacustrine conditions may have developed in isolated fault-controlled depocentres. The increasing abundance of foraminifera and dinocyst assemblages indicate that marine conditions became more pervasive during the Aptian and Albian. Only the upper, marine part of the Bronze Whaler Supersequence was deposited in the eastern part of the study area (east of Eucla 1). In this area, the sequence boundary at the base of the succession also represents a second-order scale transgressive surface. As this area is near the depositional margins of the basin, this boundary probably also approximates the maximum flooding surface for the supersequence.

BLUE WHALE AND WHITE POINTER SUPERSEQUENCES

In the westernmost part of the study area, in the Eyre 1, Madura 1 and Eucla 1 wells, the Bronze Whaler Supersequence is overlain by a mudstone dominated succession of Late Albian–Cenomanian age (Fig. 10). This section is assigned to the Blue Whale and White Pointer supersequences. In offshore wells, the sequence boundary between these two supersequences occurs within the Cenomanian section, at the base of the *A. distocarinatus* spore–pollen zone (Fig. 4). This sequence boundary could not be confidently identified in the onshore wells due to the absence of key well logs such as gamma-ray and sonic in both Eyre 1 and Madura 1, and because the remaining lithological samples in Madura 1 cannot be unambiguously placed in their correct downhole position. Palynological studies of samples from Eyre 1 by R. Helby (Appendix 1) and E. Monteil (Appendix 2), suggest that the boundary may occur at approximately 448 m in that well, however this is not consistent with the lithological (core and cuttings) data, which shows that this point occurs within a monotonous carbonaceous mudstone interval (Fig. 10). The most obvious point at which to place a major sequence boundary, based on lithological data, is at 427 m, where a shallow marine glauconitic and carbonaceous sandstone directly overlies a deeper water marine mudstone interval (Shiels, 1960). In the absence of good well log data, these apparently contradictory data sets could not be reconciled.

The basal parts of the Blue Whale–White Pointer succession in Eyre 1 and Madura 1 contain Late Albian–Cenomanian foraminiferal assemblages (D. Haig, University of Western Australia, pers. comm.). The oldest dinocyst assemblages (*X. asperatus*) occur within the thin Blue Whale Supersequence preserved in Eucla 1, and the basal 40 m of the Blue Whale–White Pointer succession in Eyre 1 (Appendix 1). The youngest fossil assemblages identified within the Blue Whale–White Pointer succession are Late Cenomanian in age (Appendix 2).

Deposition of this succession took place in dominantly shallow marine environments. Hill (1995) reported that the section in Madura 1 was dominantly fine grained and monotonous, however in Eyre 1, the basal part of the succession is dominated by medium grained, well sorted quartz sandstone (Shiels, 1960). This section is overlain by 56 m of monotonous dark grey carbonaceous mudstone, which appears to have been deposited in an anoxic shallow marine environment. Geochemical sampling of this interval (Core 20, 426.7–429.8 m) identified organic rich rocks (3% TOC) with a strong marine signature (Boreham et al., 2001; Fig 12). The mudstone interval is in turn overlain by glauconitic sandstones containing abundant carbonaceous material (Shiels, 1960), probably deposited in a deltaic environment. This succession of lithofacies is consistent with the depositional history of the Blue Whale–White Pointer interval seen in the offshore parts of the basin. The deposition of the Blue Whale Supersequence reflects the maximum marine flooding of the basin. The bland seismic character of the Blue Whale Supersequence throughout much of the basin suggests the widespread deposition of fine grained facies during the late Albian–Cenomanian (Totterdell et al., 2000). The depositional setting was a narrow restricted seaway that extended eastwards from open ocean in the west (Fig. 7). During the Cenomanian there was an influx of deltaic sediment into the narrow seaway and the establishment of a large delta on the northeastern margin of the basin. The presence of deltaic–shallow marine facies in Eyre 1 is consistent with seismic and palynological evidence of a smaller, subsidiary deltaic system in the nearby Eyre Sub-basin (Monteil, 2002).

TIGER SUPERSEQUENCE

In Madura 1, the Blue Whale–White Pointer section is overlain by a thin Tiger Supersequence succession (Fig. 10). This interval has been identified due to the presence of Turonian–Santonian palynological assemblages (*P. mawsonii* spore–pollen zone/*C. striatoconus* dinocyst zone; Appendices 1 and 2). Limited available lithological information suggests that the Tiger Supersequence in Madura 1 is similar to the underlying section, mainly consisting of mudstone and siltstone. There is no palynological evidence that the Tiger Supersequence is present in any other onshore well.

In offshore parts of the basin, the Tiger Supersequence is a dominantly aggradational succession, deposited in marginal marine–marine environments during a time of high relative sea level and steady tectonic subsidence (Figs 5 and 6). On the northern and northeastern margins of the basin, the Tiger Supersequence is truncated beneath the Eucla Basin close to the edge of the Ceduna Sub-basin (Figs 6, 8 and 9). It is also largely absent from the Eyre Sub-basin (Fig. 5). The preservation of a thin Tiger Supersequence in Madura 1, so close to the margin of the basin, is unusual, but it may give an indication of the original depositional extent of the supersequence.

HAMMERHEAD SUPERSEQUENCE

A Campanian sandstone-dominated succession present in Gambanga 1, Eyre 1 and Madura 1 is assigned to the Hammerhead Supersequence (Fig. 10). This succession consists of greensand, glauconitic medium-coarse grained sandstone and glauconitic siltstone, and reaches a maximum thickness of 300 m in Eyre 1. It unconformably overlies increasingly older sequences from east to west (Fig. 10)

A strong marine influence during deposition is indicated by the presence of glauconite and the identification of marine fossil assemblages. The Campanian dinocyst zone *X. australis* was recognised in Eyre 1 and the dinocyst zone *N. aceras* identified in both Gambanga 1 and Madura 1 (Appendix 1). Rare fish teeth were identified in Madura 1 (D. Haig, University of Western Australia, pers. comm.).

The Hammerhead Supersequence intersected in these three wells is interpreted to have been deposited in a small delta to the west of the main Hammerhead Delta in the Ceduna Sub-basin. The larger Hammerhead delta developed seaward of a river mouth located on the western side of the Gawler Block. The stratal architecture and structural fabric of the delta (Fig. 6) indicate that it prograded to the southwest, into a narrow seaway (Krassay and Totterdell, in press). The smaller delta preserved in the Madura Shelf wells appears to have formed on the northern coast of the seaway during the same accommodation cycle, possibly fed by a river, or rivers, draining Proterozoic terranes to the north.

OFFSHORE–ONSHORE CORRELATION

Due to the onshore location of the wells, seismic data cannot be used to unambiguously tie the section in these wells to the offshore succession. Offshore seismic data sets, however, do extend well onto the Madura Shelf (Fig. 3), allowing the onshore wells to be placed in a regional seismic stratigraphic context. The thick Ceduna Sub-basin succession and the succession at Potoroo 1 were correlated with the section at Apollo 1 using a single high-resolution line (HRGAB-116; Fig. 9). In addition, the extensive JNOC 1990 seismic survey, covering the Eyre Sub-basin and the adjacent shelf, extends north almost to the coast south of the Gambanga 1, Eyre 1 and Madura 1 wells (Fig. 3).

Seismic data shows that between Potoroo 1 and Apollo 1, the Cretaceous supersequences dip slightly basinwards. They dip to the south and are progressively truncated by the unconformity at the base of the Cainozoic succession (Figs 8 and 9). At Apollo 1, only a thin Blue Whale section is present, overlying the Bronze Whaler Supersequence (Fig. 11). The dip of this section and progressive truncation to the north partly explains the presence of the Bronze Whaler Supersequence, and the absence of younger sequences, in the wells and bores to the north e.g. Denman 1, Mallabie 1 and the Nullarbor bores. The Bronze Whaler Supersequence is, however, twice as thick in these wells than in Apollo 1, possibly indicating some local control on subsidence.

Farther west, to the north of the Eyre Sub-basin, the thin Cretaceous section is flat-lying and the basement surface is incised. The Eyre Sub-basin is characterised by a series of *en-echelon* Middle Jurassic–earliest Cretaceous half graben. Post-rift successions of the Early Cretaceous Southern Right and Bronze Whaler supersequences are largely confined to the half graben (Fig. 5). In contrast, transgressive and highstand deposits of the Blue Whale Supersequence extend beyond the confines of the older half graben system and overlie basement on the uplifted footwalls and across the shelf (Fig. 5). This succession can be traced on the JNOC seismic data over much of the Madura Shelf to the north and northwest of the Eyre Sub-basin, where it generally unconformably overlies basement rocks. In some areas in the western part of the seismic grid, it unconformably overlies an older Permian(?) channel complex (Stagg et al., 1990). In other areas the Blue Whale Supersequence conformably overlies a patchy, but thin, succession that infills topographic depressions and/or channels. This unit is believed to represent remnants of the Bronze Whaler Supersequence, based on the presence of this unit in the wells to the north.

A small half graben has been identified on a few seismic lines in the far north of the JNOC grid (Fig. 13). This half graben lies south-southwest of the Eyre 1 well (Fig. 3). An undifferentiated Blue Whale–White Pointer succession is interpreted to overlie the shelf and half graben; the Bronze Whaler Supersequence is interpreted to lie largely within the confines of the half graben (Fig. 13). This is similar to the situation in the Eyre Sub-basin, where, although deposition of the Bronze Whaler Supersequence was concentrated over the compacting and subsiding half graben, its stratal architecture is dominantly that of sag-fill (Fig. 5). The poorly-imaged basal portion of the section (Fig. 13) appears to have a rift-fill character. The reflections within this section lie at an angle to those above and appear to diverge towards the bounding fault. This part of the section may therefore be equivalent to Sea Lion and Minke supersequences, which form the rift-fill in the Eyre Sub-basin. Sedimentary rocks of this age were not intersected by the wells immediately to the north, although Madura 1 did not reach basement (Fig. 10). A thin seismically distinct unit at the top of the Cretaceous section is tentatively identified as Hammerhead Supersequence, based on the presence of the supersequence in the Gambanga 1, Eyre 1 and Madura 1 wells.

PETROLEUM IMPLICATIONS

The results of this study have implications for the nature and distribution of potential source rocks in the Bight Basin. Recent assessments of the potential petroleum systems in the basin, based on the integration of geochemical well data and the sequence stratigraphic interpretation of seismic data (Blevin et al., 2000; Totterdell et al., 2000; Struckmeyer et al., 2001), concluded that several stratigraphic intervals are likely to contain potential source rocks. The potential source facies are:

- Middle Jurassic–Berriasian lacustrine shale (Sea Lion and Minke supersequences)
- Berriasian fluvial–lacustrine shale and coal (Southern Right Supersequence)
- Aptian–Albian marine shale (upper Bronze Whaler Supersequence)
- Late Albian–Cenomanian marine shale (Blue Whale Supersequence)
- Cenomanian marine–deltaic shale and coal (White Pointer Supersequence)
- Turonian–Santonian marine–marginal marine shale (Tiger Supersequence)
- Santonian–Campanian marine–deltaic shale and coal (Hammerhead Supersequence)

The identification of organic-rich lacustrine facies of Barremian age (Bronze Whaler Supersequence) in Gambanga 1 (Boreham et al., 2001; Fig. 12) provides evidence of yet another potential source rock facies in the basin. Thick successions of lacustrine to fluvial Bronze Whaler Supersequence are present in both the Eyre (Fig. 5) and Duntroon sub-basins, and are interpreted on seismic data along the northern and eastern margins of the Ceduna Sub-basin (Figs 5 and 6). The presence of an oil-shale in Gambanga 1 highlights the potential for the occurrence of such facies within these thicker successions.

The organic-rich marine facies identified within the Albian–Cenomanian Blue Whale–White Pointer succession in Eyre 1 (Fig. 12) was geochemically analysed to determine whether it had geochemical similarities with asphaltites found stranded along the Australian southern margin (Boreham et al., 2001). These studies found that the sample from Eyre 1 was less mature than the asphaltites and had a pronounced terrestrial plant input, consistent with a shallow marine depositional environment. Although the sampled section has some sedimentary indicators of anoxic depositional conditions (Shiels, 1960), Boreham et al. (2001) concluded that the asphaltites were derived from more anoxic, deeper water facies. Boreham et al. (2001) also found strong similarities between the asphaltites and immature organic-rich rocks of the Toolebuc Formation (Eromanga Basin). Figure 7 shows the broad palaeogeographical and palaeolatitudinal similarities between the Albian “Blue Whale” and “Toolebuc” seaways. The presence of the Blue Whale Supersequence in Eyre 1, Madura 1 and Eucla 1 provides the only control on the northwards extent of the “Blue Whale” seaway. The presence of organic-rich facies so close to the depositional edge of the Blue Whale and White Pointer supersequences, and the palaeogeography at the time (narrow restricted seaway; Fig. 7), are positive indicators for the potentially widespread presence of source facies of this age throughout the basin.

