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Geoscience Australia

Geological Framework of the Bremer and Denmark Sub-basins, Southwest Australia

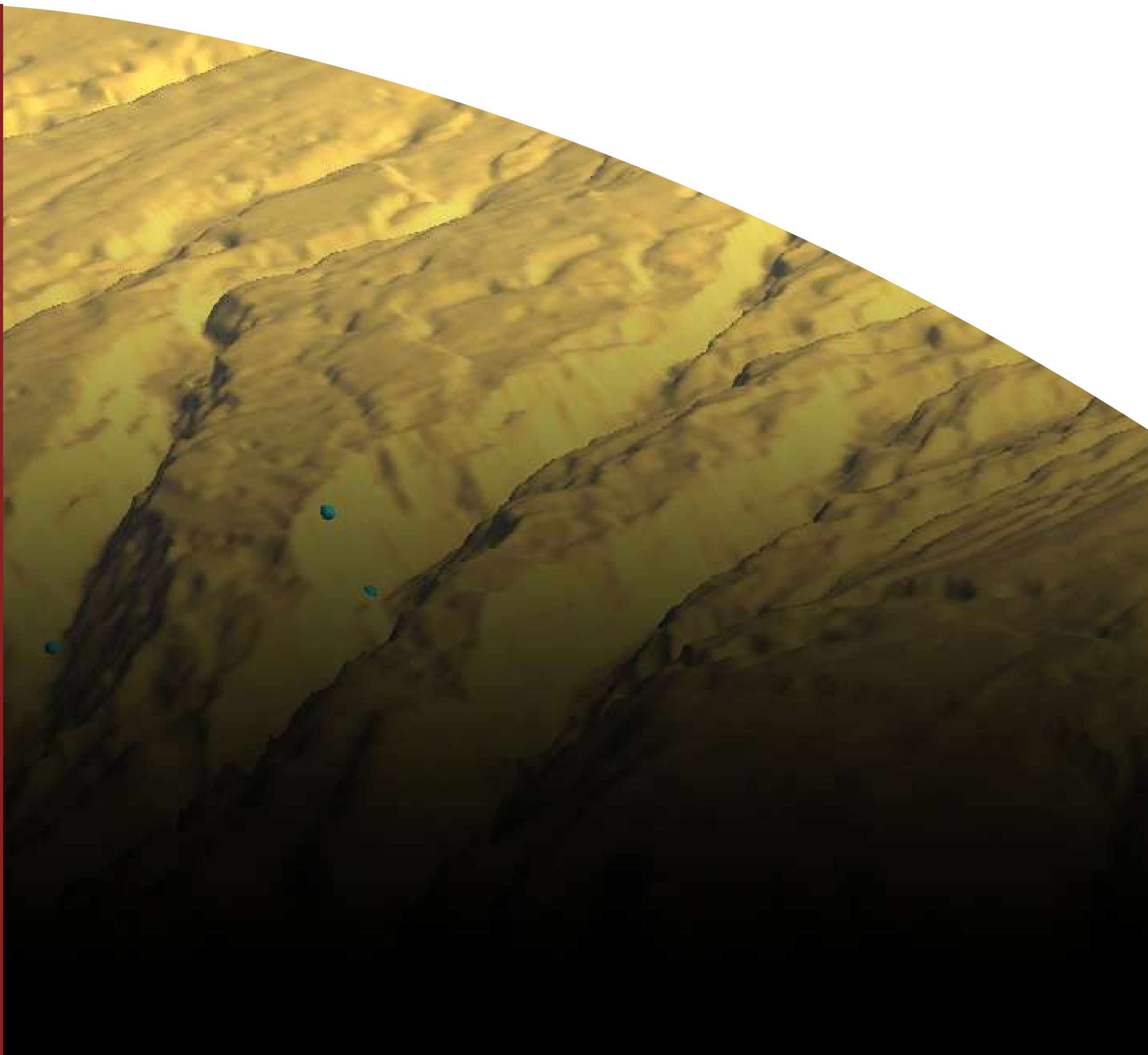
R/V *Southern Surveyor* Survey SS03/2004, Geoscience Australia Survey 265,

Post-Survey Report and GIS

Jane E. Blevin, Editor

Record

2005/05



S P A T I A L   I N F O R M A T I O N   F O R   T H E   N A T I O N

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GEOSCIENCE AUSTRALIA
RECORD 2005/05

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Geoscience Australia Website: **www.ga.gov.au**

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The following Appendices include a series of reports that were commissioned by Geoscience Australia (**Appendices F, G, H, K, L. M and N**). The reports are included in their complete form as submitted by the contractor, and summarise the post-survey analyses that were undertaken at the completion of Survey 265.

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Appendix II – CD-ROM

Appendix II is a digital product in the form of a GIS (Geographical Information System). The GIS utilizes ESRI's ArcGIS 8 software and provides accurate spatial information and metadata on the geophysical and geological data that was acquired during Geoscience Australia Survey 265. The GIS also contains spatial and metadata on the biostratigraphic and geochemical analytical results that were undertaken after the completion of the survey. The GIS contains cultural, geological and geophysical data and interpretations in the form of ESRI shapefiles and geo-referenced images. These have been structured into the seven data groups listed below. Additional information is also available as a "metadata.txt" file in each of the seven data group directories on the CD-ROM.

DATA GROUP	DESCRIPTION
Base data	Cultural and generic data
Geological data	General geological data and information.
Potential field data	Bathymetric, magnetic and gravity data.
Sample analytical data	Geological analytical geo-referenced tabular results.
Sample location data	Location data of geological sampling.
SEEBASE™	(Structurally Enhanced View of Economic Basement) is a depth-to-basement model.
Seismic data	Seismic track-line and shot-point data.

Further information on files available for each data group is available in the digital 'readme.doc' file that accompanies the GIS.

Executive Summary

In February-March 2004, Geoscience Australia undertook a 26 day geophysical and geological survey of the undrilled frontier depocentres of the Bremer and Denmark sub-basins. These sub-basins comprise the western part of the Bight Basin, and are located off the southern coast of Western Australia in water depths ranging from 100 to 4500 m. The survey was planned to recover rock samples and acquire high-speed seismic and swath data over the sub-basins in order to define a chronostratigraphic and depositional framework for the evolution of these depocentres. Ultimately, this information will be used to advance our understanding of the petroleum prospectivity of this frontier region.

Survey 265 was undertaken using the Australian National Marine Research Facility R/V *Southern Surveyor*, with funding provided as part of the Commonwealth Government's four-year, $61M, New Oil Program. The New Oil Program is aimed at identifying potential new oil provinces in the frontier regions of offshore Australia.

Seismic data acquired in the mid-1970s over the Bremer and Denmark sub-basins show the presence of half-graben depocentres that contain a sedimentary succession up to 10 km thick. Large structural features that could host potential petroleum accumulations are also observed on seismic sections, particularly in the central and eastern Bremer Sub-basin. As the basin succession does not crop out onshore and the closest petroleum exploration well was drilled almost 1000 km to the east (Jerboa-1), no information existed on the nature of the deeper sedimentary succession in the Bremer and Denmark sub-basins.

The Bremer and Denmark sub-basins are incised by a series of submarine canyons that expose parts of the sedimentary succession for dredge sampling. Prior to the survey, the nature and extent of these canyons was poorly understood. Survey 265 sought to map the morphology and geographic extent of the canyon systems, as the basis to select dredge sample sites that were subsequently undertaken during the second half of the survey.

Post-survey results have added considerably to our knowledge of the sub-basins, including a good understanding of age, lithology and depositional environment of the sediments. These data will now be integrated with existing and newly acquired seismic data to compile an integrated structural and stratigraphic model of basin formation and petroleum potential.

Over 6200 km of high-resolution swath bathymetry data were collected across the sub-basins. Now processed and merged with existing information, the swath data have yielded a 225 m resolution grided bathymetric map for the region that shows for the first time the vast extent of the canyons. Despite equipment problems, over 1000 km of high-speed seismic data were also collected in the deepwater parts of the sub-basins. The second leg of the survey set to sea on 24 February to begin the geological phase of the investigation. Using the information collected during the earlier geophysical leg, a total of 45 sites were dredged in water depths ranging from 500 to over 3000 m, and several tonnes of rocks and unconsolidated sediments were retrieved. Representative samples were retained from each dredge haul, then described and catalogued onboard for future use.

At the conclusion of the survey, biostratigraphic analysis was undertaken on 95 samples to provide age control and environmental data. Overall, 24 samples were indicative of marine environment, while 71 samples were determined to be non-marine. Despite absences of key spore-pollen taxa within some samples, age determinations, with varying degrees of confidence

were made based on quantitative data. The oldest sedimentary samples recovered are ?Early to Middle Jurassic in age, with Proterozoic basement rocks recovered at five dredge sites. The samples contain evidence of marine influence during the Berriasian to Valanginian (brackish lacustrine), with fully marine conditions established by the Early to Late Aptian.

Fifty-nine dredge samples from the Bremer Sub-basin survey were analysed to determine the petroleum potential of the entrained organic matter. Total organic carbon (TOC) contents ranged from 0.2 to 22.62%, with 20 of the samples showing good organic richness with TOC contents > 2%. Rock Eval pyrolysate yields (S2) range from 0.06 to 84.37 mg hydrocarbons/g rock, with six samples having good to excellent generative potential (S2 >5). TOC-normalised pyrolysis yields, or Hydrogen Indices (HI), ranged from 11 to 373 mg hydrocarbons/g TOC, representing potential conversion of up to 30% of the TOC into petroleum (gas and oil). However, only three samples are considered to have major potential for liquid hydrocarbon generation with HI values greater than 200 mg hydrocarbons/g TOC. Rock Eval of the isolated kerogen identified an additional 5 samples with liquids potential.

Vitrinite reflectance (VR) range from 0.31 to 4%, indicating appropriate thermal conditions existed in the Bremer Sub-basin for the total potential conversion of the organic matter into gas and oil. The majority of rock samples analysed are immature (VR < 0.65%), as only the upper 2 km of strata in the Bremer and Denmark sub-basins could be sampled by dredging sub-marine canyons. More mature successions will occur in the main half-graben depocentres where strata are buried up to 10 km sub-surface. While petrographic and fluid inclusion (GOI) analyses suggest the presence of migrated oil, the bulk (Rock Eval) and molecular geochemistry (GC) only identify an immature signature in all samples (VR <0.64%), suggesting that this trace 'oil' component is below bulk geochemical resolution. Biomarker analysis of the oil traces by GCMS could provide a more diagnostic tool.

Geochemical and biostratigraphic assessments of the Tithonian to Valanginian sediments indicate a fluvio-lacustrine depositional environment with end-member lacustrine and coaly organic facies. The former is associated with sub-ordinate low molecular weight C14-C22 n-alkanes (freshwater algal input) and abundant waxy (>C22) n-alkanes with a n-C23 dominance (fern input), while the latter has a n-C31 dominance (gymnosperm input). Intermediate n-alkane dominances at n-C25, n-C27 and n-C29 are associated with variable inputs from the end-member organic facies. Anoxic marine conditions in the Bremer Sub-basin were evident during the latest Hauterivian to earliest Barremian, leading to the deposition of an oil-prone marine organic matter. However, significant dilution by allochthonous terrestrial land plant inputs has lowered the overall hydrocarbon potential. Source areas where the terrestrial input is reduced may provide oil-prone 'sweet-spots'. In the Bremer Sub-basin, Cretaceous marine organic matter is isotopically lighter than corresponding Jurassic to Early Cretaceous non-marine kerogen. Similar isotopic discriminations are seen in organic matter of Jurassic to Early Cretaceous rocks along Australia's southern margin, suggesting that carbon isotopes can provide a good stratigraphic correlation tool and are diagnostic in gas-oil-source correlations.