CONCLUSIONS

The Cretaceous section in onshore Bight Basin wells and bores has been interpreted using the sequence stratigraphic scheme previously developed for the offshore basin succession. The onshore wells contain sedimentary rocks ranging from Valanginian to Campanian in age, and attributable to the Bronze Whaler, Blue Whale–White Pointer, Tiger and Hammerhead supersequences. The lithofacies, depositional environments and palaeogeographic evolution of the onshore succession are consistent with the depositional model for the larger, offshore, portion of the basin. The lower, Valanginian–

Aptian, non-marine portion of the Bronze Whaler Supersequence is restricted to the western part of the study area. Its location may be largely controlled by the presence of older half graben structures, such as that imaged on seismic data in the shallow offshore region. The upper, Aptian–Albian, marine-influenced part of the Bronze Whaler Supersequence has a broader distribution, reflecting an increase in accommodation related to rising relative sea level. An undifferentiated Blue Whale–White Pointer succession of Late Albian–Cenomanian age corresponds with the maximum marine flooding of the basin and the subsequent progradation of deltaic sediments into a narrow restricted seaway. In Madura 1, the Blue Whale–White Pointer succession is unconformably overlain by the Turonian–Santonian Tiger Supersequence. Based on seismic evidence, the presence of this unit in this part of the basin is unusual. The Tiger Supersequence, however, is a widespread aggradational dominantly marine unit in the offshore depocentres, and this occurrence may reflect is original depositional extent. An areally restricted occurrence of the Hammerhead Supersequence represents the progradation of a small delta on the northern margin of the basin in the Campanian during deposition of the larger deltaic complex in the Ceduna Sub-basin.

Non-marine and marine organic-rich facies encountered in Gambanga 1 and Eyre 1, respectively, provide new information about the nature and extent of potential source rocks in the Bight Basin. Lacustrine oil-shales within the Bronze Whaler Supersequence, such as that found in Gambanga 1, may have source potential in more deeply buried areas of the basin. The identification of organic-rich rocks with strong marine affinities near the depositional margins of the basin in Eyre 1, provides additional information about the palaeogeography of the area during the Albian–Cenomanian, and the source rock potential of sediments deposited in the restricted marine seaway.

ACKNOWLEDGMENTS

The authors wish to thank Chris Boreham and Virginia Passmore for sampling of cores and cuttings at the Geological Survey of Western Australia, and Primary Industries and Resources South Australia. We also wish to thank Lindell Emerton for drafting the figures, and Andrea Cortese for his assistance with Geoquest, Geolog and Petrosys. Heike Struckmeyer and Donna Cathro are thanked for their constructive reviews of the manuscript.

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Well name	***Drilled***	***TD (m)***	***Mz thickness (m)***	***Well type***	***Drilled by***
Albala-Karoo	1890	330	147	water	SA Eng.-In-Chief's Dept
Apollo 1	1975	876	240	petroleum exploration	Outback Oil
Denman 1	1966	240	170 +	stratigraphic	Outback Oil
Eucla 1	1964	222	10	stratigraphic	Alliance Petroleum
Eyre 1	1960	524	219	petroleum exploration	Exoil
Gambanga 1	1960	390	155	petroleum exploration	Exoil
Guinewarra	1892	389	159	water	SA Eng.-In-Chief's Dept
Madura 1	1902	640	357 +	stratigraphic	WA Public Works Dept
Mallabie 1	1969	1496	153	petroleum exploration	Outback Oil
Muddaugana	1923	242	101 +	water	SA Eng.-In-Chief's Dept
Nullarbor 5	1893	204	100	water	SA Eng.-In-Chief's Dept
Nullarbor 6	1899	305	74	water	SA Eng.-In-Chief's Dept
Nullarbor 7	1900	162	42	water	SA Eng.-In-Chief's Dept
Nullarbor 8	1902	457	181	water	SA Eng.-In-Chief's Dept
Roberts	1886	237	111 +	water	SA Eng.-In-Chief's Dept

Table 1. Wells and bores drilled in the onshore and shallow offshore Bight Basin

Appendix 1

A PALYNOLOGICAL RECONNAISSANCE OF SELECTED SAMPLES FROM EUCLA BASIN WELLS – ROBIN HELBY

INTRODUCTION

This project was commissioned by Dr Clinton B. Foster (Geoscience Australia) to provide a palynological reconnaissance of selected samples from six Eucla Basin wells in southwestern South Australia and southeastern Western Australia.

The material consisted of palynological slides from six wells:

Denman-1	26 ditch cuttings samples (between 250/60–780/90')
Eucla-1	2 ditch cuttings samples (669/77', 679/83')
Eyre-1	13 ditch cuttings samples, (1190/200–1690/700')
Gambanga-1	7 ditch cuttings samples and 3 conventional core samples (770/80–1250/60')
Madura-1	7 ditch cuttings samples and 4 conventional core samples (928/63–1991.5/2014')
Mallabie-1	9 ditch cuttings samples and 2 conventional core samples (632–1260/70')

APPROACH

Geoscience Australia provided palynological slides. A slide from each sample was examined for 15 minutes and an interim report was provided on the basis of these examinations. The samples were examined for a further 15 minutes and a rapid count of 100 specimens was then undertaken. These time limitations precluded fully comprehensive recording of the assemblages – with available time concentrated on the microplankton content of the samples.

Interpretations of the samples are expressed in terms of the Mesozoic zonation published in the Helby et al. (1987) paper and subsequently modified in Helby reports. A summary of the interpretations are set out on the Palynological Summary for each well.

A more comprehensive report (Helby, 2001), available through Geoscience Australia, contains the quantitative distribution of selected taxa illustrated on range charts/tables. These quantitative data are based on counts of at least 100 grains. Assemblage data from some of these wells, previously published by Cookson and Eisenack (1970, 1971) and Ingram (1968), is abstracted and included in that report.

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OUTBACK DENMAN No. 1 WELL - PALYNOLOGICAL SUMMARY

Depth Sample Concentration Preservation Diversity and Ratios Zone Age
Confidence

Deb:Pal MP SP MP%

rating

250/60ft	DC	High	P-F	<	42	30	75	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D2
260/70ft	DC	High	P-F	≤	39	27	64	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D2
290/300ft	DC	High	P-F	≤	33	27	34	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D2
310/50ft	DC	Mod.	P-F	≥	28	33	37	Upper *D. davidii* or older	2biii+	Late Aptian or older	D2
360/70ft	DC	Mod.	P-F	>	29	20	25	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
390/400ft	DC	Mod.	P-F	>	34	20	49	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
400/10ft	DC	Mod.	P-F	>	28	26	55	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
420/30ft	DC	High	P-F	≤	26	19	65	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
440/50ft	DC	High	P-F	≤	29	19	48	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
460/70ft	DC	High	P-F	<	31	18	68	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
480/90ft	DC	High	P-F	<	38	25	55	Upper *D. davidii* or older	2biiia+	Late Aptian or older	D1
503/04ft	DC	Mod.	P-F	>	44	21	46	*D. davidii* or older	2biii+	Late Aptian or older	D2
508/10ft	DC	High	P-F	≤	39	28	62	*D. davidii* or older	2biii+	Late Aptian or older	D2
512/13ft	DC	High	P-F	≤	41	31	44	*D. davidii* or older	2biii+	Late Aptian or older	D2
513/20ft	DC	High	P-F	≤	39	24	62	Upper *D. davidii* or older	2biii+	Late Aptian or older	D1
550/60ft	DC	High	P-F	≤	40	22	44	*D. davidii* or older	2biii+	Late Aptian or older	D2
580/90ft	DC	High	P-F	<	43	27	50	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
600/10ft	DC	High	P-F	≤	38	25	42	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
630/40ft	DC	High	P-F	≤	44	21	65	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
660/70ft	DC	High	P-F	<	26	29•	30	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
680/90ft	DC	High	P-F	<	23	24•	15	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
690/700ft	DC	Mod.	P-F	>	30	22•	13	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
710/20ft	DC	High	P-F	<	46	21	41	*D. davidii* to *O. operculata* or older	2biii/c+	Aptian or older	D4
750/60ft	DC	High	P-F	<	35	34	19	Lower *O. operculata* or older	2ciia+	Mid to early Aptian	D2
770/80ft	DC	High	P-F	<	31	35•	12	Lower *O. operculata* or older	2ciia+	Mid to early Aptian	D2
780/90ft	DC	High	P-F	<	43	26•	38	Lower *O. operculata* or older	2ciia+	Mid to early Aptian	D2

- Megaspores recorded

Confidence rating:	A Core	1 Excellent	High diversity assemblage with key zone species
GA Stratdat format	B Sidewall Core	2 Good	Moderate diversity assemblage with key zone species
	C Coal cuttings	3 Fair	Low diversity assemblage with key zone species
	D Ditch cuttings	4 Poor	Mod.-high diversity assemblage without key zone species
	E Junk Basket	5 Very poor	Low diversity assemblage without key zone species
	F Miscellaneous	>5	

EUCLA NO. 1 WELL - PALYNOLOGICAL SUMMARY

Depth	Sample	Concentration	Preservation	Deb:Pal	MP	SP	MP%	Zone		Age	Confidence rating
669/77'	DC	High	P-F	<	38	26	76	*Xenascus asperatus* or older	1aiii+	Late Albian	D4
679/83'	DC	High	P-F	≈	35	28	60	*Xenascus asperatus* or older	1aiii+	Late Albian	D2

Confidence rating: GA Stratdat format					
	A	Core	1	Excellent	High diversity assemblage with key zone species
	B	Sidewall Core	2	Good	Moderate diversity assemblage with key zone species
	C	Coal cuttings	3	Fair	Low diversity assemblage with key zone species
	D	Ditch cuttings	4	Poor	Mod.-high diversity assemblage without key zone species
	E	Junk Basket	5	Very poor	Low diversity assemblage without key zone species
	F	Miscellaneous	>5		
	G	Outcrop			

Sidewall core rating:

1 sidewall core totally crushed - substantial contamination
2 substantial mud penetration - minor to substantial contamination possible
3 minor to moderate mud penetration - minor contamination possible
4 mud penetration not evident - should be no mud contamination

EXOIL EYRE No. 1 WELL - PALYNOLOGICAL SUMMARY

Depth	Sample	Concentration	Preservation	Diversity and Ratios Deb:Pal	MP	SP	MP%		Zone		Age Confidence rating
1190/1200'	DC	Mod.	P-F	>	13	28	16	Indeterminate	Ca+	Campanian or older	D4
1220/1230'	CC 29 •	-	-	-	5	-	-	*X.australis* or older	Ca2a	Early Campanian or older	A3
1340/1350'	DC	Mod.	P-F	>	25	10	90	*X.australis* or older	Ca2a	Early Campanian or older	D4
1405/1410'	DC	Mod.	P-F	>	31	6	94	Upper *P. infusorioides* or older	1aia+	Turonian or older	D4
1410/1420'	DC •	-	-	-	18	-	-	Upper *P. infusorioides* or older	1aia+	Turonian or older	D4
1440/1450'	DC	Mod.	P-F	>	33	15	90	Upper *P. infusorioides* or older	1aia+	Turonian or older	D4
1450/1460'	DC	Mod.	P-F	>	38	12	86	Upper *P. infusorioides* or older	1aia+	Turonian or older	D4
1460/1470'	DC	Mod.	P-F	>	38	12	84	*A. distocarinatus* or older	1aiia+	Mid Cenomanian or older	D4
1530/1540'	DC	Mod.	P-F	>	47	27	65	*A. distocarinatus* to *X. asperatus*	1aii/iii+	Cenomanian to late Albian	D4
1560/1570'	DC	Mod.	P-F	>	48	27	51	*D. multispinum* or older	1aii+	Mid Cenomanian or older	D2
1570/1580'	DC	Mod.	P-F	>	47	33	67	*D. multispinum* or older	1aii+	Mid Cenomanian or older	D2
1580/1585'	DC	Mod.	P-F	>	42	22	59	*X. asperatus* or older	1aiii+	Late Albian	D4
1585/1590	DC	Mod.	P-F	>	43	29	59	*X. asperatus* or older	1aiii+	Late Albian	D4
1670/1680'	DC	Mod.	P-F	>>	44	25	62	*X. asperatus* or older	1aiii+	Late Albian	D4
1690/1700'	DC	Mod.	P-F	>>	32	24	60	*X. asperatus* or older	1aiii+	Late Albian	D4

• Data from Ingram (1968) and Cookson and Eisenack (1970, 1971).

Confidence rating: GA Stratdat format	A Core	1 Excellent	High diversity assemblage with key zone species
	B Sidewall Core	2 Good	Moderate diversity assemblage with key zone species
	C Coal cuttings	3 Fair	Low diversity assemblage with key zone species
	D Ditch cuttings	4 Poor	Mod.-high diversity assemblage without key zone species
	E Junk Basket	5 Very poor	Low diversity assemblage without key zone species
	F Miscellaneous	>5	
	G Outcrop		

Sidewall core rating:
1 sidewall core totally crushed - substantial contamination
2 substantial mud penetration - minor to substantial contamination possible
3 minor to moderate mud penetration - minor contamination possible
4 mud penetration not evident - should be no mud contamination

EXOIL GAMBANGA No, 1 WELL - PALYNOLOGICAL SUMMARY

Depth	Sample	Concentration	Preservation	Diversity and Ratios				Zone		Age	Confidence rating
				Deb:Pal	MP	SP	MP%				
770/80'	DC	V.low	P-F	>>	15	4	-	Indeterminate	-	Tertiary or older	D5
1070/80'	DC	Low	P-F	>>	29	26	39	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D2
1080/90'	DC	Low	P-F	>>	28	16	61	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D2
1090/1100'	DC	Low	P-F	>>	23	29	54	Lower *M. tetracantha* or older	2biib+	Early Albian or older	D4
1120/30'	DC	Mod.	P-F	>>	17	21	33	*D. davidii* or older	2biii+	Late Aptian or older	D2
1150/60'	DC	Mod.	P-F	>	9	20	1	*D. davidii* or older •	2biii+	Late Aptian or older	D5
1202.33'	CC	High	P-F	<	5	22	1	*B. limbata*	2biii-3c	Aptian to Valanginian	A2
1204.33'	CC	High	P-F	<	6	22	5	*B. limbata*	2biii-3c	Aptian to Valanginian	A2
1250/60'	DC	Mod.	P-F	>>	6	18	2	*B. limbata* or older	2biii-3c	Aptian to Valanginian or older	D4

• Possibly *B. limbata* Zone, with some late Aptian caving
Early Campanian taxa noted in ditch cuttings samples - at lower levels.