A summary of the Survey 265 is available on the CSIRO Marine website at the following link:
http://www.marine.csiro.au/nationalfacility/voyagedocs/2004/sum_ss03_2004.pdf

ADDENDUM TO THIS REPORT

Following the completion of this report, a question arose about the consistency of age data in relation to two sub-samples. A review highlighted that sub-samples 265/23/DR23/G1.1 and 265/23/DR23/G1.2, which were previously thought to have originated from the same rock, were indeed taken from two different rock samples. This error came to light when the two sub-samples (265/23/DR23G1.1 and G1.2) yielded different age dinoflagellate assemblages, and also showed different geochemical characteristics.

A further review showed that the sub-sample 265/23/DR23/G1.1 was sampled on the ship at the time of dredging, while sub-sample 265/23/DR23/G1.2 was sampled after the return of dredge rocks to Canberra. Sub-sample 265/23/DR23/G1.1 has now been reclassified as sub-sample 265/23/DR23/I1.1. This sample returned a high confidence rated age of Middle to Late Albian (*E. ludbrookiae pp*., *Dioxya armata* and *Xenascus asperatus* zones) based on both occurrence of *Endoceratium turneri* and *Diconodinium cristatum*. This sample also had a hydrogen index (HI) value of 285 mg hydrocarbons/g TOC. With this new age, sub-sample 265/23/DR23/I1.1 is assessed to be the chronostratigraphic equivalent of a Middle-Late Albian potential source rock interval in the eastern Bight Basin (i.e., the Blue Whale Supersequence equivalent of Totterdell et al., 2000).

Please note that the new age assignment for sub-sample 265/23/DR23/I1.1 does not modify any other part of the palynology or geochemistry sections. Any figures affected by this revision will be incorporated into future publications.

1. Introduction

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AIMS OF SURVEY 265

The Bremer, Denmark, and deepwater Recherche sub-basins are located on Australia's southwest margin (Figure 1.1). Collectively, these frontier depocentres comprise the western part of the Bight Basin. Regional grids of seismic, magnetic and gravity data were first acquired over this region by the former Bureau of Mineral Resources (now Geoscience Australia) as part of the Continental Margins Program (Surveys 17 and 19) during the early 1970s. Most of this data is of marginal to poor quality. Since that time, only the Bremer and Denmark sub-basins have been briefly explored for petroleum, with Esso Australia Ltd holding a single lease over the main depocentres and adjacent shelf during the 1970s (Cooney, 1974). The regional seismic survey acquired over the area by Esso (Survey R74A) indicates that the Bremer Sub-basin contains up to 10 km of inferred Jurassic to Recent age sediments (Cooney, 1974; Stagg and Willcox, 1991). The Bremer and Denmark sub-basins contain faulted and folded structures that appear prospective for trapping any hydrocarbons generated (Bradshaw et al., 2003). However, no wells have been drilled to constrain the age of the sedimentary succession and timing of deformation. No further exploration has occurred since the surrender of the permit by Esso in the late 1970s.

The aims of Geoscience Australia Survey 265 were to investigate the nature of sedimentary sequences and aspects of basin evolution in the Bremer and Denmark sub-basins in order to further assess the petroleum potential of this frontier province. A 26-day geophysical and geological survey was undertaken on contract from 9 February to 5 March 2004, using the Australian National Marine Research Facility R/V *Southern Surveyor* with Dr Neville Exon as Survey Leader and Chief Scientist.

Geoscience Australia Survey 265 was the first new data acquisition survey funded as part of the Commonwealth Government's *New Oil Program* initiative aimed at identifying potential new petroleum provinces in offshore Australia. A major contract survey acquired industry-standard seismic data over this area during November to December 2004 (Geoscience Australia Survey 280), also as part of the *New Oil Program*.

Present-day water depths over the main depocentres of the Bremer and Denmark sub-basins range from 500 to over 3000 m, while the Recherche Sub-basin extends from around 3000 m to the abyssal plain of the Southern Ocean. A series of submarine canyons transects parts of the outer continental shelf and slope and provides good exposure of some of the basinal sedimentary succession. The high-resolution bathymetric mapping and dredge sampling of the submarine outcrops undertaken during Survey 265 provided an excellent opportunity to sample the sedimentary succession of these depocentres.

Specifically, Geoscience Australia Survey 265 was undertaken to:

- acquire high-resolution bathymetric data using a multibeam sonar swath system to map the submarine canyon systems and identify potential sample sites;
- acquire additional subsurface data using a 24-channel high-speed seismic system;
- ground-truth seismic data by sampling older outcropping sequences;

- acquire gravity cores to help determine the origin and composition of hydrocarbons that may have migrated into near surface sediments; and
- acquire gravity cores to establish the nature of the Holocene and older sedimentary succession for environmental planning purposes.

The geographic area of interest lies in 200 to 4500 m water depth and between longitudes 116°30'E to 121°30'E (Figure 1.2). Approximately 40 potential dredge sites were identified during the pre-survey planning phase, which were later refined using the new bathymetric data acquired during the survey. Seismic and magnetic profiling, and swath-mapping of the sea floor were undertaken on the first leg of the survey (15 days). The purpose of this leg was to collect information on the shape and depth of the canyons with a view to identifying suitable sites to collect outcropping rock samples from the steep canyon walls. After a crew change in Albany on 24 February 2004, the second leg of the survey (11 days) was devoted to further swath-mapping and geological sampling (dredge samples and gravity cores).

The high-speed reflection seismic data was acquired using two GI airguns with a combined volume of 90 cubic inches, and a 550 m long, 24 channel solid streamer towed at approximately 8 knots, while multibeam sonar data were acquired during the entire 26-day survey. Transits between areas of interest were undertaken at a speed of approximately 11 knots. A list of survey participants, on-board equipment and an operations report are included as Appendices O and P of this Record. A survey narrative is presented in Appendix S.

Figure 1.1 *Location map of the Bremer, Denmark and Recherche sub-basins of the western Bight Basin, offshore Western Australia (from Totterdell and Bradshaw, 2004).*

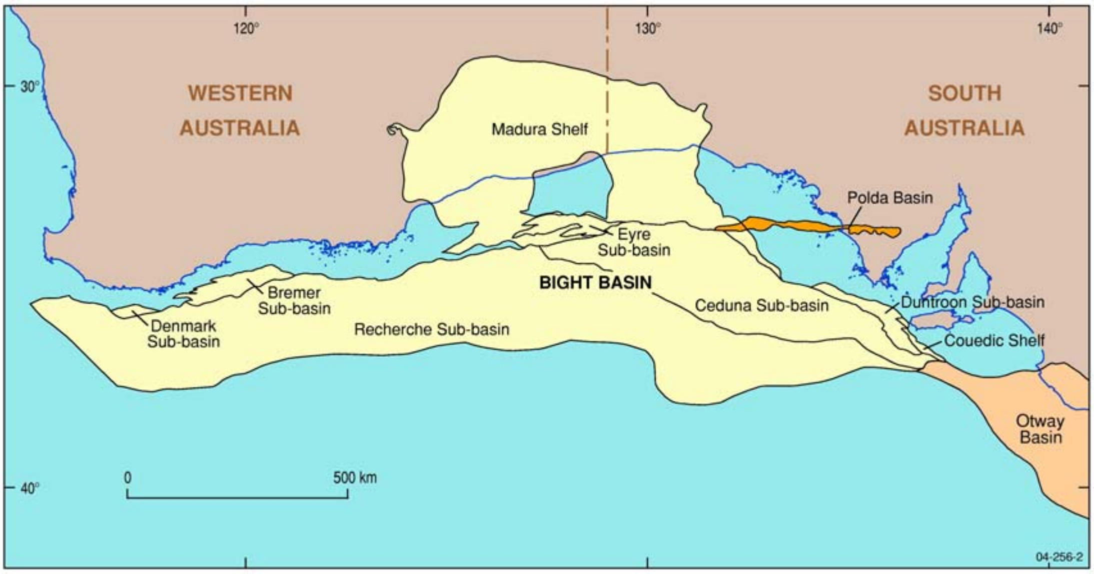
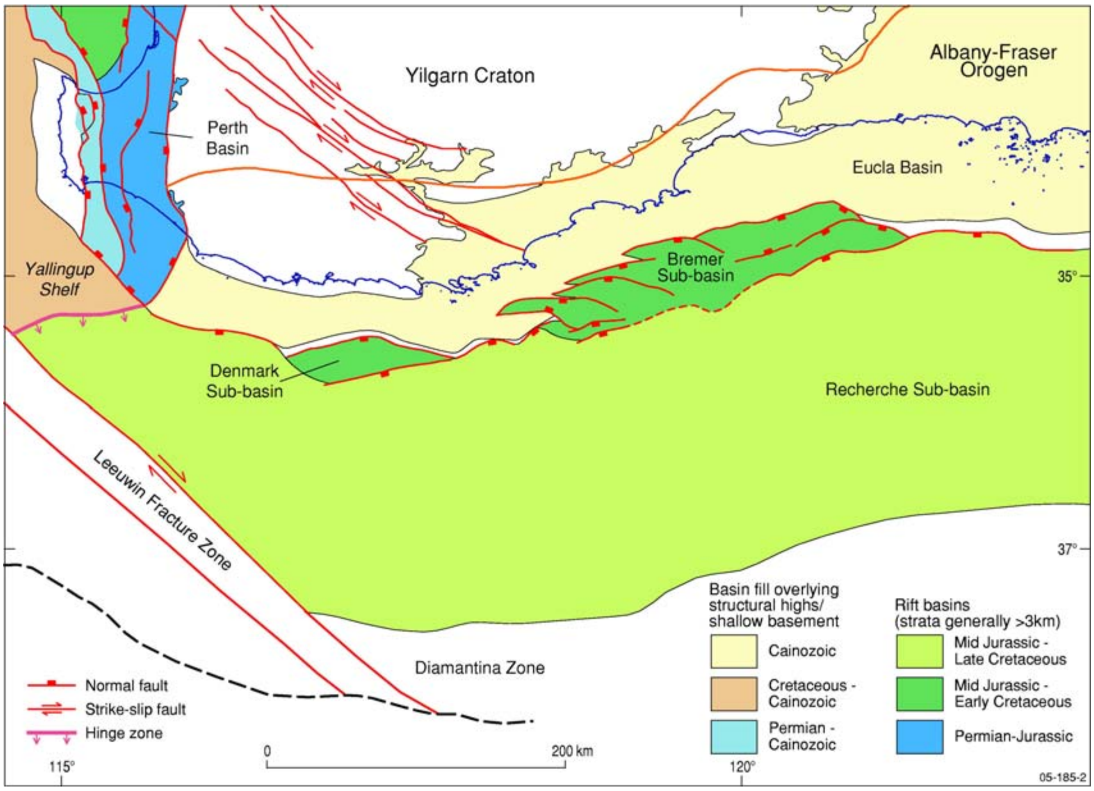


Figure 1.2 *Location map of the area of interest in Survey 265 – the Bremer, Denmark and Recherche sub-basins of the western Bight Basin, offshore Western Australia (from Bradshaw et al., 2003).*



2. Regional Geological Setting

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REGIONAL TECTONIC SETTING

The Bight Basin is one of a series of Mesozoic to Cainozoic depocentres that developed along Australia's southern margin as part of the Southern Rift System (Stagg et al., 1990), 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). A recent reassessment of basin terminology along the southern Australian margin by Bradshaw et al. (2003) groups Mesozoic successions into the Bight Basin, and Cainozoic successions into the Eucla Basin. The Jurassic to Cretaceous Bight Basin is a large, >800,000 km^2, east-west to northeast-southwest-trending, mainly offshore basin that extends for 2100 km along the southwest continental margin of Australia (Bradshaw et al., 2003; Figure 2.1). The basin is bounded to the north by continental basement, and to the south by ultramafic rocks, seafloor basalts and oceanic sediments of the Southern Ocean (Royer and Beslier, 1998).

The broad structural architecture of the Bight Basin is the product of northwest-southeast to north-south oriented crustal extension during the Middle-Late Jurassic to Early Cretaceous, superimposed on east-west and northwest-southeast orientated basement structures (Stagg et al., 1990; Stagg and Willcox, 1991; Totterdell et al., 2003; Bradshaw et al., 2003; Totterdell and Bradshaw, 2004). The Bremer and Denmark depocentres are located in the western Bight Basin, while the Madura Shelf, Ceduna, and Eyre sub-basins are in the eastern part of the Bight Basin (Figure 2.2). The deepwater Recherche Sub-basin appears to be continuous across the eastern and western regions of the Bight Basin.

The timing of breakup and the initiation of seafloor spreading between Australia and Antarctica differs along the Southern Margin. The earliest extension appears to be in the western and central parts of the margin, in the Bight Basin, with breakup being later farther to the east in the Otway Basin. In the eastern Bight Basin (Ceduna, Eyre, Recherche and Duntroon sub-basins), Middle-Late Jurassic to earliest Cretaceous upper crustal extension was followed by post-rift thermal subsidence and a subsequent phase of accelerated subsidence, which commenced in the late Albian (Totterdell et al., 2000). Accelerated subsidence continued until continental break-up at 83 Ma in the late Santonian-early Campanian (Totterdell et al., 2000; Totterdell and Bradshaw, 2004). During this time, the structural framework of the eastern Bight Basin was modified by a system of gravity-driven detached extensional and contractional structures (Totterdell and Krassay, 2003). Evidence for upper crustal extension during this period of enhanced subsidence is limited to Turonian-Santonian extensional faulting in the Ceduna Sub-basin and the reactivation and propagation of Cenomanian growth faults (Totterdell and Krassay, 2003). After slow seafloor spreading commenced at about 83 Ma (Sayers et al., 2001), there was a further period of thermal subsidence and the establishment of a passive margin (Totterdell et al., 2000). The fast north-south spreading that started in the Eocene (Cande and Mutter, 1982) probably accelerated subsidence on the margin, but had no other major effects. The timing of initial rifting and continental break-up in the western Bight Basin appears to be similar to the eastern Bight Basin, as indicated by seismic interpretations constrained by biostratigraphic dating of dredge samples in the Bremer Sub-basin (B. Bradshaw, pers comm., 2005).

GEOLOGY OF THE BREMER AND DENMARK SUB-BASINS

The Bremer Sub-basin is defined by Bradshaw et al. (2003) as an extensional depocentre within the western part of the Bight Basin. Previously, the Bremer Sub-basin has also been referred to as the Bremer Basin and Albany Sub-basin (Middleton, 1991; Stagg and Willcox, 1991; Hocking, 1994). The Denmark Sub-basin was previously described by Stagg and Willcox (1991) as the Denmark Trough. Bradshaw et al. (2003) have redefined this structure as a small rift basin and reclassified it as the Denmark Sub-basin. The Denmark Sub-basin appears to be structurally distinct and geographically separated from both the Bremer Sub-basin to the east and the deepwater Recherche Sub-basin. In the present nomenclature scheme, both the Bremer and Denmark sub-basins are considered part of the western Bight Basin (Figure 2.2; Bradshaw et al., 2003; Totterdell and Bradshaw, 2004).

Stagg and Willcox (1991) and Bradshaw et al. (2003) described the overall structure of the Bremer Sub-basin as a complex series of perched half graben that underlie the continental slope in water depths of 100 to 4500 m (Figure 2.3). The continuation of rift structures, from the perched half graben of the Bremer Sub-basin into the down-thrown half graben of the adjoining deepwater Recherche Sub-basin, appears similar to the relationship observed between the Eyre/Ceduna sub-basins and the Recherche Sub-basin in the eastern Bight Basin (Bradshaw et al., 2003; Totterdell and Bradshaw, 2004).

The Bremer Sub-basin covers an area of approximately 11,500 km^2, while the Denmark Sub-basin is much smaller (approximately 2,300 km^2). Total sediment thickness estimates in the Bremer Sub-basin are highly variable, ranging from ~10 km by Cooney (1974), to ~ 5 km by Teasdale (2004). Bradshaw et al. (2003) estimated that the Denmark Sub-basin contains at least 2.5 km of sediments. Bradshaw et al. (2003) also concluded that there appeared to be similarities in the structures and seismic sequences between the Denmark and Bremer sub-basins.

The half-graben depocentres within the western Bight Basin, namely the Denmark and Bremer sub-basins (Figure 2.2), were formed by Jurassic to Early Cretaceous extension oblique to east-west trends within the southern margin of the Albany Fraser Orogen, and orthogonal to northeast-southwest trends within the same province (Bradshaw et al., 2003). Poorly defined low-angle fault blocks within the deepwater Recherche Sub-basin are also interpreted to have formed during this period of extension. Evidence for initial northwest-southeast extension in the Bremer Sub-basin includes (Stagg and Willcox, 1991; Bradshaw et al., 2003):

- dominant east-northeast strike of rift border faults;
- southeast trend of interpreted transfer faults at the eastern and western boundaries of the sub-basin; and,
- east to east-northeast trend of half graben in the Bremer Sub-basin.

Events after initial rifting in the western Bight Basin are poorly understood due to a lack of chronostratigraphic control on the tectonic megasequences. In addition, the age and nature of a possible second phase of extension, interpreted on seismic sections by Bradshaw et al. (2003) in the Bremer Sub-basin, is unresolved.

Figure 2.4 illustrates the half-graben geometry of the Bremer Sub-basin, and the possible division of the sedimentary succession into two rift and two sag successions. Bradshaw et al. (2003) proposed that sedimentation during the earliest rift sequence may correlate to the Middle Jurassic to Early Cretaceous northwest-southeast extensional event that initiated basin formation in the Bight Basin. Prior to Survey 265, the nature and age of sediments in the Bremer, Denmark and Recherche sub-basins have only been inferred by comparison to areas in the eastern Bight Basin, in particular the Eyre Sub-basin. The early rift succession in the Eyre Sub-basin was deposited in a fluvio-lacustrine environment, and has been divided into the Sea Lion and Minke supersequences (Middle-Late Jurassic to earliest Cretaceous; Totterdell et al., 2000).

In the Bremer Sub-basin, the early rift succession appears to be overlain by an interpreted Early Cretaceous thermal sag succession that has since been inverted (Figure 2.3; Bradshaw et al., 2003). This period of inversion may have been driven by structural reactivation prior to (or during) breakup between Australia and Greater India along the southwest margin of Australia during the Valanginian (Bradshaw et al., 2003).

A proposed second rift phase may have been related to the period of mid-Cretaceous rapid subsidence that is observed in the eastern Bight Basin (Bradshaw et al., 2003; Totterdell et al., 2000). A second possibility is that the prominent unconformity that separates the two rift–sag phases correlates to an Early Cretaceous (Valanginian) unconformity that is observed in rocks throughout the Perth and Mentelle basins to the west (Cooney, 1974; Stagg et al., 1990). A related hypothesis suggested by Bradshaw et al. (2003), is that the second period of extension was in response to the Australia/Greater India breakup during the Valanginian, with faults in the Bremer Sub-basin reactivated by movement along Archaean shear zones in the Yilgarn Craton. Shear zones in the Archaean Yilgarn Craton, that were active during the Phanerozoic (Dentith et al., 1994), appear to extend into the rift systems from the Perth Basin and Bremer Sub-basin.

In summary, while the initial rifting event apparent in the Bremer and Denmark sub-basins was part of the formation of the Bight Basin, it is unclear whether a second rifting event had an affinity with events in the eastern Bight Basin (accelerated subsidence), or those in the Perth Basin to the west. Geophysical data and rock samples acquired during Survey 265 aimed to provide some spatial and chronostratigraphic control on the basinal sequences to resolve these questions. The acquisition of seismic lines in Surveys 265 was designed to test current interpretations of basement structure in the western region of the Bight Basin.

CORRELATIVE SEQUENCES

Potential analogues for the sedimentary succession present in the Denmark, Bremer, and Recherche sub-basins are provided by the Jurassic to Cretaceous succession intersected in the Jerboa-1 well from the Eyre Sub-basin. Cainozoic strata from the Eucla Basin have been interstected in isolated drillholes across the onshore Nullarbor Shelf. A succession of Eocene rocks is exposed in the onshore Eucla Basin on the Esperance Shelf and Scaddan Embayment. Miocene deepwater chalks and oozes blanket the offshore basins and correlate to shallow-water facies exposed in the coastal cliffs along the southern Australian coastline and scattered exposures across the onshore Eucla Basin. Interpreted facies variations between the onshore region and the Bremer and Denmark sub-basin are sufficient to suggest that application of the onshore terminology of Lowry (1970) is not appropriate for the offshore region. Further discussion on the Cainozoic succession is presented later in this chapter.

Three nomenclature schemes have been applied to the sedimentary successions intersected at Jerboa-1 and across the Eucla Basin. The first was the lithostratigraphic framework proposed by

Lowry (1970) for the onshore Eucla Basin and applied to Jerboa-1 (Bein and Taylor, 1981), with some later modification by Hocking (1990). The second (Messent, 1998) extends the lithostratigraphic framework used in South Australia some 700 km west to Jerboa-1. The most recent scheme applies a sequence stratigraphic framework to the entire Bight Basin sedimentary succession (Totterdell et al., 2000).

Jurassic and older

Jurassic rocks have been intersected only in Jerboa-1, where intercalated fluvial sandstone and lacustrine claystone and siltstone of Tithonian to ?Callovian age (*M. Forida–R. Watherooensis* spore-pollen zones) overlie Precambrian metabasalt. These belong to the Sea Lion and Minke supersequences of Totterdell et al. (2000). Older sedimentary rocks can be inferred from seismic data above a pronounced basal unconformity, and they are assumed to be continental deposits like those in Jerboa-1 (Sea Lion Supersequence; Totterdell et al., 2000). There is no intermediate unconformity apparent on seismic data that would suggest that much older rocks (e.g. Permian glacial rocks or earlier Palaeozoic sandstone) are present.