Confidence rating: GA Stratdat format			
A Core	1	Excellent	High diversity assemblage with key zone species
B Sidewall Core	2	Good	Moderate diversity assemblage with key zone species
C Coal cuttings	3	Fair	Low diversity assemblage with key zone species
D Ditch cuttings	4	Poor	Mod.-high diversity assemblage without key zone species
E Junk Basket	5	Very poor	Low diversity assemblage without key zone species
F Miscellaneous	>5		
G Outcrop			

WAPWD MADURA No. 1 WELL - PALYNOLOGICAL SUMMARY

Depth	Sample	Concentration	Preservation	Diversity and Ratios Deb:Pal	MP	SP	MP%	Zone		Age	Confidence rating
928/63'	DC	Mod.	P-F	>	40	24	74	*N. aceras* or older	Ca2b+	Early Campanian or older	D2
963/98'	DC	High.	P-F	<	25	21	63	*N. aceras* or older	Ca2b+	Early Campanian or older	D2
1073/04'	CC	Mod.	P-F	>	59	25	79	*C. striatoconus* to *A. suggestium*	Co-Sa2	Coniacian to early Santon	A4
1104/07'	CC	Mod.	P-F	>	55	11	96	*C. striatoconus* to *A. suggestium*	1aia-Co	Mid Turonian to Coniacian	A4
1209/27'	CC	Low	P-F	>>	5	18	5	*P. mawsonii*	1aia-Co	Turonian to Coniacian	A5
1471/86'	DC	Mod.	P-F	>	53	29	65	*D. multispinum* or older	1aii+	Mid Cenomanian or older	D2
1486/523'	DC	Mod.	P-F	<	42	30	64	*D. multispinum* or older	1aii+	Mid Cenomanian or older	D2
1838/77'	CC	Mod.	P-F	>	37	13	78	*D. davidii*	2biii	Late Aptian	A1
1960/78'	CC	Mod.	P-F	≈	37	26	46	Lower *O. operculata*	2ciia	Mid to early Aptian	A2
1978/79'	CC	High	VP-P	<	21	30	<	Lower *O. operculata*	2ciia	Mid to early Aptian	A5
1991.5/2014'	DC	High	P-F	<	46	23	56	Lower *O. operculata*	2ciia	Mid to early Aptian	D2

Confidence rating:
GA Stratdat format

A Core — 1 Excellent — High diversity assemblage with key zone species
B Sidewall Core — 2 Good — Moderate diversity assemblage with key zone species
C Coal cuttings — 3 Fair — Low diversity assemblage with key zone species
D Ditch cuttings — 4 Poor — Mod.-high diversity assemblage without key zone species
E Junk Basket — 5 Very poor — Low diversity assemblage without key zone species
F Miscellaneous — >5
G Outcrop

Sidewall core rating:
1 sidewall core totally crushed - substantial contamination
2 substantial mud penetration - minor to substantial contamination possible
3 minor to moderate mud penetration - minor contamination possible
4 mud penetration not evident - should be no mud contamination

Appendix 2

BIOSTRATIGRAPHIC REASSESSMENT OF PALYNOLOGICAL SAMPLES FROM MADURA 1 AND EYRE 1 – ERIC MONTEIL

INTRODUCTION

A palynological reassessment of samples from critical sections in Eyre 1 and Madura 1 was requested by Jennifer Totterdell (Project Leader, Bight Basin Studies), in order to better understand the stratigraphy of these intervals. Initial reconnaissance palynological studies by Robin Helby (2001; Appendix 1, this Record) indicated the presence of significant sections of Turonian-Santonian age rocks in these wells. Seismic data from the offshore part of the basin shows that the Turonian-Santonian Tiger Supersequence is generally absent from the Madura Shelf. Therefore, the possible presence of this interval in the onshore wells required further investigation.

The data presented in this Appendix detail the palynological reassessment of three samples from Madura 1 and four samples from Eyre 1, as undertaken by Eric Monteil (Geoscience Australia). This study confirms two Turonian-Santonian age determinations in Madura 1, but indicates that the samples from Eyre 1 could be interpreted as being Late Cenomanian in age.

Issues related to the preservation of core material from Madura 1 are outlined in the Data and Methodology section of this Record.

MADURA 1

Core Sample 327-336 m (1073′-1104′)

Taxa listed by R. Helby:

- Dinocysts: *Acanthaulax wilsonii*, *Canningia* spp., *Chlamydophorella* spp., *Compositosphaeridium paracostatum*, *Cribroperidinium* spp., *Diconodinium* spp., *Heterosphaeridium* spp., *Hystrichodinium* spp., *Hystrichosphaeridium tubiferum*, *Odontochitina costata* (s.l.), *Oligosphaeridium complex*, *Paleohystrichophora infusorioides*, *Spinidinium lanternum*, *Spinidinium* spp., *Spiniferites* spp., *Trichodinium* spp., *Trithyrodinium* spp., unidentified chorate cysts, unidentified microplankton, *Xenascus* sp. (square), *Actinotheca aphroditae, Apteodinium granulatum*, *Batiacasphaera spp.,* *Cometosphaeridium* spp., *Coronifera oceanica*, *Disphaeria macropyla*, *Escharisphaeridia* spp., *Exochosphaeridium bifidum*, *Exochosphaeridium* spp., *Florentinia* spp., *Hystrichosphaeridium palmatum, Isabelidinium balmei, Kiokansium polypes*, *Leptodinium* spp., *Maduradinium pentagonum*, *Oligosphaeridium pulcherrimum*, *Palaeoperidinium cretaceum*, *Silicisphaera temera, Tanyosphaeridium* spp., *Trigonopyxidia ginella, Valensiella* spp.

- Spores and pollen: *Amosopollis cruciformis*, bisaccates undifferentiated, *Camerozonosporites bullatus*, *Corollina* spp., *Cyathidites* spp., *Gleicheniidites* spp., *Microcachryidites antarcticus*, *Perotrilites oepikii*, unidentified spore-pollen, *Cicatricosisporites pseudotripartitus*, *Cicatricosisporites* spp., *Australopollis obscuris*, *Ceratosporites* spp., *Clavifera triplex*, *Phyllocladidites mawsonii*, *Podocarpidites* spp., *Tricolpites* spp., *Vitreisporites pallidus*, *Kuklisporites* spp., *Latrobosporites* sp. (large), *Cingutrilites clavus*, *Laevigatosporites* spp., *Monosulcites belugaensis*, *Retitrilites* spp., *Sestrosporites pseudoalveolatus*.

OUTBACK MALLABIE No. 1 WELL - PALYNOLOGICAL SUMMARY

Depth	Sample	Concentration	Preservation	Diversity and Ratios Deb:Pal	MP	SP	MP%	Zone		Age	Confidence rating
632	CC	Mod.	P-F	>	37	22	18	Upper *Muderongia tetracantha*	2biia	Early Albian	A2
642	CC	High	P-F	<	43	23	21	Upper *Muderongia tetracantha*	2biia	Early Albian	A2
750/60	DC	High	P-F	<	36	29	46	Upper *Diconodinium davidii* or older	2biiia+	Late Aptian or older	D2
780/90	DC	High	P-F	<	48	16	47	Upper *Diconodinium davidii* or older	2biiia+	Late Aptian or older	D1
820/30	DC	High	P-F	≤	43	21	63	Upper *Diconodinium davidii* or older	2biiia+	Late Aptian or older	D1
830/40	DC	High	P-F	≈	37	18	77	Upper *Diconodinium davidii* or older	2biiia+	Late Aptian or older	D1
850/60	DC	High	P-F	≤	35	24	60	Upper *Diconodinium davidii* or older	2biiia+	Late Aptian or older	D1
1100/1110	DC	Mod.	P-F	>	22	26	15	*Diconodinium davidii* or older	2biii/APP1	Late Aptian or older	D4
1190/1200	DC	Mod.	P-F	>	30	26	21	*Granulatisporites confluens* or older	APP122+	Basal Permian or older	D4
1240/1250	DC	Mod.	P-F	>	11	27	27	*Granulatisporites confluens* or older	APP122+	Basal Permian or older	D4
1260/70	DC	Mod.	P-F	>	5	18	24	*Granulatisporites confluens* or older	APP122+	Basal Permian or older	D4

Confidence rating: GA Stratdat format	A Core	1 Excellent	High diversity assemblage with key zone species
	B Sidewall Core	2 Good	Moderate diversity assemblage with key zone species
	C Coal cuttings	3 Fair	Low diversity assemblage with key zone species
	D Ditch cuttings	4 Poor	Mod.-high diversity assemblage without key zone species
	E Junk Basket	5 Very poor	Low diversity assemblage without key zone species
	F Miscellaneous	>5	
	G Outcrop		

Sidewall core rating:
1 sidewall core totally crushed - substantial contamination
2 substantial mud penetration - minor to substantial contamination possible
3 minor to moderate mud penetration - minor contamination possible
4 mud penetration not evident - should be no mud contamination

- Other algae: *Botryococcus* spp., *Micrhystridium* spp., *Veryachium* spp., *Pterospermella aureolata*, *Pterospermella australiensis*, *Sentusidinium* spp., *Cymatiosphaera* spp., *Paralecaniella* spp., *Fromea fragilis*, *Platycystidia* sp.

Diagnostic species: *Actinotheca aphroditae, D. macropyla, Isabelidinium balmei, Maduradinium pentagonum, Xenascus* sp. (square), *Phyllocladidites mawsonii*, *Camerozonosporites bullatus*,

Discussion: *Actinotheca aphroditae* is restricted to the *Conosphaeridium striatoconus* Zone (latest Turonian to basal Santonian). FDO of *D. macropyla* marks the downhole top of *the Conosphaeridium striatoconus* Zone (latest Turonian to basal Santonian) and occurs also in older sediments. *Camerozonosporites bullatus* has its last downhole occurrence in the late *Tricolporites apoxyexinus* Zone (Santonian). ?*Phyllocladidites mawsonii*'s last downhole occurrence defined the base of the *P. mawsonii* Zone (Turonian to basal Santonian).
This sample may be interpreted as Latest Turonian to Early Santonian.

Core Sample 368-373 m (1209'-1227')

Taxa listed by R. Helby:

- Dinocysts: Unidentified microplankton, *Escharisphaeridia* spp.

- Spores and pollen: Unidentified spores and pollen, *Amosopollis cruciformis*, *Lecaniella* sp. A, Bisaccates (undifferentiated), *Corollina* sp., *Cyathidites* spp., *Cyathidites* spp., *Gleicheniidites* spp., *Microcachryidites antarcticus*, ?*Phyllocladidites mawsonii*, *Phyllocladites* spp., *Retitrilites* spp., *Araucariacites australis*, *Callialasporites dampieri*, *Leptolepidites major*, *Punctatisporites* spp.

Diagnostic species: ?*Phyllocladidites mawsonii*, *Phyllocladites* spp.

Discussion: The last downhole occurrence of ?*Phyllocladidites mawsonii* defines the base of the *P. mawsonii* Zone. If this taxon is *in situ* then the sample may be dated as Turonian to basal Santonian (*P. mawsonii* Zone) or younger. As the age of the core sample 327-336 m (1073'/1104') is Latest Turonian to Early Santonian (see below), a **Turonian age is likely** for core sample 368-373 m (1209'-1227').

Core Sample 336-429 m (1104'-1407')

Taxa listed by R. Helby:

- Dinocysts: *Acanthaulax wilsonii*, *Callaiosphaeridium asymmetricum*, *Chlamydophorella* spp., *Compositosphaeridium paracostatum*, *Cribroperidinium* spp., *Diconodinium* spp., *Hystrichodinium* spp., *Hystrichosphaeridium tubiferum*, *Odontochitina costata* (s.l.), *Oligosphaeridium complex*, *Paleohystrichophora infusorioides*, *Spinidinium* spp., *Spiniferites* spp., unidentified chorate cysts, unidentified microplankton, *Apteodinium granulatum*, *Cometosphaeridium* spp., *Coronifera oceanica*, *Disphaeria macropyla*, *Escharisphaeridia* spp., *Exochosphaeridium* spp., *Florentinia* spp., *Kiokansium polypes*, *Leptodinium* spp., *Oligosphaeridium pulcherrimum*, *Palaeoperidinium cretaceum*, *Tanyosphaeridium* spp., *Anthosphaeridium* spp., *Ascodinium ovale*, *Cassiculosphaeridia reticulata*, *Chatangiella* spp., *Cleistosphaeridium* spp., *Cribroperidinium edwardsii*, *Cyclonephelium membraniphorum*, *Diconodinium multispinum*, *?Heslertonia striata*, *Heterosphaeridium distinctum*, *?Isabelidinium acuminatum*, *Isabelidinium* spp., *Litosphaeridium siphoniphorum*, *Microdinium ornatum*, *Prolixosphaeridium conulum*, *Wallodinium krutschii.*

- Spores and pollen: *Amosopollis cruciformis*, bisaccates undifferentiated, *Camerozonosporites australiensis*, *Corollina* spp., *Cyathidites* spp., *Gleicheniidites* spp., *Microcachryidites antarcticus*, *Perotrilites oepikii*, unidentified spore-pollen, *Cicatricosisporites* spp., *Falcisporites grandis*, *Foraminisporis asymmetricus*.

- <u>Other algae</u>: *Micrhystridium* spp., *Palambages* spp., *Veryachium* spp., *Eyrea nebulosa*, *Pterospermella aureolata*, *Sentusidinium* spp..