Cretaceous

The Cenomanian and Lower Cretaceous succession in Jerboa-1 and onshore drillholes is assigned to the Loongana Sandstone (Neptune Formation) and Madura (Boorda Formation) and Toondi (Ceduna and Platypus) formations (South Australian terminology in brackets). These units correspond closely to the Southern Right, Bronze Whaler, Blue Whale, and White Pointer supersequences defined in the eastern Bight Basin by Totterdell et al. (2000). The succession is dominated by siliciclastic claystone and siltstone, with discrete intervals of sandstone in the Neocomian. There is limited marine influence in the post-Neocomian rocks. Older sandstones and claystones are regarded as fluvial and lacustrine respectively (Bein and Taylor, 1981; Hocking, 1990; Totterdell et al., 2000).

Cretaceous sedimentary rocks are exposed onshore in the Gunbarrel Basin as thin weathered outcrops, and have been intersected in several drillholes beneath the Eucla Basin. The Nurina Formation (Hocking, 1990) is a greensand to glauconitic sandstone and siltstone of probable Santonian to early Campanian age, that probably relates to the upper Tiger Supersequence of Totterdell et al. (2000). By analogy with the Upper Cretaceous succession in the Southern Carnarvon Basin and Perth Basin, variably glauconitic chalks and marls could be expected higher in the Upper Cretaceous succession, although far to the east in South Australia there was a major influx of deltaic sediments (Hammerhead Supersequence) in the later Cretaceous (Totterdell et al., 2000).

EXPLORATION HISTORY OF THE WESTERN BIGHT BASIN

While there has been some exploration activity in the eastern part of the Bight Basin (Ceduna Sub-basin), the Bremer, Denmark, and Recherche sub-basins of the western Bight Basin have remained exploration frontiers. Regional grids of seismic, magnetic and gravity data were first acquired over the western Bight Basin by the former Bureau of Mineral Resources (now Geoscience Australia) as part of the Continental Margins Program (Surveys 17 and 19) during the early 1970s. Most of this data is of marginal to poor quality. Initial hydrocarbon exploration in the Bremer and Denmark sub-basins was undertaken by Esso Australia Limited between 1972 and 1974, in exploration permits WA-50-P and WA-51-P. Work carried out in 1974 as part of Esso's exploration work program included a 2224 km marine seismic survey and a 7025 line km aeromagnetic survey. No drilling or further work was undertaken and the permits were relinquished in 1975.

Between 1972 and 1973, Continental Oil Company of Australia Ltd. held the adjacent exploration permit to the east (WA-47-P). Exploration of the permit area included a 595 km seismic survey conducted in the shallow waters (less than 200 m) of the Archipelago of the Recherche region. The prospectivity of that area was regarded as poor and the permit was relinquished in 1973 with no further work carried out. Exploration of the western part of the Bight Basin has remained dormant since 1975.

In unrelated activity in the early 1970s, three regional reconnaissance lines were acquired over the Bremer and Denmark sub-basins by Shell, as part of a global survey of continental margins undertaken by the roving M/V *Petrel* (Survey lines N400, N401 and N402). However, all but one of the Shell lines missed the main depocentres of the Bremer and Denmark sub-basins. Both the Esso and Shell seismic surveys have recently been reprocessed by Fugro Multi-Client Services. Geoscience Australia acquired licensing rights to the reprocessed Esso R74A data, while Fugro MCS retains rights to the reprocessed Shell N400 data.

Stratigraphic mapping and palaeontological studies of the onshore Eucla Basin began as early as 1955 (Clarke and Phillips, 1955). Subsequent exploration for Middle Eocene brown coal in the southern region of the Western Australian Shield has generated a large volume of unpublished data (Hocking, 1990). During 1974-1976, three wells were drilled onshore in permit EP68 by Silfar Oil and Gas Search Limited and W.I. Robinson (Kendenup-1, Sunday Swamp-1 and Ocumup-1). Drilling results were not encouraging and hydrocarbon exploration onshore was subsequently suspended.

HYDROCARBON POTENTIAL OF THE WESTERN BIGHT BASIN

As there are no petroleum exploration wells drilled in the western part of the Bight Basin, no stratigraphic, geochemical or geothermal data has previously been available to directly assess the petroleum prospectivity of this region. The sedimentary succession in the Bremer Sub-basin is interpreted by Cooney (1974) as up to 10 km thick. A similar age succession in the Denmark Sub-basin is interpreted by Bradshaw et al. (2003) to be significantly thinner (at least 2.5 km thick). Jerboa-1, located about 1000 km to the east in the Eyre Sub-basin, is the closest and most relevant well for assessment of the prospectivity of the Bremer and Denmark sub-basins. In addition, some wells drilled within the half graben of the Duntroon Sub-basin may also be relevant to an assessment of the Bremer and Denmark sub-basins.

In the Eyre and Duntroon sub-basins, oil-prone Middle to Late Jurassic lacustrine source rocks have been intersected in several exploration wells (Smith and Donaldson, 1995; Totterdell et al., 2000; Blevin et al., 2000; Ruble et al., 2001). In Jerboa-1, geochemical analyses indicate that average total organic carbon (TOC) concentrations range from 0.94% in Albian strata, to 1.84% within the Berriasian-Valanginian section (Huebner, 1980). The most organic rich shales occur towards the base of the Berriasian succession, where TOC reaches a maximum of 5.46%.

Fluid inclusion studies undertaken by Ruble et al. (2001) on Jerboa-1 documented a 15 m thick palaeo-oil column in fluvio-lacustrine Callovian to Kimmeridgian sandstones. The palaeo-accumulation was sealed by an overlying thick succession of Tithonian lacustrine shales, while modelling suggests the trap was breached during the Late Cretaceous (Ruble et al., 2001). Work on oil inclusions within the palaeo-oil column suggest that it was derived from mature source rocks containing algal and bacterial organic material. Deposition within a non-marine, probable lacustrine environment was interpreted by Ruble et al. (2001). There was no geochemical evidence of hypersalinity within the lacustrine setting and minimal input of terrestrial organic matter was also recorded.

In Jerboa-1, the Late Jurassic to Early Cretaceous succession consists of non-marine, fluvio-deltaic sandstones and lacustrine claystones (Totterdell et al., 2000; Ruble et al., 2001). Vitrinite reflectance data acquired from the fine-grained lacustrine section indicate that any potential source rocks are immature for hydrocarbon generation (Ruble et al., 2001). It is unclear whether the immaturity is due to insufficient palaeo-heatflow, depth of burial or chemical kinetics of the organic matter (Ruble et al., 2001). Geohistory modelling at pseudo-well sites that flank the Jerboa-1 fault block suggests greater maturities would be reached with probable migration into the Jerboa structure (Blevin et al., 2000). Good quality reservoirs were identified within the Berriasian-Valanginian age lacustrine and fluvial succession at Jerboa-1, with average porosities ranging from 17 to 24% (Bein and Taylor, 1981).

It is expected that fluvio-deltaic and lacustrine environments also dominated during the Late Jurassic to Early Cretaceous within the half-graben and graben structures that comprise the Bremer and Denmark sub-basins. Similar to the Eyre Sub-basin, depth of burial and regional heatflow in the Bremer and Denmark sub-basins are expected to be key factors that determine the success of an active petroleum system (or systems). Basement underlying the depocentres of the eastern and western parts of the Bight Basin differs (Totterdell and Bradshaw, 2004), thus there may be a difference in regional basement-derived heatflow. Mesoproterozoic igneous and metamorphic rocks of the Albany-Fraser Orogen adjoin and underlie the Bremer and Denmark sub-basins, which Teasdale (2004) interprets to have moderate to high heat flow.

Structurally, the Bremer Sub-basin appears to have been affected by a second Early Cretaceous extension event that is absent from the Eyre Sub-basin. The Early Cretaceous event resulted in the formation of large anticlinal and fault-related structures in the Bremer Sub-basin that may have been formed prior to hydrocarbon charge (Bradshaw et al., 2003). Several of these structures are located in water depths of 500–750 m.

CAINOZOIC CARBONATE MARGIN

The southern margin of Australia contains one of the world's largest cool-water carbonate platforms, extending for some 4,000 km along the entire shelf-slope break (Conolly and von der Borch, 1967). The low terrigenous input to the shelf allows the production and preservation of carbonate sediments across this region (James and von der Borch, 1991). The shelf margin and upper slope off southern Australia are characterised by pure carbonate deposits composed of grainstone, packstone and wackestone, and sourced largely from prolific bryozoan growth (von der Borch and Hughes Clarke, 1993). The Holocene carbonates are composed dominantly of bryozoa, foraminifera and molluscs, with phototrophs such as coralline algae occurring in water depth of less than 70 m (James et al., 1992). Several deep-water piston and gravity cores up to 12 m in length have been obtained from within the study area. These cores penetrate mostly Pleistocene to Pliocene material, but the climatic record from these cores is often marred by thick turbidite deposits.

Our current interpretation of the Cainozoic history from the offshore southern margin is drawn largely from sequences in the Great Australian Bight, the Otway Basin and the Naturaliste Plateau, with no comprehensive studies from offshore southern Western Australia. A recent compilation from onshore outcrops and bores provides a consistent stratigraphic framework for the Eocene sedimentary sections (Clarke et al., 2003).

Extensive carbonate sedimentation was initiated on the southern margin during the late Middle Eocene, with the deposition of the Wilson Bluff Formation in the central Eucla Basin (James and von der Borch, 1991). Along the western margin of the Eucla Basin, these marine carbonates form part of the Nanarup/Neridup Limestone, most likely equivalent to the Norseman Formation (Clarke et al., 2003). The onset of carbonate sedimentation was associated with the acceleration of sea floor spreading rates that produced fully marine conditions (McGowran et al., 1997). However, calcareous nannoplankton and foraminifera dredged from the western Great Australian Bight date from the early Maastrichtian, providing evidence for marine incursions during the post-breakup period (Davies et al., 1989). Circulation during the late Middle Eocene was dominantly west-to-east and fed by the circum-equatorial Tethys Ocean (Shackleton and Kennett, 1975). The opening of the Australian-Antarctic margin propagated from west to east, so analysis of Bremer Sub-basin carbonates may provide data for the onset of marine conditions. The early marine record from southwestern margin sediments may also help to resolve questions about the timing of onset of the Leeuwin Current.

It has been proposed that the gradual migration of warm water organisms from west to east along the southern margin reflects the increasing influence of warmer waters along this margin, akin to the present-day Leeuwin Current (McGowran et al., 1997; Craig, 2002). Modern circulation patterns along the western and southern margins result in the flow of the warm, low salinity Leeuwin Current from near North West Cape southward, and then eastwards around Cape Leeuwin and towards the Great Australian Bight (Cresswell and Golding, 1980).

CANYON-CONTROLLED SEDIMENTATION ON THE SOUTHERN MARGIN

The continental shelf of Australia is dissected by many submarine canyons, particularly along the western and southern margins of the continent. Among the deepest canyon complexes are the Bass Canyon in eastern Bass Strait, the Murray Canyons off the Spencer and St Vincent gulfs, and the Albany Canyons between 115° and 124°E (von der Borch, 1968). The Albany Canyons incise the underlying basinal succession of the Bremer and Denmark sub-basins, and include at least 32 canyons with channel depths of up to 2500 m. Canyon development in the offshore Albany area appears to be structurally controlled (Stagg and Willcox, 1991). The formation of canyons along fault-block boundaries and accommodation zones has resulted in the orientation of some canyons trending oblique or parallel to the continental slope.