Diagnostic species: *Ascodinium ovale, Diconodinium multispinum, Palaeoperidinium cretaceum, Chatangiella* spp., *?Isabelidinium acuminatum*, I*sabelidinium* spp., *Litosphaeridium siphoniphorum*, *Microdinium ornatum*, *Foraminisporis asymmetricus.*

Discussion: FDO of *F. asymmetricus* marks the lower part of the *Tricolporites apoxyexinus* Zone (Santonian) and occurs also in older sediments. FDO of *D. macropyla* marks the downhole top of the *Conosphaeridium striatoconus* Zone (Latest Turonian to basal Santonian) and occurs also in older sediments. FDOs of *M. ornatum* and *D. multispinum* mark the downhole top of the *Palaeohystrichophora infusorioides* Zone (Late Cenomanian to Turonian) and occurs also in older sediments. FDO of *L. siphoniphorum* indicates downhole top of *D. multispinum* Zone (Cenomanian). *Ascodinium ovale* range is Albian-Cenomanian.
This sample may be interpreted as belonging to the *D. multispinum* Zone (Cenomanian).

Conclusion

Suggested new biostratigraphic breakdown.

327-336 m (1073'/1104'): Latest Turonian to Early Santonian (*Conosphaeridium striatoconus* Zone)
368-373 m (1209-1227'): Turonian (*Phyllocladidites mawsonii* Zone)
336-429 m (1104'/1407'): Cenomanian (*Diconodinium multispinum* Zone)

EYRE 1

Core Sample 428-430 m (1405'-1410')

Taxa listed by R. Helby:

- <u>Dinocysts</u>: *Chlamydophorella nyei*, *Chlamydophorella* spp., *Cribroperidinium* spp., *Hystrichodinium* spp., *Odontochitina costata* (s.l.), *Paleohystrichophora infusorioides*, *Kiokansium polypes*, *Spiniferites* spp., unidentified chorate cysts, unidentified microplankton, *Coronifera oceanica*, *Exochosphaeridium* spp., *Florentinia* spp., *Xenascus* sp. (square), *Cleistosphaeridium* spp., *Heterosphaeridium* spp., *Isabelidinium* spp., *Baticasphaera scrobiculata*, *Gonyaulacysta cooksoniae*, *Caddasphaera halosa*, *Microdinium ornatum*, *Microdinium veligerum, Microdinium spp.*, *Trichodinium* spp.,

- <u>Spores and pollen</u>: *Amosopollis cruciformis*, *Cyathidites* spp., *Microcachryidites antarcticus*, unidentified spore-pollen, *Cicatricosisporites* spp., *Clavifera triplex*, *Dictyophyllidites* spp.,

- <u>Other algae</u>: *Micrhystridium* spp., *Palambages* spp., *Veryachium* spp., *Pterospermella aureolata*, *Pterospermella australiensis, Cymatiosphaera* spp.

Diagnostic species: *Microdinium ornatum*, *Microdinium veligerum, Microdinium spp.* and *Clavifera triplex,* as well as *Apteodinium maculatum* (this study).

Core sample 439-442 m (1440'-1450')

Taxa listed by R. Helby:

- Dinocysts: ?*Acanthaulax wilsonii*, *Chlamydophorella* spp., *Cribroperidinium* spp., *Odontochitina costata* (s.l.), *Paleohystrichophora infusorioides*, ? *Kiokansium polypes, Spiniferites* spp., unidentified chorate cysts, unidentified microplankton, *Exochosphaeridium* spp., *Florentinia* spp., *Oligosphaeridium complex,, Cleistosphaeridium* spp., *Heterosphaeridium* spp., *Isabelidinium* spp., *Gonyaulacysta cooksoniae*, *Microdinium ornatum*, *Leptodinium* spp., *Fromea amphora*, *Fromea fragilis.*

- Spores and pollen: *Amosopollis cruciformis*, *Cyathidites* spp., *Gleicheiidites* spp., *Microcachryidites antarcticus*, unidentified spore-pollen, *Cicatricosisporites* spp., *Clavifera triplex*, *Dictyophyllidites* spp., *Spheripollenites* spp., *Austalopollis obscuris*, *Laevigatosporites* spp., *Lygistepollenites* spp., *Osmundacidites* spp., *Podocarpidites* spp., *Tricolpites* spp., *Ischiosporites* spp.,

- Other algae: *Micrhystridium* spp., *Palambages* spp., *Pterospermella aureolata*, *Pterospermella australiensis, Cymatiosphaera* spp.

- Foram liners:

Diagnostic species: *Microdinium ornatum* and *Clavifera triplex,* as well as *Apteodinium maculatum* (this study).

Core sample 442-445 m (1450'-1460')

Taxa listed by R. Helby:

- Dinocysts: *Compositosphaeridium paracostatum*, *Cribroperidinium* spp., *Hystrichodinium* spp., *Odontochitina costata* (s.l.), *Paleohystrichophora infusorioides*, *Kiokansium polypes*, *Spiniferites* spp., unidentified chorate cysts, unidentified microplankton, ?*Coronifera oceanica*, ?*Disphaeria macropyla*, *Exochosphaeridium* spp., *Leptodinium* spp., *Oligosphaeridium complex, Oligosphaeridium pulcherrimum*, *Cleistosphaeridium* spp., *Cyclonephelium membraniphorum*, *Heterosphaeridium* spp., *Isabelidinium* spp., *Gonyaulacysta cooksoniae*, *Microdinium ornatum*, *Microdinium* spp., *Membranilarnacia* spp.
- Spores and pollen: bisaccates undifferentiated*, Cyathidites* spp., *Gleicheiidites* spp., *Microcachryidites antarcticus*, unidentified spore-pollen, *Cicatricosisporites* spp., *Cicatricosisporites venustus*., *Clavifera triplex*, *Dictyophyllidites* spp., *Spheripollenites* spp., *Podocarpidites* spp., *Callialasporites dampieri*, *Cingutrilites clavus*.

- Other algae: *Micrhystridium* spp., *Palambages* spp., *Veryachium* spp., *Pterospermella aureolata*, *Pterospermella australiensis, ?Sentusidinium* spp., *Cymatiosphaera* spp.

Diagnostic species: *Microdinium ornatum*, *Microdinium* spp. and *Clavifera triplex,* as well as *Apteodinium maculatum* (this study).

Sample 445-448 m (1460'-1470')

Taxa listed by R. Helby:

- Dinocysts: *Acanthaulax wilsonii*, *Apteodinium maculatum*, *Callaiosphaeridium asymmetricum*, *Cribroperidinium* spp., *Hystrichodinium* spp., *Odontochitina costata* (s.l.), *Oligosphaeridium complex*, *Paleohystrichophora infusorioides*, *Kiokansium polypes*, *Spiniferites* spp., unidentified chorate cysts, unidentified microplankton, *Coronifera* *oceanica*, *Exochosphaeridium* spp., *Florentinia* spp., *Palaeoperidinium cretaceum*, *Tanyosphaeridium* spp., *?Cyclonephelium membraniphorum*, *?Heslertonia striata*, *Heterosphaeridium* spp., *?Isabelidinium* spp., *Gonyaulacysta cooksoniae*, *Microdinium ornatum*, *Leptodinium* spp., *?Canningia* spp., *Fromea fragilis*.

- Spores and pollen: *Amosopollis cruciformis*, *Corollina* spp., *Cyathidites* spp., *Gleicheiidites* spp., *Microcachryidites antarcticus*, unidentified spore-pollen, *Cicatricosisporites* spp., *Clavifera triplex*, *Podocarpidites* spp., *Foveoglecheiniidites* spp., *Retitrilites* spp., *Densoisporites velatus*, *Foveosporites multifoveolatus*.

- Other algae: *Micrhystridium* spp., *Palambages* spp., *Pterospermella aureolata*, *Pterospermella australiensis, Sentusidinium* spp., *Hoegisporis* spp.

Diagnostic species: *Microdinium ornatum* and *Clavifera triplex,* as well as both *Apteodinium maculatum* and *Appendicisporites* sp. Burger *in* Norvick & Burger 1976 (this study).

Discussion

FDOs of *M. ornatum, Microdinium veligerum* and *Microdinium* spp., mark the downhole top of the *Paleohystrichophora infusorioides* Zone (Late Cenomanian to Turonian) or older. FDO of *A. maculatum* indicates a Late Cenomanian age (not the uppermost part) or older (see Fig.8 *in* Morgan, 1980). The occurrence of *Appendicisporites* sp. Norvick & Burger 1976 (pl. 21, fig. 3) in sample 445-448 m (1460'-1470') supports also a Late Cenomanian age for this sample. So far, this morphotype has only been reported by Norvick & Burger (1976) from samples containing Late Cenomanian dinoflagellate cyst and spore & pollen assemblages (Bathurst Island 1; Northern Territory).

Conclusion

Suggested new biostratigraphic breakdown.

428-430 m (1405'-1410'): Late Cenomanian (not the uppermost part).
439-442 m (1440'-1450'): Late Cenomanian (not the uppermost part).
442-445 m (1450'-1460'): Late Cenomanian (not the uppermost part).
445-448 m (1460'-1470'): Late Cenomanian (not the uppermost part).

REFERENCES

Helby, R., 2001. A palynological reconnaissance of selected samples from Eucla Basin wells. Geoscience Australia, Professional Opinion 2001/07 (unpublished).

Morgan, R., 1980. Palynostratigraphy of the Australian Early and middle Cretaceous. Geological Survey of New South Wales, Palaeontology Memoir, 18, 1-153.

Norvick, M.S. & Burger, D., 1976. Stratigraphic palynology of the Cenomanian of Bathurst Island, Northern Territory, Australia. Bureau of Mineral Resources, Australia, Bulletin 151.

PLATE 1

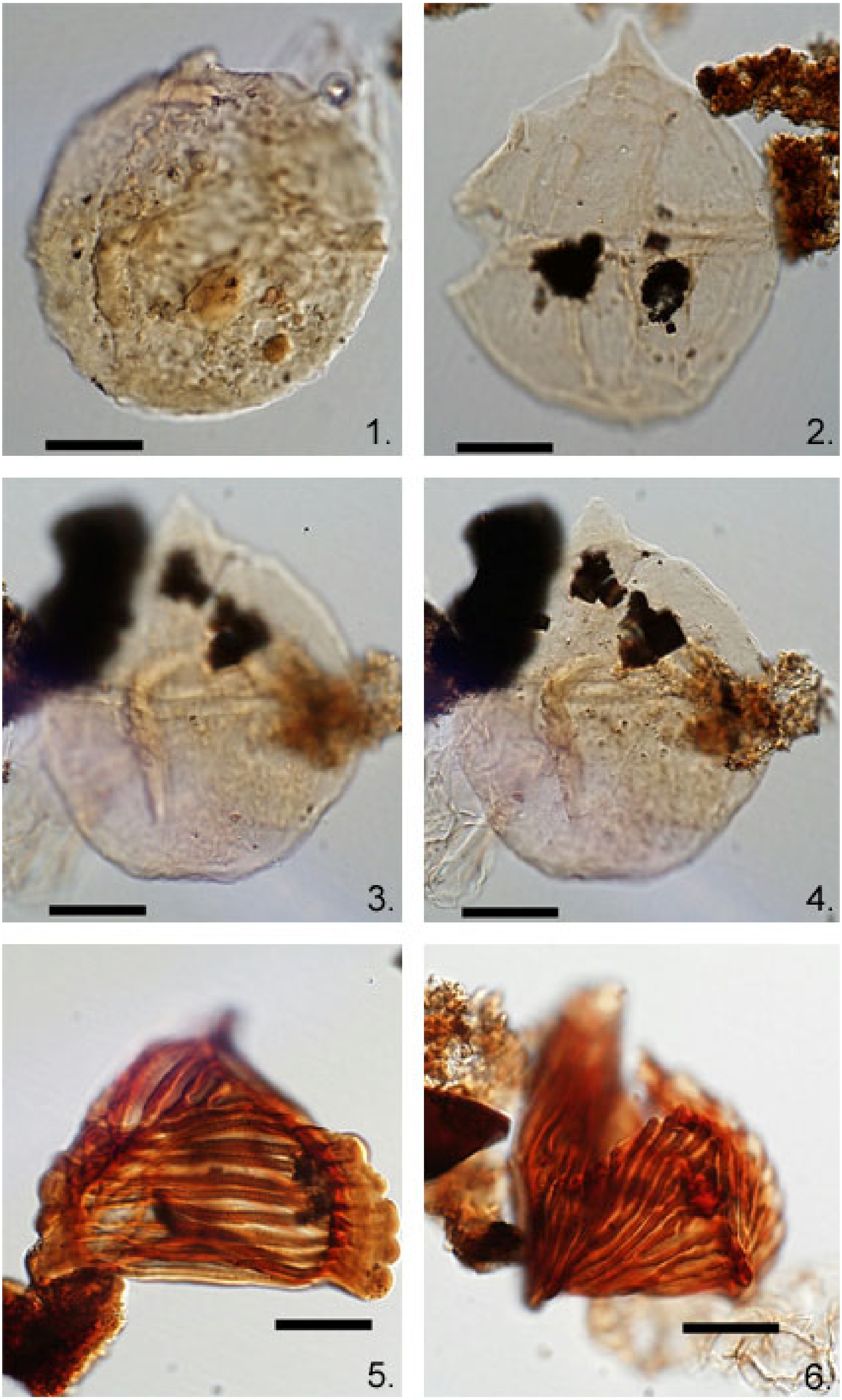
For all pictures, the scale-bar is 20 µm

Figs. 1-4. *Apteodinium maculatum.*

1: Well Eyre 1, core sample 428-430m (1405'-1410'). Slide 6404076, n°1. Coord. EF: K37/1, label on the left.
2: Well Eyre 1, core sample 428-430m (1440'-1450'). Slide 6404077, n°1. Coord. EF: J32/1-3, label on the left.
3-4: Well Eyre 1, core sample 428-430m (1450'-1460'). Slide 6404078, n°1. Coord. EF: R37/1-3, label on the left. 3: high focus. 4: low focus.