Large gravity slumps up to 50 km wide on the continental terrace and slope (Rollet et al., 2001) may be the result of widespread sediment transfer through the canyons via mass-wasting processes. Cores from the continental rise and abyssal plain contain numerous graded beds that are the result of turbidite flows down the slope (Conolly and von der Borch, 1967). Recent transport processes through the canyons are still unknown. In the Otway region, it is suggested that the canyons are no longer an active conduit for sediment transfer as turbidite sequences are overlain by 8 to 10 cm of hemipelagic sediment (Passlow, 1997).

Figure 2.1 *Location map showing the depocentres along Australia's southern (Bight, Polda and Eucla basins) and southwest (Perth, Yallinaup Shelf, Mentelle Basin and Naturaliste Plateau) continental margin (from Bradshaw et al., 2003).*

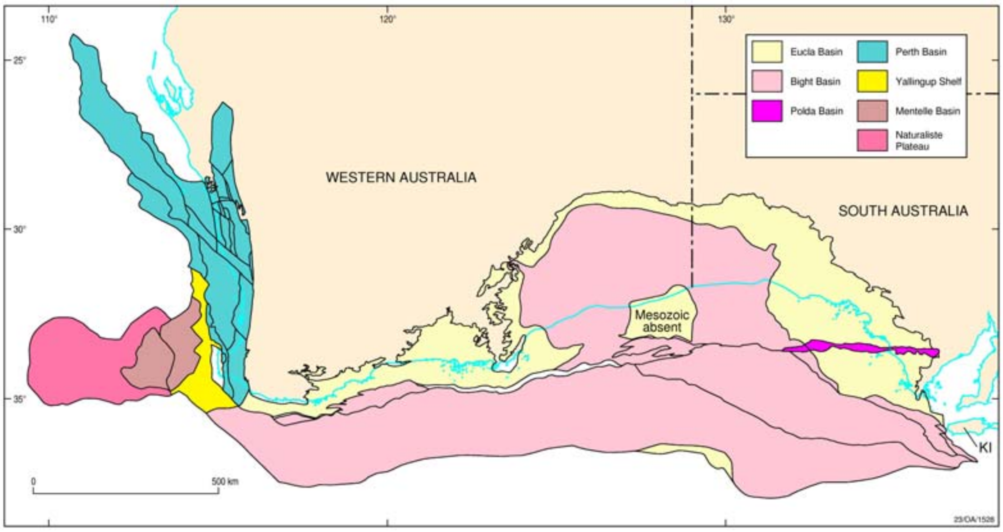


Figure 2.2 *Location map of the depocentres of the Bight Basin (from Totterdell and Bradshaw, 2004). The location of the adjacent Polda and Otway basins is also shown.*

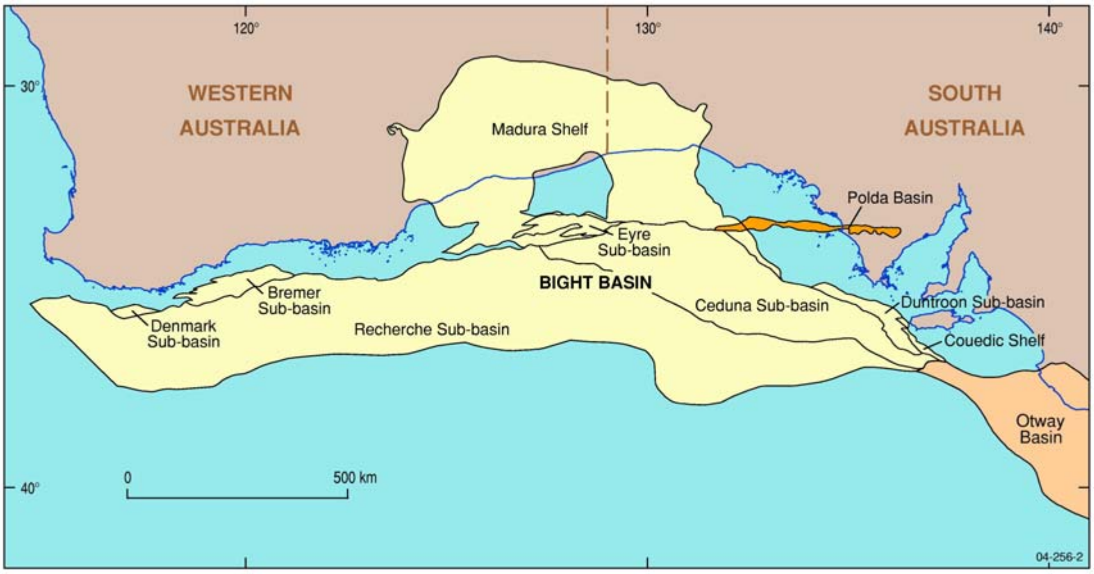


Figure 2.3 *Cross-section through the Bremer Sub-basin and western Recherche Sub-basin (from Bradshaw et al., 2003).*

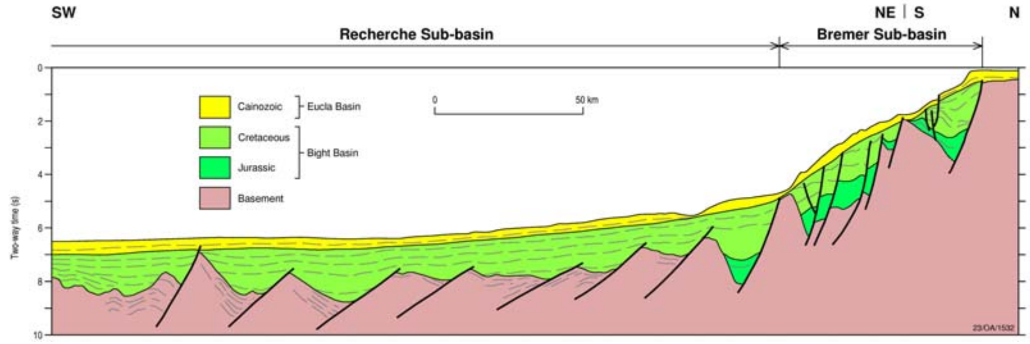
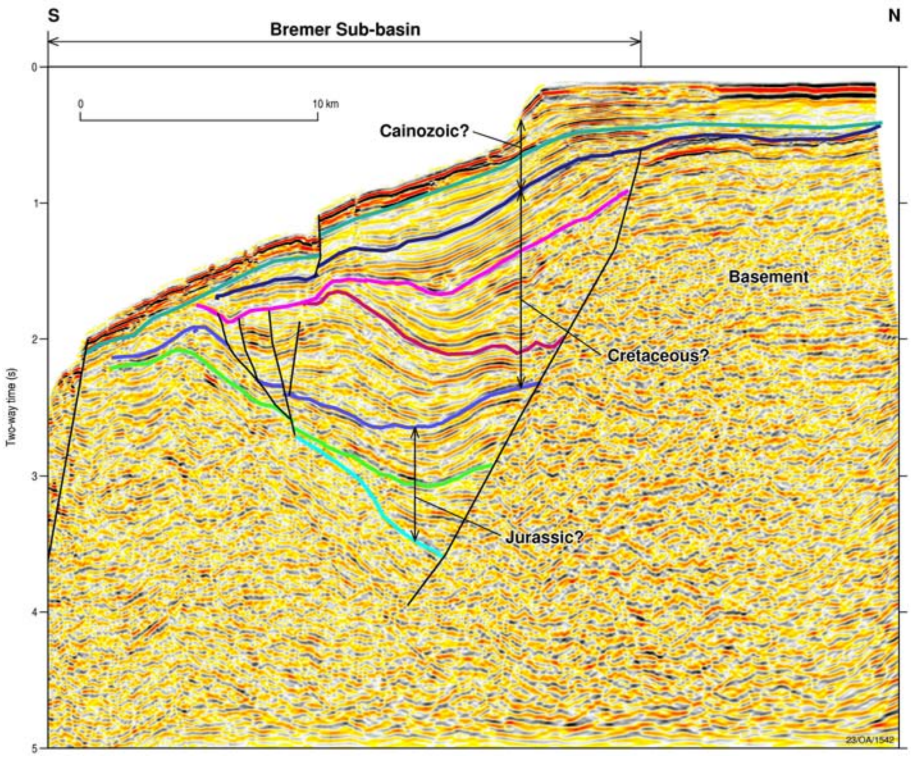


Figure 2.4 *Seismic line through half graben in the eastern Bremer Sub-basin. Note the evidence for two rift-sag successions in Jurassic and Cretaceous strata (from Bradshaw et al., 2003).*



3. Results of Survey 265

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INTRODUCTION

Geoscience Australia Survey 265 was undertaken in two parts (Tables 3.1 and 3.2): **Leg 1** comprised a 15 day, mainly geophysical data acquisition program (seismic/magnetic profiling, swath mapping and dredge sampling), followed by **Leg 2**, an 11 day geological data acquisition program (dredge samples, gravity cores and swath mapping). The survey departed from Fremantle on Monday, 9 February 2004, and berthed in Hobart on Wednesday, 10 March 2004, with a total time at sea of 31 days (including 5 transit days).

LEG 1 – SEISMIC AND SWATH ACQUISITION PROGRAM WITH DREDGE SAMPLES

Reflection seismic profiles were acquired using a 300 m active section (500 m total cable length), 24 channel streamer (12.5 m group interval, 50 m shotpoint interval) at an average speed of 8 knots, or 15 km/hour. A detailed equipment list and operations report is provided in Appendix P. The seismic and swath systems used onboard the R/V *Southern Surveyor* had been recently purchased by Geoscience Australia, and sea trials were conducted prior to the start of Survey 265. The deepwater lines of the planned grid were acquired first while the systems were being commissioned.

A total of 1027 km of seismic data were acquired on three east-west lines crossing the Bremer, Denmark and Recherche sub-basins (Figure 3.1 and Table 3.3). The survey started in the west (35°47.9'S, 116°51.4'E) with line BREM-1 ending at 35°55.6'S, 121°22.5'E. BREM-2 was acquired from 34°49.5'S, 121°22.8'E in an easterly direction finishing at 35°41.9'S, 116°54.3'E, and BREM-3 was acquired from 35°39.6'S, 117°51.5'E towards the east and terminating at 34°59.9'S, 119°31.7'S. The acquired seismic data were processed on-board during the survey and proved to be of moderate quality, with the deepest penetration ranging from 2 to 3 s TWT. Seismic acquisition was abandoned on Day 10 of Leg 1 after recurring compressor-related problems resulted in terminal equipment failure. A description of the acquisition details of each line is given in Appendix R.

The swath-mapping profiles of the final 4.5 days of Leg 1 were acquired at a speed of 9 knots, or 17 km/hr. The swath-mapping program was designed to give full seabed coverage of the upper slope in the area from Albany to approximately 150 km west of Esperance. Previous deepwater swath coverage in this area, acquired by the *Marion Dufresne* and *L'Atalante*, was generally limited to depths exceeding 2000 m. The present survey infilled large gaps in the existing coverage of the upper slope, resulting in full seabed coverage from water depths of 700 to 1000 m. Bathymetric data from all three swath surveys have subsequently been merged, to produce a

225 m resolution bathymetry map of the study area (Figure 3.1). A JPG-format image of the merged bathymetry is provided as the background image in the ArcGIS project supplied with this Record (Appendix II).