Figs. 5-6. *Appendicisporites* sp. Burger *in* Norvick & Burger (1976).

5-6: Well Eyre 1, core sample 428-430m (1460'-1470'). Slide 6404079, n°1. 5: Coord. EF: O16/3, label on the left. 6: Coord. EF: M35/1-3, label on the left. Both specimens show the characteristic appendices formed by coalescence of opposite pairs of equatorial and distal ribs, as described by Burger in Norvick & Burger (pl. 21, fig. 3; 1976).


1.
2.
3.
4.
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6.

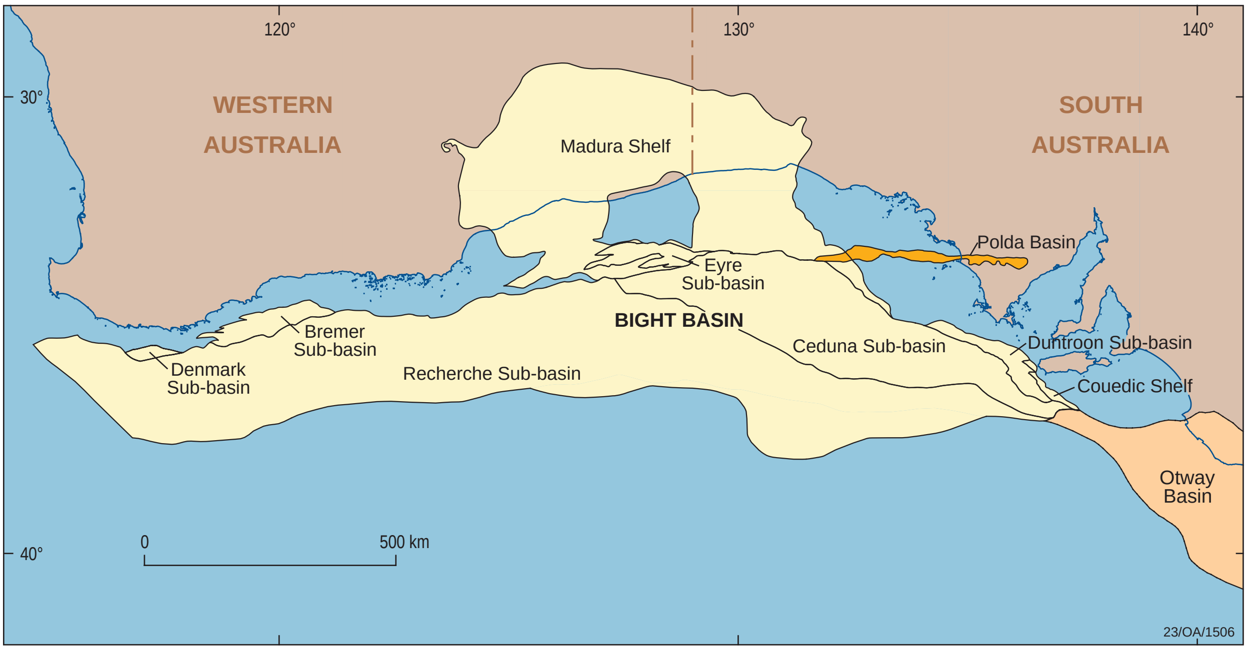


Figure 1. Structural elements map of the Bight Basin, showing the revised definition and extent of the basin (from Bradshaw et al., in prep.).

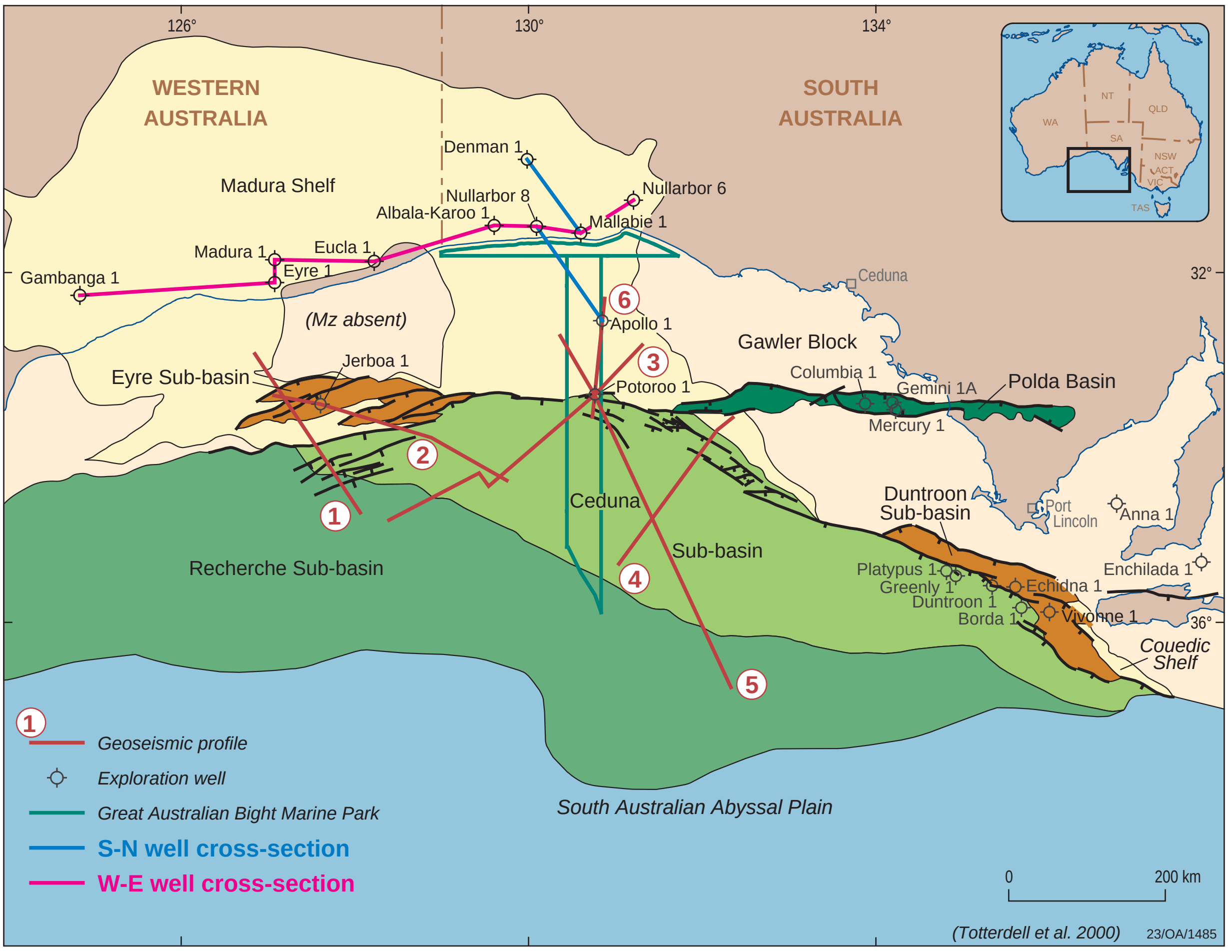


Figure 2. Structural elements map of the eastern Bight Basin. Also shown are the locations of geoseismic profiles and well cross-sections used in this study.

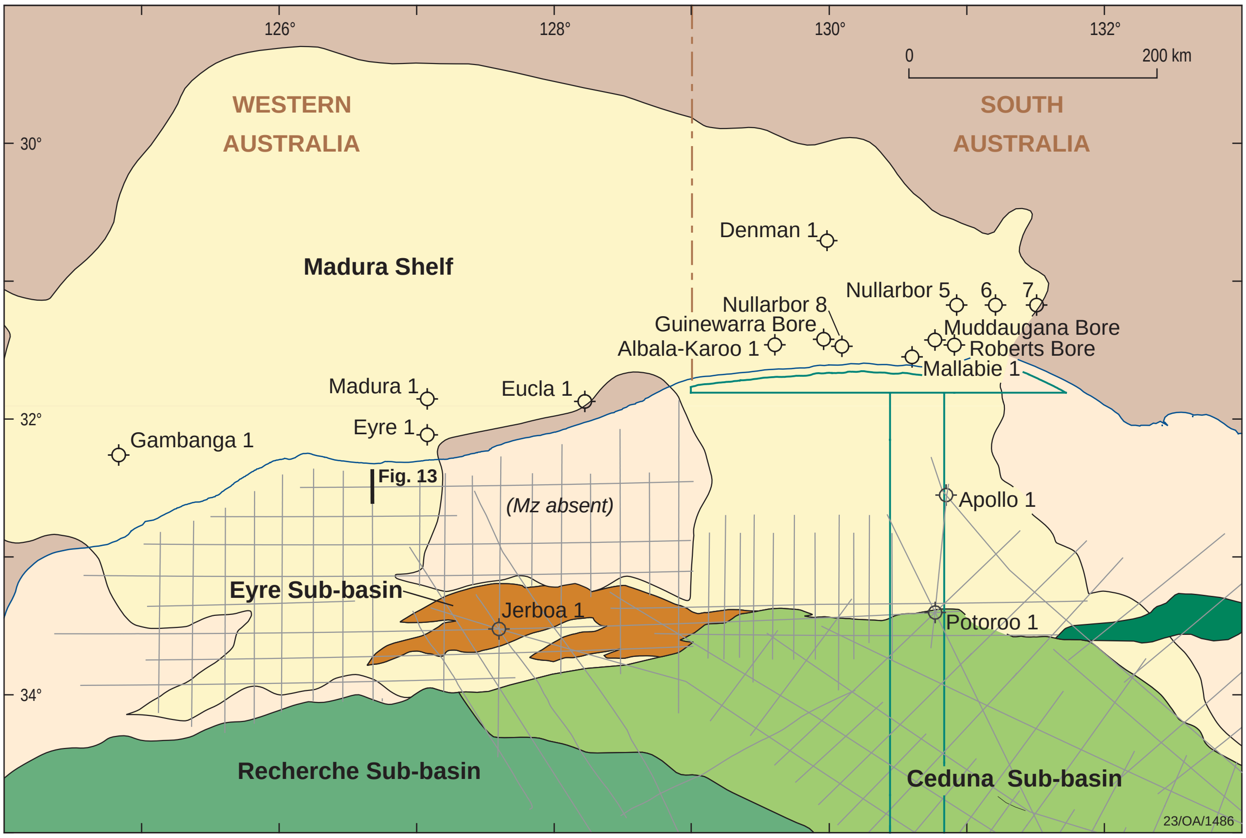


Figure 3. Well and water bore location map for the northern Madura Shelf and adjacent areas of the Eyre and Ceduna sub-basins. Also shown are the available seismic data in the area, and the location of the seismic line used in Figure 13.

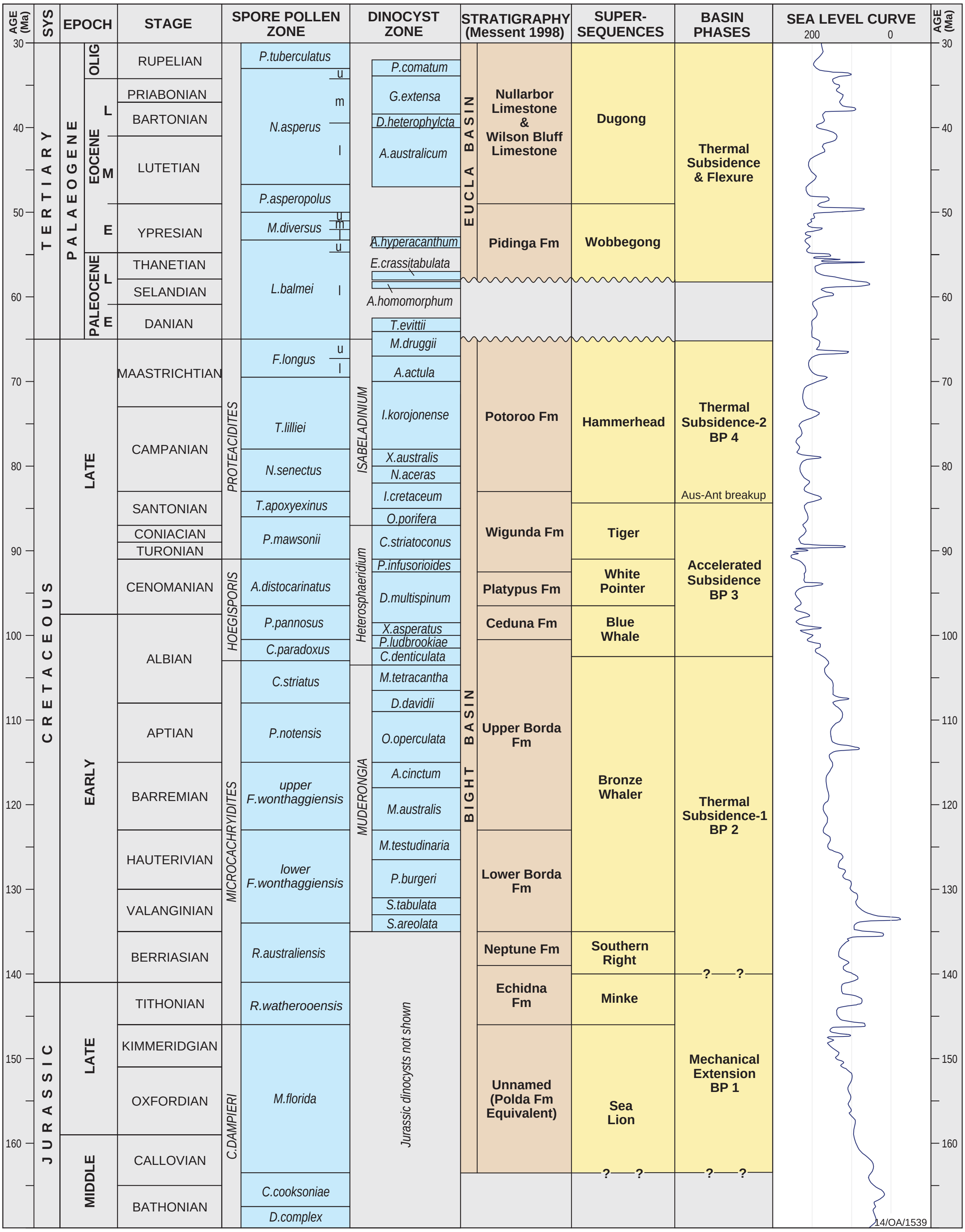


Figure 4. Correlation chart showing the relationship between sequence stratigraphic and lithostratigraphic units of the Bight Basin and overlying Eucla Basin, basin phases and the sea-level curve of Haq et al., 1988 (modified from Totterdell et al., 2000).