Together with the existing 1974 Esso industry seismic data (Appendix Q; Esso Survey R74A), the newly acquired seismic and swath data were used onboard to finalise the geological sampling program that was subsequently undertaken. An example of a targeted dredge site is shown in Figure 3.2. Due to downtime related to recurring problems with the seismic system, five dredge sites were sampled during Leg 1 to maximise the use of available shiptime.

LEG 2 – GEOLOGICAL SAMPLING PROGRAM AND SWATH MAPPING

The geological program undertaken during Leg 2 aimed to acquire a variety of rock types and ages, in order to establish a chronostratigraphic and lithostratigraphic framework for the depocentres. This program was the first attempt to recover rocks from the Bremer and Denmark sub-basins, and thus provide a basis to understand basin development and the petroleum potential of the region.

Dredging operations during Leg 2 were undertaken at 45 sites in canyons that incise the Denmark and Bremer sub-basins (Figure 3.3 and Table 3.4). Dredging operations were undertaken in water depths ranging from 1174 to 4000 m, and all but one dredge site recovered sediment or rock samples. The main dredge consists of a large steel frame and attached chain bag capable of recovering approximately 200 kg of rocks and semi-consolidated sediments per deployment. Finer-grained, mostly unconsolidated, sediments were generally captured within the two pipe dredges (steel cylinders) that hang below the dredge during underwater deployment (Figure 3.4). The dredge was deployed off the stern of the R/V *Southern Surveyor* using a hydraulic winch system.

After retrieving the dredge, the contents of the chain bag and cylinders were emptied onto the deck, where the rocks were washed, sorted and representative samples taken. The dredged rocks were then catalogued and described in the ship's laboratory mainly using hand specimens, although selected samples were sawn to allow closer examination. The rocks and sediments were sorted into various lithotypes for each dredge haul before sub-samples were taken for subsequent specialist studies. The detailed analysis of the samples undertaken on-board was limited to foramifera identification (Taylor and Haig, 2004; Appendix H). A further ten samples were analysed immediately after the survey for source rock characterisation and age (AusGEO News, 2004).

The nomenclature used by Geoscience Australia to catalogue the marine samples is described by Hancock (2003). The survey number is listed first in the sequence, followed by a survey station number and an abbreviation to indicate the sample type (e.g. DR=dredge, GC=gravity core) and its corresponding number in the sequence of samples. For each dredge haul, a lithologic type was assigned a letter, and individual samples were given a numerical suffix, with further subsamples designated by another numerical suffix. A typical sample designation for Survey 265 is 265/05/DR02/A1.2, where:

- Survey No. 265
- Station No. 05
- Sample Type: DR = dredge; GC = gravity core
- Sample No. 02
- Lithotype A

- Lithotype Sample No. 1
- Lithotype Sub-sample No. 2

Towards the end of the survey, surface and shallow subsurface samples were collected along a transect parallel to seismic line R74-25A in the eastern Bremer Sub-basin (Figure 3.5). Four gravity cores were sited near canyons where the Cainozoic cover was thin or absent. These sites were regarded as potential seepage areas where possible hydrocarbons could migrate into the near surface sediments from steeply dipping, deeper mature source rocks. The base of these cores were flash-frozen onboard the ship and later analysed for pore space gases in the laboratories of CSIRO-Petroleum (Perth). On the inboard part of the R74-25A sampling transect, three Van Veen grab samples were collected from the continental shelf and upper slope (78 to 478 m depth), and 10 gravity cores were recovered from the upper to lower continental slope (482 to 3530 m depth). Two additional gravity cores were collected further east near Esso seismic line R74-31.

Of the 14 gravity cores that were attempted at the 12 sites, only eight could be considered successful in terms of recovery (Table 3.5). The gravity core barrel had a maximum capacity of 4 to 6 m. The longest core measured 335 cm, while recovery in the other cores ranged from <10 to 194 cm. Details of the location and recovery of cores and grab samples are presented in Table 3.5.

GEOLOGICAL RESULTS – DREDGE SAMPLES

The 45 dredge sites yielded samples from a range of geological provinces (Bremer, Denmark and Recherche sub-basins), and included sedimentary, metamorphic and igneous rock types (Figure 3.3 and Table 3.4). Basement rock types dredged from the Recherche Sub-basin (265/13/DR13), and Albany (265/01/DR02 to DR04), Wilson (265/05/DR06), Wongerup (265/20/DR20), Wilyunup (265/21/DR21) and Stokes canyons (265/57/DR/45) included granite, gneiss and schist. A ‘red bed’ sandstone of unknown age was recovered from near basement in the eastern Bremer Sub-basin (Stokes Canyon; 265/56/DR44), while syn-depositional basalts were recovered at dredge site 265/21/DR21, near Wilyunup Canyon in the central Bremer Sub-basin. Unconsolidated, muddy, siliceous and calcareous sediments were recovered at nearly all dredge sites in the pipe dredges and as coatings on older rock samples.

The majority of rocks recovered were sedimentary and ranged from Middle Jurassic to Recent in age (see Chapter 4). Dredges in the Denmark and westernmost Bremer Sub-basin recovered mainly Late Cretaceous and younger sediments. Post-survey analyses (Chapter 4) have shown that some of the oldest sedimentary samples confidently dated were fluvial siltstones and organic-rich, lacustrine shales of Callovian–Kimmeridgian age (*M. florida* spore/pollen zone; 265/20/DR20, 265/28/DR28, 265/54/DR42 and 265/56/DR44). A single sample of Early to Middle Jurassic quartz arenite recovered from the eastern Bremer Sub-basin was the oldest sedimentary sample recovered (265/52DR40; *C. torosa* spore/pollen zone).

Dredges 265/15/DR15 to 265/24/DR24 were recovered from the incised shallower parts of the canyons of the western Bremer Sub-basin. These dredge hauls yielded abundant samples and a variety of rock types, including sandstones, siltstones, black mudstones and minor coal of a delta plain sequence, and greensands and related sediments with *Inoceramus*, of probable Coniacian-Campanian age. Mudstone was the most abundant rock type recovered, and many samples were highly carbonaceous. Deepwater dredge 265/25/DR25 was dominated by a hard, blocky and fractured silicified siltstone. Dredges 265/27/DR27 to 265/57/DR45, in the central Bremer Sub-basin and extending as far east as Stokes Canyon, contained similar rock types, but the volume of arkosic sandstone, quartz sandstone and micaceous quartz sandstone dominated over mudstones. The carbonaceous mudstones that were frequently recovered in the western Bremer Sub-basin were generally rare.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS OF DREDGED SEDIMENTARY ROCKS

Dredge samples recovered during Survey 265 ranged from unconsolidated calcareous ooze, to variably indurated sedimentary rocks, and hard crystalline basement rocks. From consideration of the known sedimentary fill along the southern margin and the continental hinterland, these suggest ages of Quaternary to Neogene, Paleogene to Early Cretaceous, possibly Jurassic, and Proterozoic. Dredge samples of semi-consolidated to well-consolidated (?older) rocks included lithofacies from continental, coastal and nearshore marine depositional settings. Continental facies included poorly-sorted, feldspathic sandstone, laminated siltstone (commonly with shaly to coaly partings or imprints) and redbeds. The interpretation of a coastal to marine depositional environment was based on evidence of bioturbation, texture (e.g. degrees of sorting and rounding) and mineralogical maturity (e.g. quartz-dominated, as opposed to feldspathic- or lithic-dominated). Calcareous oozes generally range from unconsolidated to plastic, although some samples are puggy and almost consolidated to chalk. Discounting Late Cretaceous chalk (which is considered with the carbonate marine assemblage), the oldest oozes are probably Eocene, with Miocene the most common age recorded in Survey 265 dredges.

The assemblages of basinal sediments were classified during the survey and include (in order of interpreted decreasing age):

- Terrestrial, coal-bearing, arkose, laminated siltstone, carbonaceous mudstone/shale and coal; poorly-sorted sandy lithofacies (continental, fluvial channel) and laminated silty lithofacies (continental, inter-channel, overbank and swamp).
- Marginal marine, winnowed quartz arenite, interbedded fine sandstone and siltstone, and bioturbated mudstone; well-sorted sandy siliciclastic lithofacies (marine, nearshore to foreshore).
- Shallow marine, greensand and cherty radiolarian-bearing mudstone; bioturbated silty siliciclastic lithofacies (marine, low energy and possibly tidal).
- Shallow marine calcarenite.
- Deep marine, Oligocene to Miocene, lithified and semi-lithified spiculitic chalk and calcareous mudstone.
- Ubiquitous deep marine Pleistocene and Holocene, foraminiferal and nannofossil ooze, grading to less spiculitic and more clayey facies to the east.

Continental fluvial channel assemblage

Immature feldspathic sandstone

Moderately consolidated, texturally immature quartzose and arkosic (feldspar-rich) sandstone was collected in numerous dredges. The sandstone is poorly sorted, medium- to very coarse-grained, locally gritty and pebbly, and in a few samples has siltstone or mudstone interbeds or shaley intraclasts. The colour ranges from light oxidized brown through pale ferrous green to pale grey, and cross-bedding was observed in some samples. The textural immaturity and mineralogy indicates rapid deposition in a fluvial channel setting. Bein and Taylor (1981), Hocking (1990), Totterdell et al. (2000) and Bradshaw et al. (2003) considered that deposition along the western part of the southern margin of Australia was largely non-marine, in part fluvial, in the Jurassic and Lower Cretaceous, with marine conditions becoming dominant in the mid-Cretaceous.

Redbed sandstone and mudstone

Distinctive brick-red quartzose sandstones were recovered in dredges 265/34/DR34 and 265/56/DR44. In dredge DR34, the sandstone is medium-grained, well-sorted, and intercalated with brick-red mudstone. The sorting and the association with mudstone suggest an oxidizing tidal sandflat setting rather than a fluvial setting. Dredge 265/56/DR44 is coarse-grained, poorly-sorted and gritty to slightly pebbly, which suggests subaqueous deposition in a fluvial channel system.

The red colouration is sufficiently distinctive that the two samples are interpreted as being from a different depositional system to other continental and tidal rocks recovered during the survey. Assuming most siliciclastic rocks recovered along the southern margin are Jurassic or Lower Cretaceous, based on the known ages of deposition along the southern margin (Totterdell et al., 2000; Bradshaw et al., 2003), the redbeds are tentatively inferred to be older, as redbed facies have not previously been recognized in the Bight Basin. By comparison with the rest of Western Australia, possible ages are Lower Jurassic, Middle to Upper Triassic or Devonian. Redbeds are present in the Perth Basin in the Lower Jurassic Eneabba Formation, and Triassic sandy successions are widespread around the Western Australian margin (e.g. Erskine Sandstone, Canning Basin; Mungaroo Formation, Northern Carnarvon Basin; Lesueur Sandstone, Perth Basin), above a similarly widespread Lower Triassic shale. Devonian sandy deposition was widespread in the interior of Australia, with the Wanna Formation (probable Devonian age, south of Musgrave Complex) the nearest of these units to the Bremer and Denmark sub-basins.