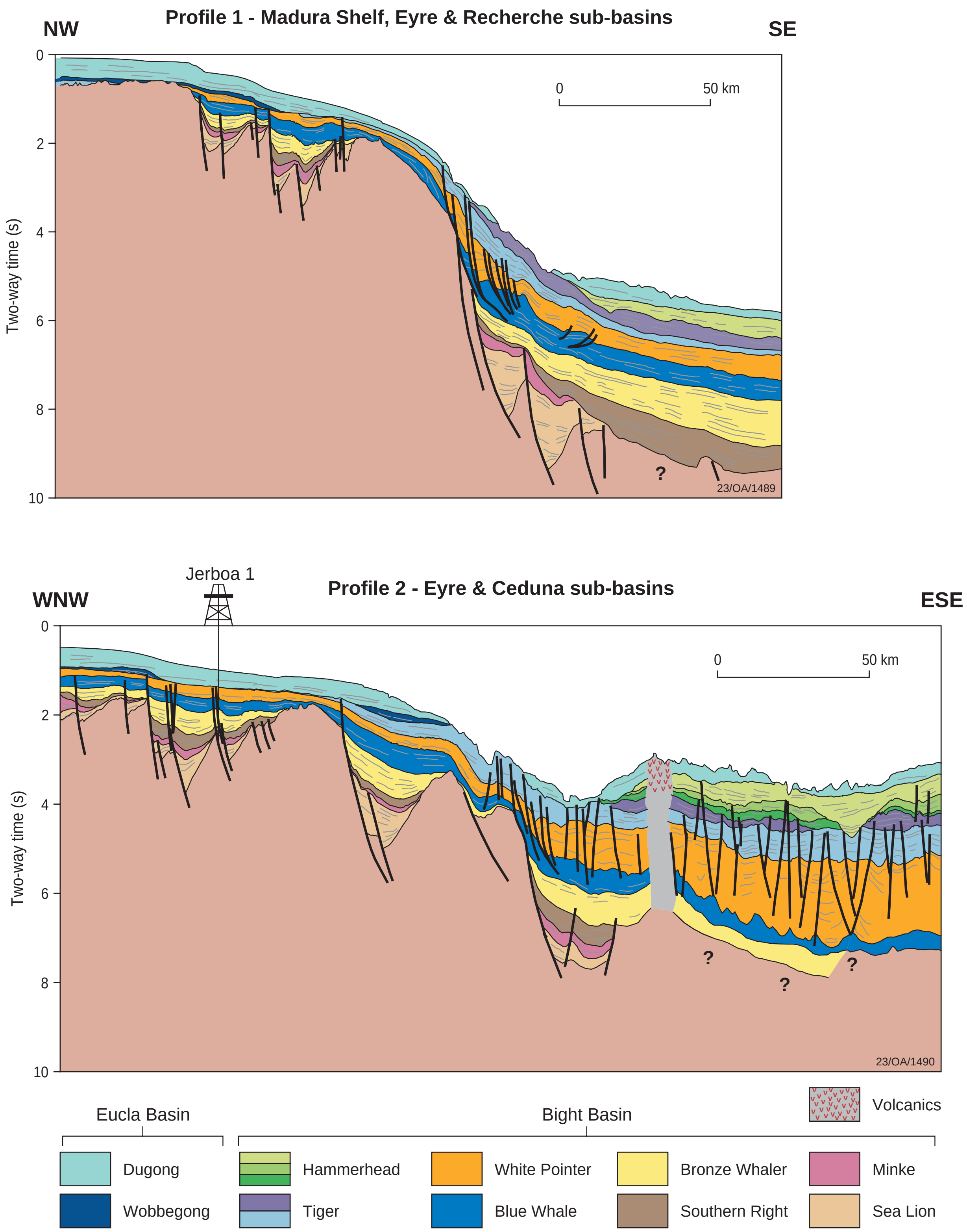


Figure 5. Geoseismic Profiles 1 and 2 from the Eyre, Recherche and Ceduna sub-basins and adjacent Madura Shelf. Profile 1 based on seismic line 199-09; Profile 2 based on seismic line DWGAB-28. Location of profiles shown in Figure 2.

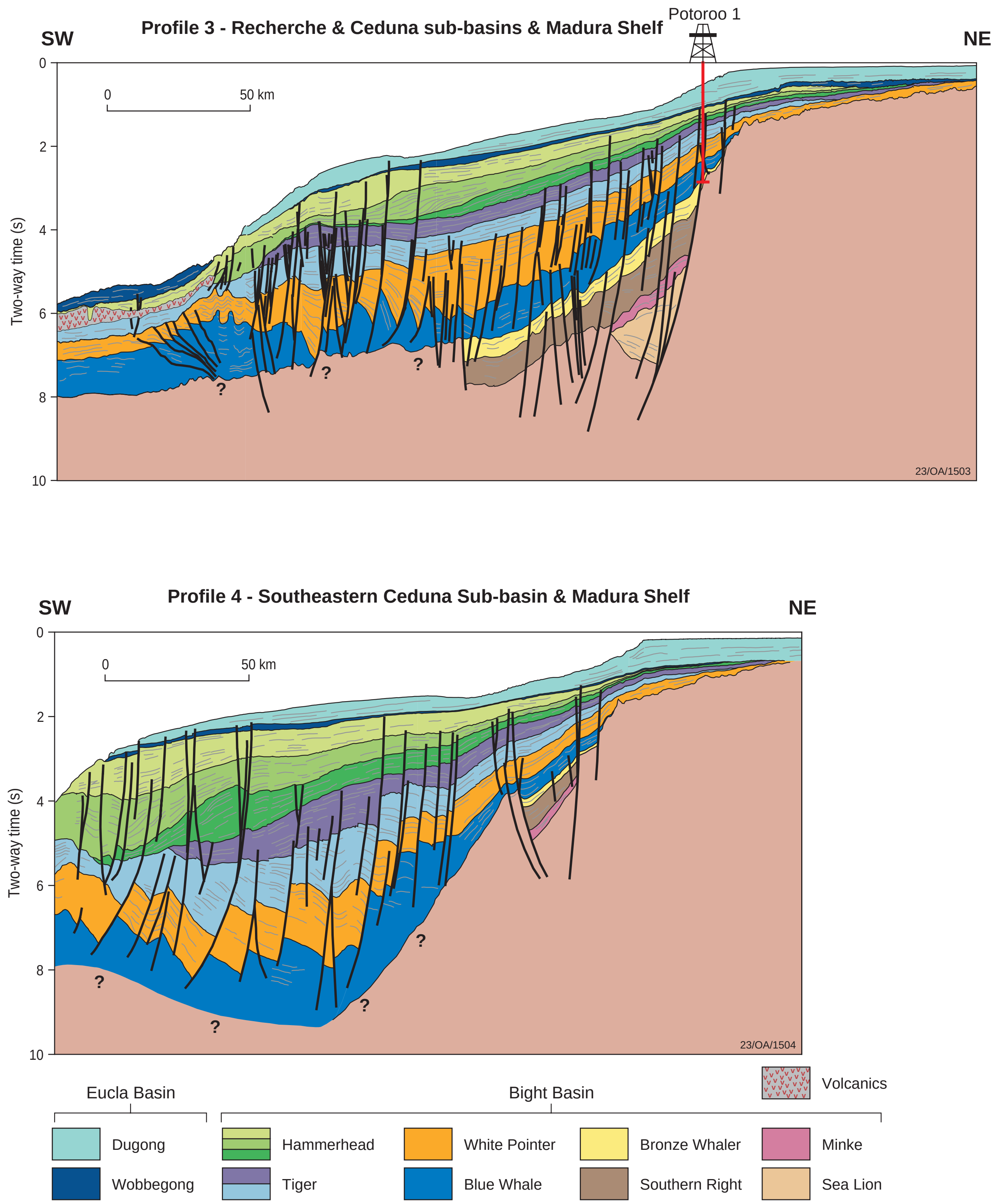


Figure 6. Geoseismic Profiles 3 and 4 from the Ceduna and Recherche sub-basins and adjacent Madura Shelf. Profile 3 based on seismic lines DWGAB-02 and 065-07; Profile 4 based on seismic line DWGAB-10. Location of profiles shown in Figure 2.

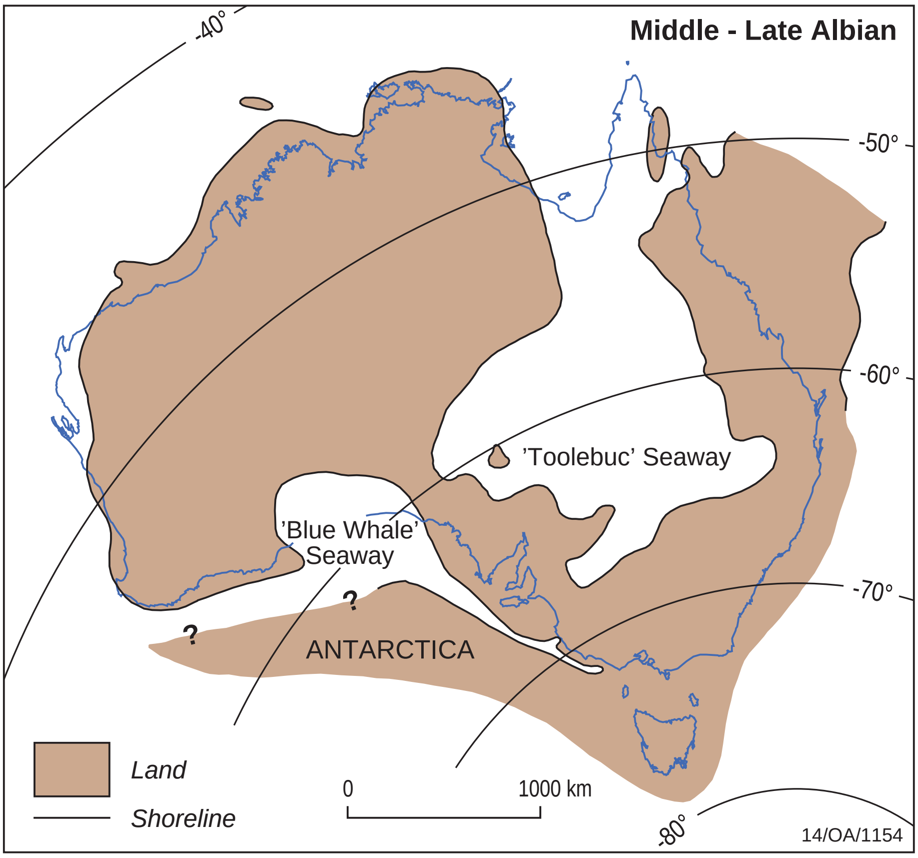


Figure 7. Mid–Late Albian palaeogeography of Australia. Note the similar palaeogeographic and palaeolatitudinal settings of the restricted Cretaceous seaways in which organic matter-rich facies of the Toolebuc Formation and Blue Whale Supersequence were deposited. Palaeogeography modified from Dettmann et al. (1992). Palaeolatitudes from Schmidt and Clark (2000) (from Boreham et al., 2001).

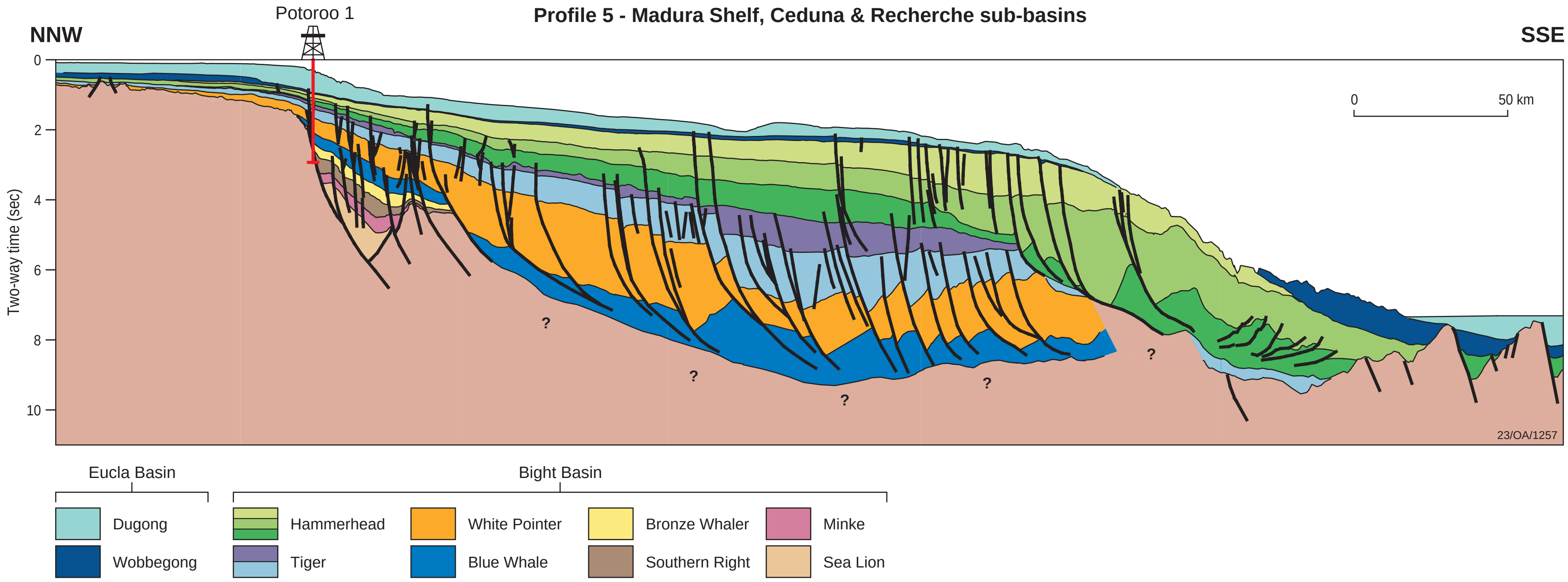


Figure 8. Geoseismic Profile 5 from the Ceduna and Recherche sub-basins and adjacent Madura Shelf. Based on seismic lines 199-08 and 199-11. Location of profile shown in Figure 2.

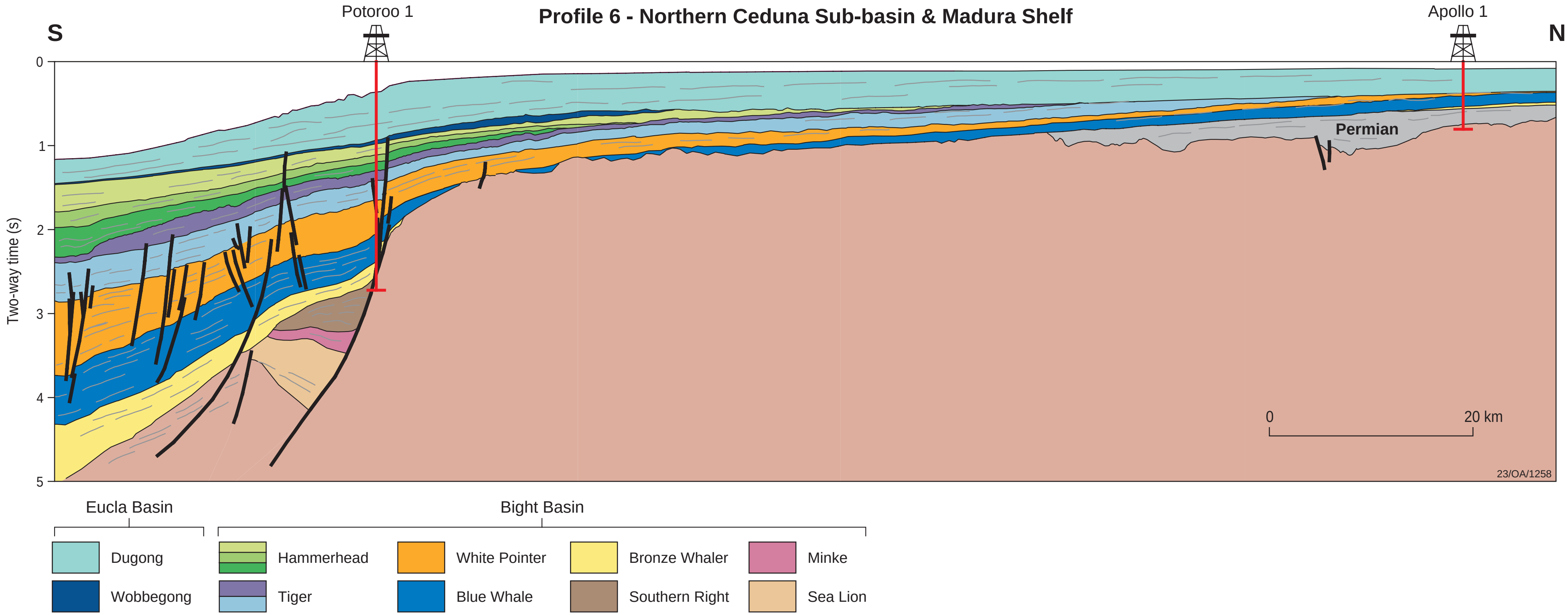


Figure 9. Geoseismic Profile 6 from the northern Ceduna Sub-basin and adjacent Madura Shelf. Based on seismic line HRGAB-116. Location of profile shown in Figure 2.

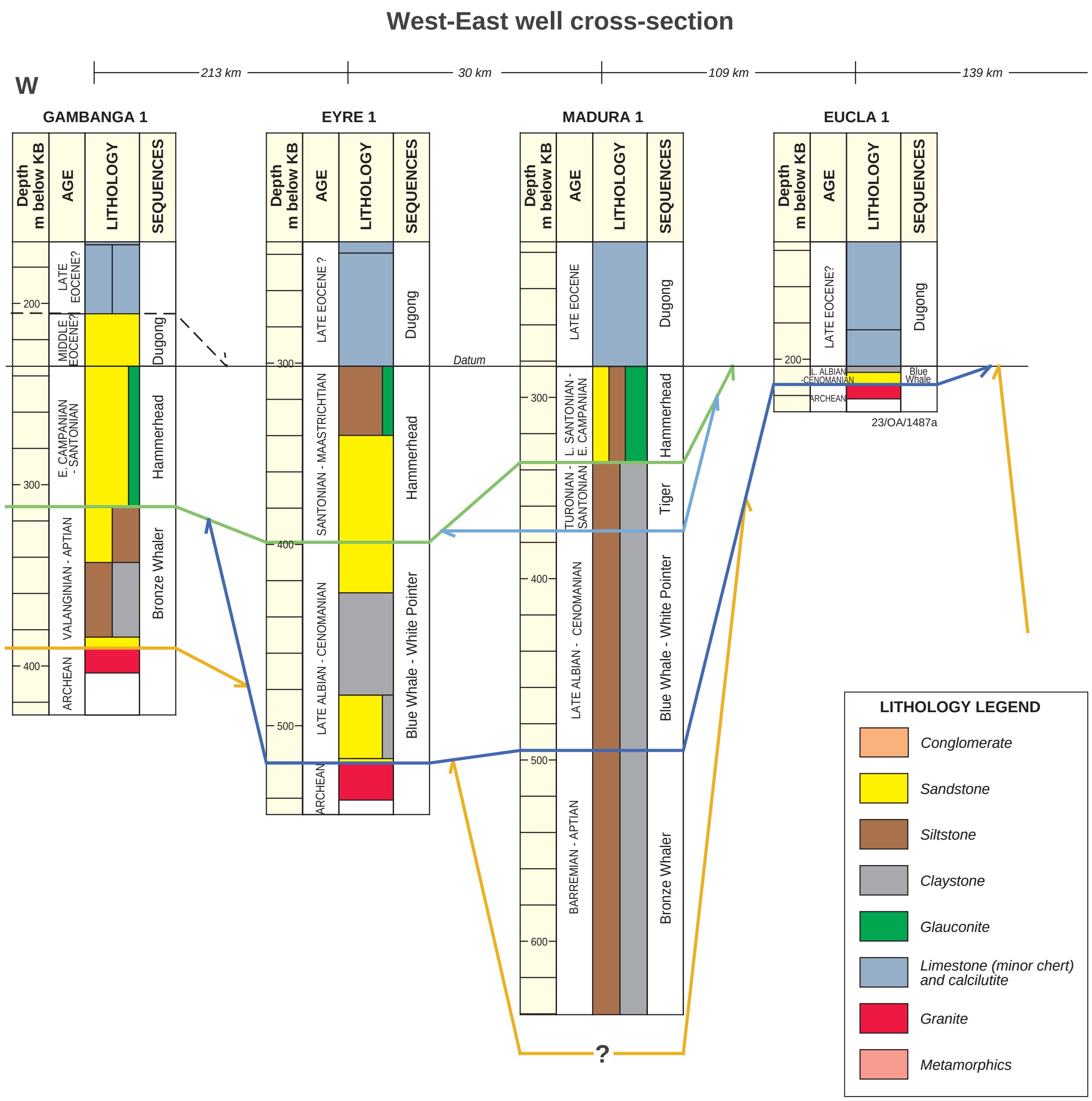
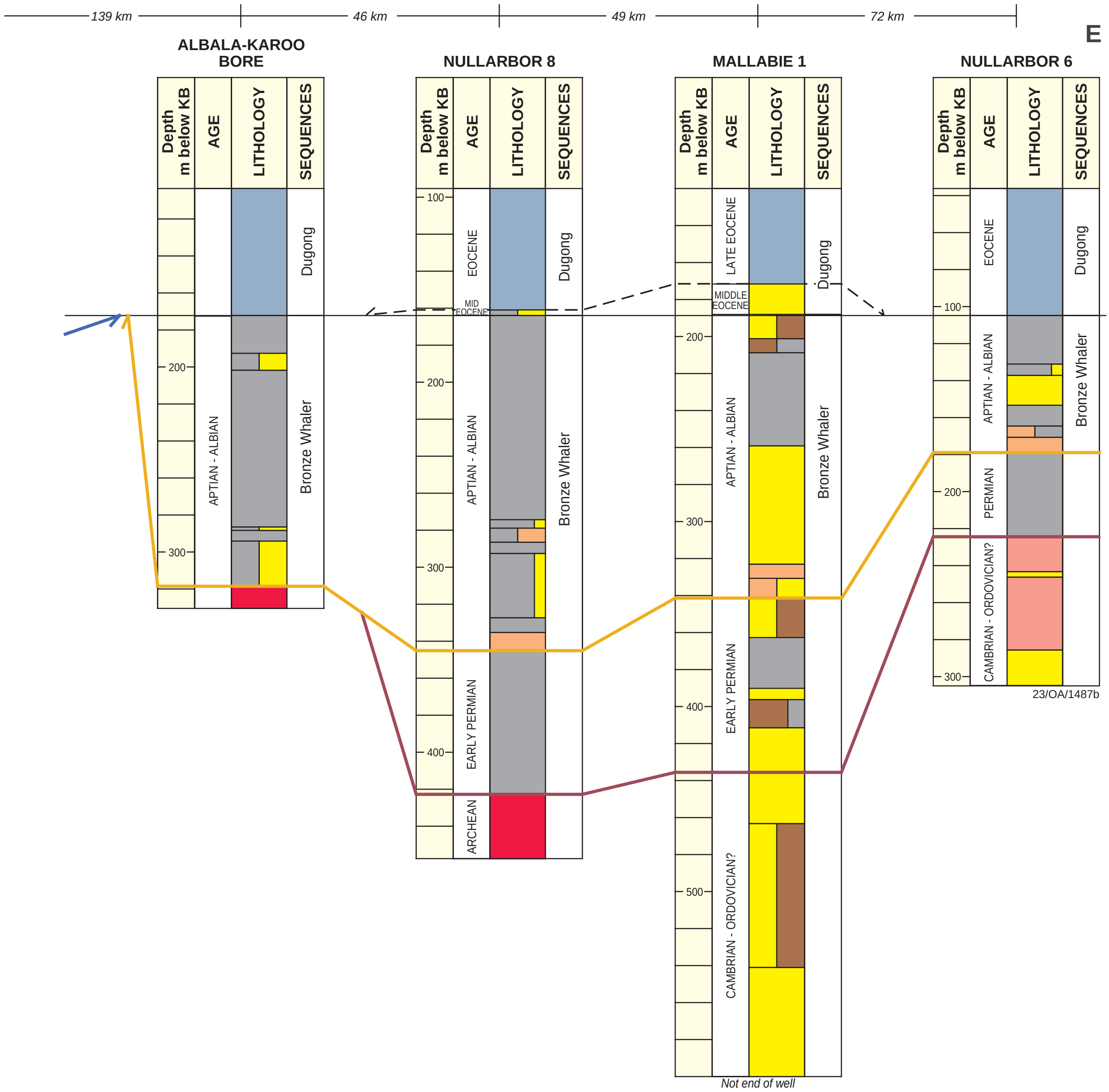


Figure 10. West–east well cross-section from the northern Madura Shelf. Location of section shown in Figure 2.