Indurated quartz sandstone and shale

Coarse-grained, poorly-sorted, sparsely pebbly, moderately silicified quartz sandstone was recovered in dredge 265/52/DR40, together with well-indurated, fissile, dark grey to black shale. Neither displays a metamorphic fabric, but both are more indurated than most other sedimentary rocks recovered in the dredging program. This may indicate they are samples of Precambrian sedimentary rocks such as the Mount Barren Group, from beneath the Bremer Sub-basin, or simply that they have undergone deformation and silicification (due to greater fluid movement) near a fault zone. The sandstone is only slightly more silicified than the poorly sorted redbed sandstone, and could be a pallid variant of this facies.

Continental interchannel assemblage

This assemblage consists of dominantly fine-grained sedimentary rocks that are, in general, laminated or coaly, and show no visible evidence of bioturbation. However, without unequivocal diagnostic characteristics, marine siltstone or mudstone may be indistinguishable from similar continental deposits.

Laminated siltstone to mudstone

Dark grey to black and chocolate brown siltstones, silty mudstones and mudstones, commonly micaceous (detrital muscovite) and visibly carbonaceous, were common in dredge samples. Coaly flakes are present in some samples. Rootlets have not been recognized, and siltstone with plant imprints is distinguished as a different facies. Lamination is at times visible, and micas show good alignment along bedding planes, locally imparting a superficially fissile appearance. Samples show varying degrees of oxidation. Those that have undergone preliminary processing for microfossils are barren of foraminifers, but contain common plant and woody material (Appendix H). A lithified fragment of organic-rich mudstone recovered in dredge 265/22/DR22 contains granular aggregates of pyrite crystals that cover the rock face and voids. In this sample, a swampy continental environment of deposition is inferred, but the siltstone could easily be marine or coastal (tidal or estuarine) even where bioturbation is not apparent. Laminated siltstone grades into massive, grey to chocolate, firm to puggy mudstone, silty mudstone and claystone.

Laminated siltstone with rip-up clasts

Dark grey to black, plate-shaped shale rip-up clasts up to about 5 cm in diameter are present in some samples of micaceous siltstone to fine-grained sandstone. The facies is distinguished as the rip-up clasts appear to be siliciclastic shale rather than carbonaceous material. The rip-up clasts are oriented approximately parallel to bedding, appear to have been derived from reasonably indurated (as opposed to soft) shale and have undergone some rounding prior to redeposition. Such reworking is more probable in a continental or coastal setting, where delta-plain siltstone to shale is reworked either by migrating or avulsing channels, or at the delta front.

Siltstone and sandstone with carbonaceous material

Grey siltstone and fine-grained sandstone with carbonaceous plant imprints and flakes of carbonaceous to coaly material are relatively common, and abundant in dredge 265/23/DR23. Imprints of fern fronds and other small leaves are clear, generally aligned with bedding but locally apparently distorted around early cementation zones in the siltstone. The siltstone and sandstone are variably micaceous. They are interpreted as fluvial overbank to coastal swamp deposits.

Coal

Small fragments of bright black coal displaying remnant woody textures have been recovered from several dredges, and both coaly and bright coal partings and flakes are present in some sandy and silty samples. The coal fragments are fissile and commonly lithified.

Shale

Dark grey to black, fissile to sub-fissile shale and siltstone was recovered in a few dredges. There appears to be a complete gradation from virtually massive, carbonaceous siltstone through sub-fissile siltstone to fissile shale, although pronounced fissility is less common. The shales also contain varying amounts of organic and micaeous material, and are commonly lithified but visibly weathered. A shale in dredge 265/25/DR25 exhibits mud and silt lamination at sub-millimetre scale, and preliminary palaeontological examination shows it to be barren of foraminifers. A shale sample in dredge 265/17/DR17 is cleaved and has a slight crenulation due to bedding and cleavage intersection, but contains some plant material, indicating the cleavage originated through proximity to a fault zone rather than being preserved in an eroded piece of underlying deformed Precambrian rock.

Shallow marine sandy (high energy) assemblage

Quartz arenite

Well-sorted, fine-grained quartz arenite with trace amounts of feldspar and mafic minerals is common across the Bremer Sub-basin. Bedding is locally well-defined, and the sandstone is generally friable to moderately consolidated. A silty matrix is present in some samples. The degree of sorting and mineralogical maturity indicates winnowing by waves or tidal currents. Tidal bundles and flaser bedding are not apparent suggesting that the facies originated in a wave-winnowed middle or upper shoreface to foreshore environment rather than in tidal channels. A single sample, from dredge 265/56/DR44, shows mud-poor lenticular bedding in fine-grained rippled quartz sandstone. This is characteristic of a tidal sandflat setting. Siltier variants may have been deposited in lower shoreface conditions near to wavebase.

Shallow marine silty (low energy) assemblage

Laminated to burrowed sandstone

Laminated to burrowed sandstone consisting of couplets of bioturbated fine-grained silty sandstone overlying lithologically similar laminated to hummocky cross-stratified sandstone with a transitional contact. Laminated to burrowed sandstone is interpreted as the product of deposition just seaward of the shoreface zone on a marine shelf, where deep storm waves or offshore-directed deep currents periodically rework shelfal sands at depths greater than the normal fair-weather limit of wave action. After the reworking, some, but not all, of the sand body was bioturbated to the normal depth of bioturbation.

Bioturbated siltstone to fine-grained sandstone

Bioturbated rocks are interpreted both where bioturbation is visible and has destroyed most bedding, and where bedding cannot be readily distinguished through a diffuse lumpy to vermiform texture. Such textures are present in silty, fine-grained sandstone, siltstone and muddy siltstone. Deposition in a low-energy coastal to marine shelf setting is inferred.
A mid-to-dark grey siltstone recovered in dredge 265/55/DR43 contains low-angle cross-bedding and cross-sections of probable *Zoophycos* and *Helminthopsis* traces. These structures and ichnofossils, along with the presence of radiolarians (Appendix H), suggest deposition in a lower shoreface to inner marine-shelf environment during the upper Aptian to Albian.

Siltstone and mudstone

Mid-grey to olive-grey and black siltstone, silty mudstone and mudstone are common across the Bremer Sub-basin. Siltstone is generally reasonably consolidated and firm, but mudstone ranges from hard to slightly puggy and plastic when wet. The mudstones and silty mudstones are superficially similar in lithology to Albian and Cenomanian (mid-Cretaceous) siltstone and mudstone units from the Perth and Southern Carnarvon basins (upper Winning Group) for which low-energy shelfal to offshore depositional environments prevailed. Dredge 265/53/DR41 recovered Albian to Cenomanian age rocks (Appendix H), but without further palaeontological control, it remains uncertain whether other dredged samples are of similar age.

Some samples contain radiolarians, and one sample from dredge 265/25/DR25, of hard silicified mudstone with a sub-conchoidal fracture (black when wet, very pale grey when dry), is very similar to outcrop samples of Windalia Radiolarite (Southern Carnarvon Basin) or Bejah Claystone (Gunbarrel Basin) where radiolarian siltstone has undergone opaline to cryptocrystalline silicification during surface weathering. The Windalia Radiolarite and Bejah Claystone are Late Aptian and Early Albian in age, and dredge samples containing radiolarians are of similar or slightly younger age (the Gearle Siltstone from the southern Carnarvon Basin also contains radiolarian-rich horizons, and is of Albian to mid-Cenomanian age), and to have been deposited in shelfal to offshore conditions. In many cases, a marine or non-marine origin cannot be established without palaeontological work, as there is no control from adjacent rock types.

Marine carbonate and chemical assemblages

Calcareous marl

Consolidated pale green to light grey, poorly-bedded to massive, variably calcareous marl (chalk) was recovered in several samples. Some samples contain scattered grains and stringers of glauconite, and fragments of a prismatic bivalve, *Inoceramus*, are present in one sample. Cherty nodules (see below) probably formed in this facies, based on comparisons with outcropping Late Cretaceous calcareous pelagic sedimentary rocks from the Perth and southern Carnarvon basins, and indicate the sediment was pervasively bioturbated prior to lithification. Correlation with these units is assumed from the microfauna and presence of *Inoceramus*. From lithology, sedimentary structures, and known faunal habitats, deposition took place in shelfal to offshore conditions with low terrigenous influx.

Flint nodules

Flint nodules were recovered from two dredges. Those in dredge 265/28/DR28 are indurated, slightly glauconitic, bioturbated claystone, and a fragment of the prismatic-structure bivalve *Inoceramus* is present in the rind of one nodule, enabling a confident Late Cretaceous age determination. These nodules resemble flint nodules found in outcrop in the Toolonga Calcilutite of the southern Carnarvon Basin. A single nodule recovered in dredge 265/56/DR44 is of amorphous pale brown cherty silica, showing no internal structure.

Greensand and glauconitic sediments

Greensand, variably glauconitic siliciclastic sandstone and mudstone, and glauconitic calcareous marl are present in scattered samples across the Bremer Sub-basin. Bedding is parallel to massive, and some samples have been ferruginised by exposure at the seafloor. Deposition is interpreted to have been in a shelfal to offshore setting with generally low terrigenous influx but in oxygenated conditions. Foraminifers indicate greensand and glauconitic siltstone to mudstone from several dredges is Late Cretaceous (Turonian to mid-Coniacian; dredges 265/07/DR07 and 265/09/DR09). Both lithology and age are comparable to the central Perth Basin, which contains the Late Cretaceous Molecap and Poison Hill greensands. Some horizons within the Toolonga Calcilutite of the Southern Carnarvon Basin are also glauconitic.

Calcarenite

White to pale cream, hard, bioclastic, foraminifera-rich calcarenite is present in three dredges. The calcarenite in dredge 265/24/DR24 contains branching bryozoa, other shelly fauna and coralline algae, abundant quartz and some glauconite. The calcarenites are moderate- to high-energy shallow marine deposits. They could come from near the shoreface or, by analogy with the modern outer shelf bryozoan sands, could come from deeper water areas swept by bottom currents. They presumably represent the onset of carbonate sedimentation in the region, so could be Late Paleocene or Eocene in age. Foraminifers are generally sparse and poorly preserved, and, where present, are hard to interpret because of recrystallisation.

Calcareous ooze (chalk)

White to pale grey chalk and variably consolidated calcareous mud and mudstone is very widespread in the basin, and was recovered in nearly every dredge. Apart from calcareous nannofossils it contains variably abundant planktonic foraminifera and robust sponge spicules, some benthic foraminifera, and rare ostracods and echinoid debris. Interestingly, the spicule content appears to be highest in the west, in the Denmark Sub-basin, and decreases eastwards across the Bremer Sub-basin. It is clearly a bathyal to pelagic sediment, and ages range from possibly Late Eocene to Early Pliocene, with Miocene by far the commonest age (Appendix H). Many muds of Miocene age are unconsolidated to barely consolidated, suggesting only minor compaction and lithification since that time, perhaps as a result of little post-Miocene sedimentation in many areas.

Depositional systems

Four depositional systems, of which two are closely related, are apparent from dredge sampling. The ages of the systems are inferred from the known age and character of rocks in the Eyre Sub-basin and onshore.

The redbed samples are interpreted as part of a fluvial to coastal system that has a minimum probable age of Early Jurassic, and could be as old as Devonian. Deposition may have been in an early pre-rift trough which later developed into the early rift basins of the Jurassic, or in an intracratonic basin perhaps related to the Palaeozoic Gunbarrel Basin to the north, rather than to the initial stages of breakup along Australia's southern margin. It is unlikely that palaeontological work will clarify the age of these rocks.