West-East well cross-section - continued



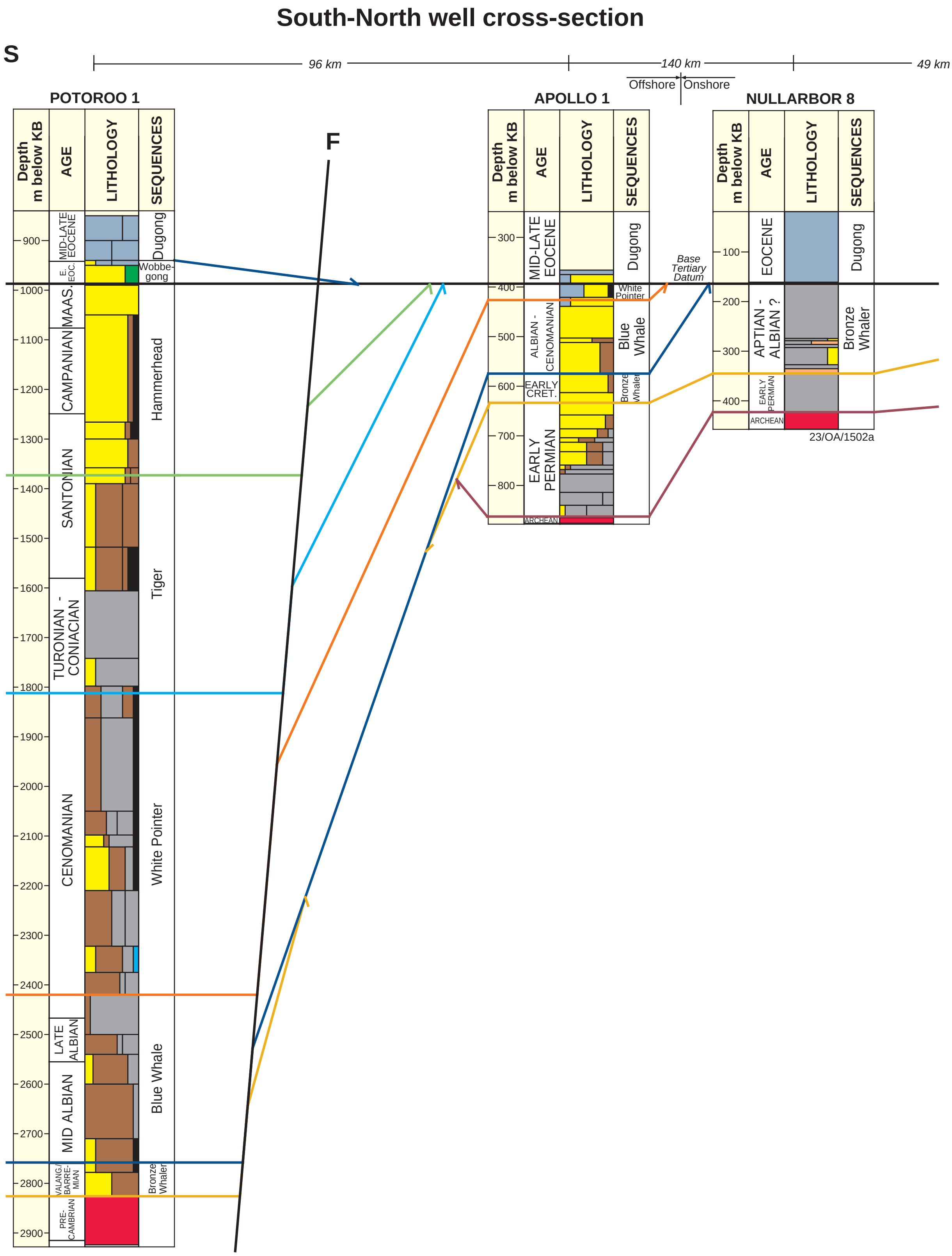
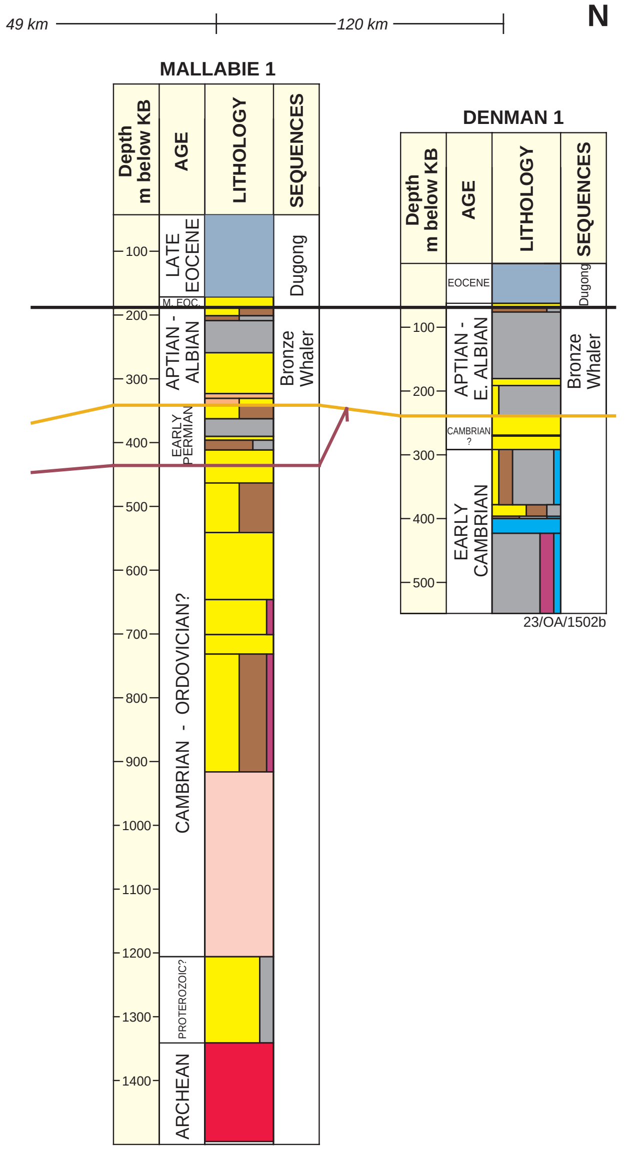
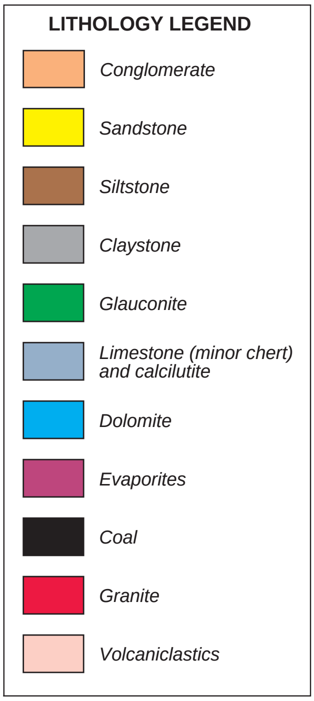


Figure 11. South–north well cross-section from the northern Ceduna Sub-basin and adjacent Madura Shelf. Location of section shown in Figure 2.

South-North well cross-section - continued





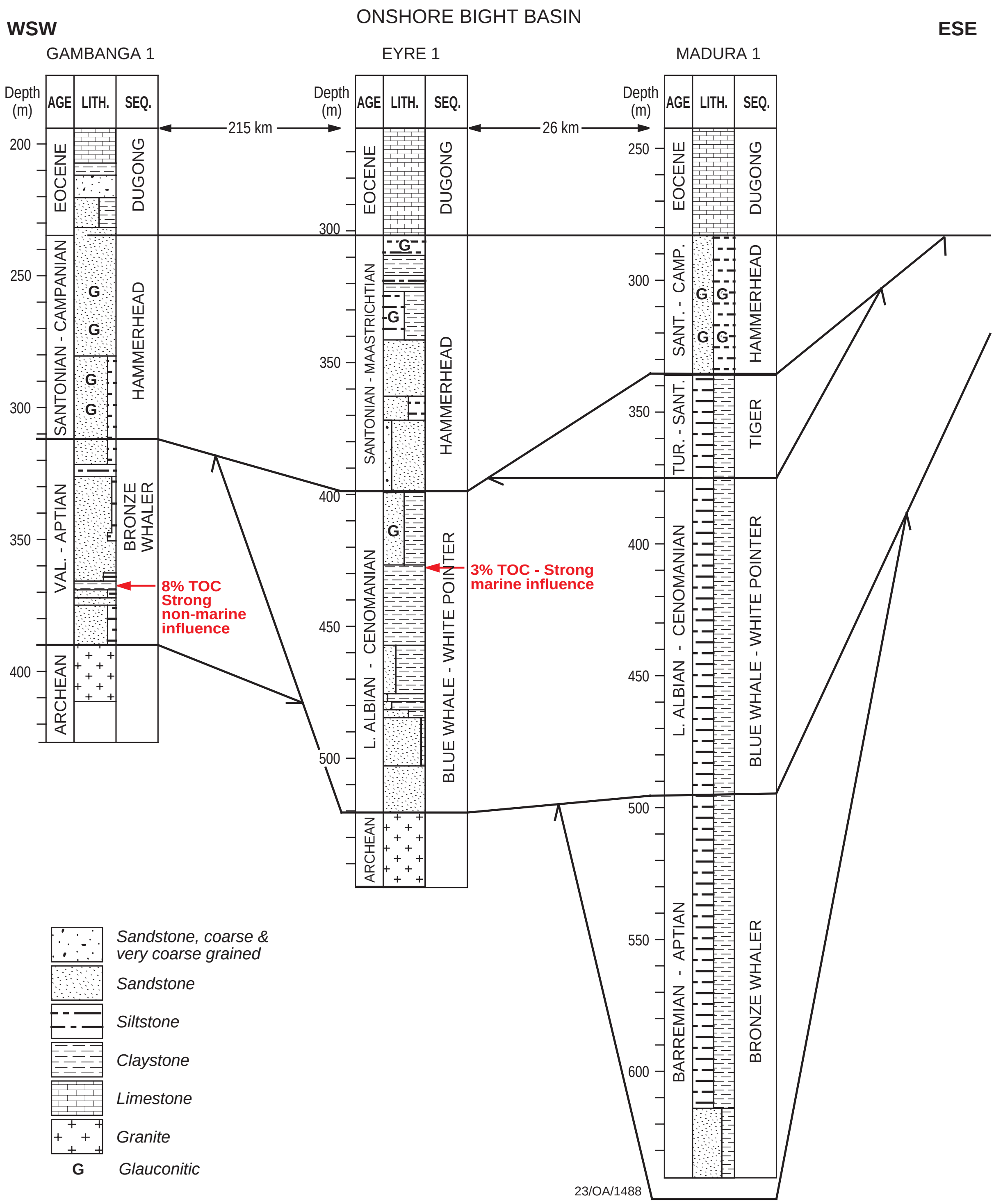


Figure 12. Detail of west–east well cross-section showing the location of organic-rich samples in the Gambanga 1 and Eyre 1 wells (modified from Boreham et al., 2001).

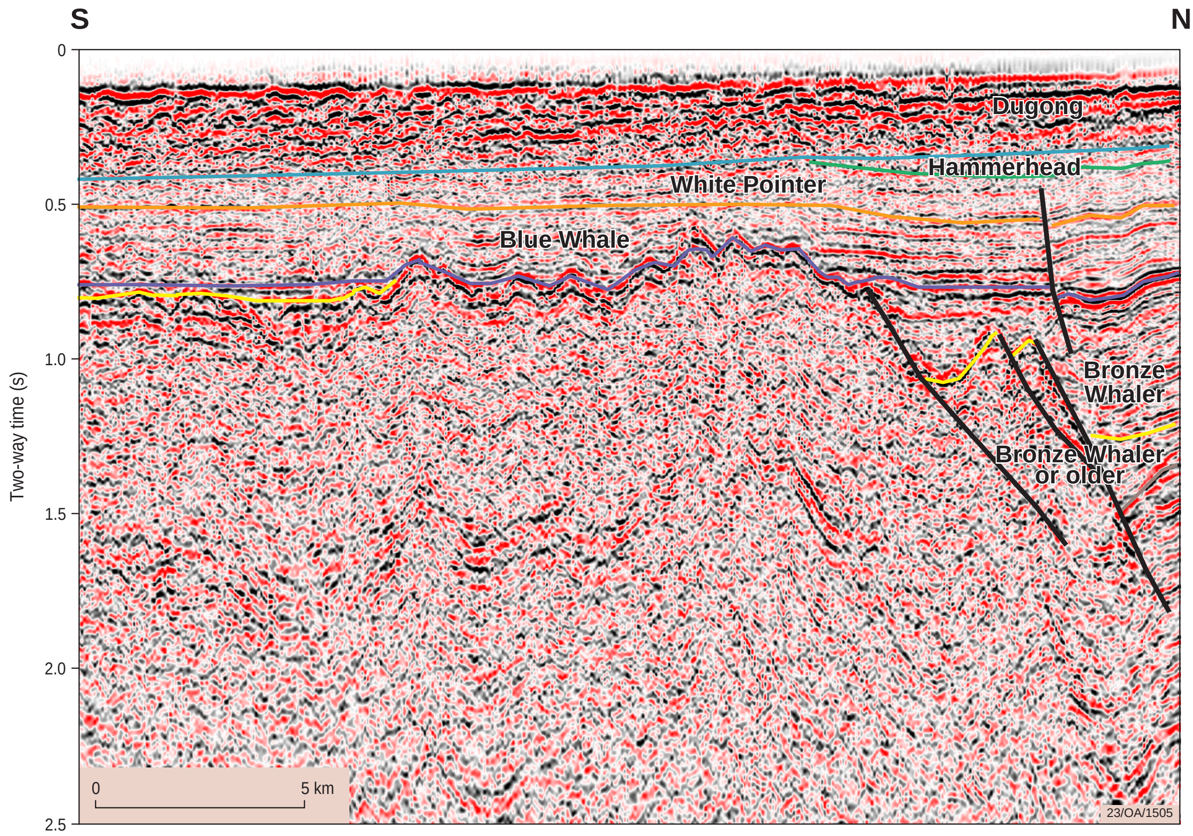


Figure 13. Portion of seismic line JA90-15 from the northern part of the JNOC 1990 survey. Note the presence of a small half graben at the north end of the line and the thin veneer of Bronze Whaler Supersequence underlying the Blue Whale Supersequence. Location of section is shown in Figure 3.