Fluvial channel and continental interchannel facies are interpreted as part of a delta plain to coastal swamp system that periodically prograded into the developing rift basins of the Denmark, Bremer, and Eyre sub-basins, sourced from the Western Australian craton. Down-to-the-south growth faulting (Totterdell et al., 2000; Bradshaw et al, 2003) indicates a northern provenance rather than the Antarctic craton. The age of the system presumably ranges from Jurassic to late Early Cretaceous. A coastal to nearshore, marine-dominated siliciclastic depositional system lay immediately seaward of the delta, and presumably interfingered with it. Marine influence was via a westwards-opening, periodically widening and deepening gulf. By the late Early Cretaceous, continental influx was waning or at least retreating northwards and southwards, and siliciclastic marine conditions became dominant in the western Bight Basin and extended onshore to the northern limit of the Madura Shelf (Naries Point; Jackson and van de Graaff, 1981). Siliceous pelagic deposition (in the Bight Basin; the Bejah Claystone) extended over much of the Western Australian craton, and fine-grained siliciclastic marine deposition, in part glauconitic, was dominant through the Bight Basin.

In the mid-to-Late Cretaceous, global circulation patterns changed as Gondwana fragmented. Along the southwestern Australian margin, carbonate-bearing outer shelfal to bathyal deposition became dominant in the newly forming Australo-Antarctic Gulf. Calcareous greensands, glauconitic marls and cherts reflect this change. Totterdell et al. (2000) noted a decollement surface at this level, where growth faults in the Late Cretaceous succession had a decollement plane along the uppermost shales beneath. The plastic marine mudstones noted in dredges, which are interpreted as Albian to Cenomanian low-energy marine deposits, could readily act as a decollement surface.

On the evidence of a few shelfal calcarenites, and from the regional context, it appears that deposition still kept up with subsidence into the Eocene, although the Paleocene was a hiatus in most areas (Totterdell et al., 2000). The Middle Eocene onset of fast spreading, leading to rapid marginal subsidence, and the opening of the Tasmanian Gateway at the Eocene/Oligocene boundary, had profound effects on sedimentation. In this period, along much of the southern Australian margin, dominantly siliciclastic sedimentation gave way to dominantly carbonate sedimentation, and the outer margin subsided into deep water. Chalks then dominated the pelagic domain, and the Oligocene and younger chalks of the offshore Bremer Sub-basin are in accord with this regional pattern. These could be considered as a fifth depositional system, or grouped with the Late Cretaceous carbonate system.

Onshore, drainage systems along the Albany-Fraser Orogen and southern Yilgarn Craton show a reversal of flow in the Cainozoic, from north-flowing in the Palaeogene to south-flowing in the Neogene (Cope, 1975; Hocking, 1990). Drainage systems that previously flowed north into the Cowan-Lefroy system and ultimately into the eastern side of the Eucla Basin, reversed and flowed into the Southern Ocean, along a line referred to by Cope (1975) as the Jarrahwood Axis; the area south of this line is the Ravensthorpe Ramp. The confirmation of Cretaceous fill in the Bremer and Denmark sub-basins, and the probability of older fill recorded by the redbed samples, suggests that the north-flowing drainage systems may have developed due to pre-rift thermal uplift or arching along the southern margin, possibly in or even before the Early Jurassic, depending on the age of the redbeds. The later reversal to southwards drainage is attributed to post-rift collapse and thermal subsidence through crustal cooling, as a south-facing passive margin developed. The cessation of flow in the drainages in the Eocene (recorded by the paralic to continental Werillup Formation overlain by the marine Pallinup Formation; Clarke et al., 2003) reflects first the overall pattern of increasing aridity on the Australian continent, followed by continued subsidence due to breakup and consequent transgression up the palaeovalleys.

GEOLOGICAL RESULTS – GRAVITY CORES

The eight successful gravity cores were cut into one metre lengths and refrigerated onboard the ship (Table 3.5). As the cores were not split, only sediments at the top and base of the metre sections were described. Cores from water depths of 482 to 1981 m (265/37/GC1 to 265/44/GC8) consisted primarily of light olive-brown to light grey, clayey, calcareous, foraminifera and nannofossil ooze. To the east, cores 265/58/GC11 and 265/59/GC12 in Powell and Stokes canyons (1950 and 2611 m water depths, respectively) recovered pale grey, calcareous ooze.

Two gravity cores reached total depth in possible older sequences. Core 265/40/GC4 recovered 25 cm of dark grey carbonaceous and micaceous mudstone of possible Cretaceous age in 1570 m water depth, while core 265/46/GC10 recovered small lumps of dark grey carbonaceous mudstone of possible Cretaceous age in 3530 m water depth.

Quaternary sediments and slope morphology

Quaternary sediments in the study area are unconsolidated bioclastic deposits. Bryozoal sand was recovered from the outer shelf and calcareous ooze was recovered from the slope. Quaternary sediments were sampled at all dredge and surface grab sites and at all core sites with successful recoveries, except for 254/45/GC10, where an indurated mudstone of probable early Cretaceous age was recovered. Quaternary sediments exhibit a range of colours, textures, compositions, and consistencies that are inferred to reflect the different ages and depositional environments of the sediments.

Shelf sediments

On the outer shelf, the Quaternary sediments consist of poorly-sorted medium- to coarse-grained calcareous sand with some biogenic gravel (265/35/GR1 and 265/36GR2). The principal constituent is bryozoans, with minor components including molluscs, foraminifers, and quartz and lithic grains (<5%). Preservation of the bioclastic fraction is variable, with older, iron-stained clasts intermixed in approximately equal proportions with modern, fresher material. Rounded reworked grains are also common. The coarseness of the sediment and the rounded grains indicate that the seabed on the outer shelf may be affected by high-energy storm waves and tides. The presence of living soft corals and the high-amplitude reflections suggest the seabed is a hard-ground substrate. Although largely palimpset, the outer shelf deposits probably consist mostly of Holocene material.

Slope sediments

On the slope, the Quaternary sediment is calcareous ooze, which is generally bioclastic mud in variable quantities with a smaller amount of carbonate sand. In all cases, the material is highly reactive to dilute hydrochloric acid confirming the presence of carbonate components. Visual inspection under a binocular microscope reveals that the sand fraction contains abundant planktonic foraminifera and sponge spicules, common calcareous benthonic foraminifera, and rare agglutinating benthonic foraminifera, and fragments of molluscs, echinoids and ostracods. The mud fraction consists largely of calcareous nannofossils, clay and fragments of shelly fossils. Sponge spicules are present in all samples and are 0.5 to 1 mm in length. Subangular quartz sand grains are also present in some ooze samples. Generally, nannofossils and clay comprise greater than 75% of the sample, with foraminifers <10%, sponge spicules <10%, and other material <5%, although the abundance of each constituent can vary considerably between samples. For example, the concentration of sponge spicules was generally <10% across the study area, commonly ranging from 5 to 7%, but occasionally as high as 20%.

The calcareous ooze ranges in colour from pale-grey and light olive grey to yellowish-grey, and in consistency from very unconsolidated (especially the surface deposits) to semi-consolidated. There does not appear to be a consistent correlation of colour and consistency with texture and composition. However, the lighter coloured material was generally unconsolidated and the darker, grey material was generally more consolidated. On this basis, the lighter material is interpreted to be Holocene in age, and the darker material to be Pleistocene in age. This preliminary interpretation is supported by the fossil content of the samples. The Quaternary pelagic foraminifer *Globorotalia truncatulinoides* is the most abundant species in the calcareous ooze. All samples examined biostratigraphically show evidence of contamination by older material, resulting in a range of foraminiferal species being present. Other foraminifera, indicative of Quaternary (and older) material and abundant in the calcareous ooze, include *Orbulina universa*, *Globorotailia siphonifera* and *Globorotalia conica/conoidea* (Appendix H). The principal mechanism for the contamination is probably bioturbation, both during and after deposition. Older, more consolidated rocks contain burrows filled and lined with calcareous ooze containing Quaternary foraminifera. The presence of this younger ooze, including foraminiferal tests, in burrows in older rocks points to the significant degree to which the deposits have been bioturbated.

The sponge spicules are autochthonous, but the siliciclastic grains (i.e. quartz sand) have probably been reworked from the associated outcrops of older sandstones and silty sandstones. The presence of the siliciclastic grains in some Quaternary ooze is more likely to be a product of erosion of the older outcropping sandstones on the canyon walls rather than from transport from modern sources. Interestingly, the apparent abundance of sponge spicules in the samples decreases from west to east.

Subsurface sediment thickness

Cores targeting different sedimentary environments on the continental slope recovered variable thicknesses of Quaternary sediment. The thickness of calcareous ooze ranges from <0.02 m recovered from a low-gradient platform on the mid-slope east of Bremer Canyon (265/40/GC04; Table 3.4) to more than 3.3 m recovered from low-gradient slopes on the mid to lower slope (265/45/GC09 and 265/58/GC11; Table 3.4). In most cases, the cores terminated in light-grey, semi-consolidated calcareous ooze inferred to be of Quaternary (presumably Pleistocene) age (265/58/GC11; Appendix H). While gravity core 265/38/GC02 terminated in medium quartz sand and core 265/40/GC04 terminated in indurated organic-rich mudstone, only 10 cm^3 of mudstone was present in barrel of core 265/45/GC10. Several cores were unsuccessful, and in one case, the steel core barrel returned bent with no sediment recovery. The results of the coring indicate that in many places these underlying deposits either crop out at the surface or occur very close to the seabed and that Quaternary sediments no more than a few meters thick overlie indurated, semi-lithified (Tertiary and older?) deposits. There is no obvious relationship between the type of sedimentary environment or gradient of the slope, and the thickness of Quaternary deposits recovered in the cores, although further coring over a wider area may reveal regional trends.

Distribution of Quaternary sediments

Calcareous ooze was the most abundant sediment type recovered in the dredges and cores. However, the volume of material recovered generally decreased from west to east across the study area. There are several possible and non-exclusive explanations for this trend, including: 1) increased productivity in the west associated with upwelling of cooler nutrient-rich currents, possibly in the canyons; 2) enhanced preservation of carbonate material in the west; and 3) higher energy and more active erosion and sweeping of sediments from the canyons in the east. The swath bathymetry (Figure 3.1) shows that the floors of some of the canyons in the central and eastern regions of the study area contain well-developed narrow inner channels (e.g., Knob Canyon) with relatively steep walls, and are bounded by narrow, sharply-crested interfluves (e.g., tributaries of Wilyunup Canyon). These geomorphic features indicate that some eastern canyons are recently active, and may be transporting a significant amount of material downslope. This may account for the relatively thin sequence of Quaternary deposits on their flanks and the reduced thicknesses found in the central and eastern regions. The present-day erosive material may be calcareous sand and gravel swept from the outer shelf into canyon heads during storms, or perhaps displaced by gravity-induced slumps or earthquakes. During interglacials the present outer shelf would have been dry land, and rivers or migrating dunes could have fed sand and gravel into the canyons.

GEOPHYSICAL RESULTS – SWATH MAPPING OF THE SLOPE

Submarine canyons

The swath-mapping done by the *Marion Dufresne* and *L'Atalante* in conjunction with Geoscience Australia has enabled the preparation of accurate canyon maps (e.g. Hill and de Deckker, 2004). These data confirm that there are many canyons of different sizes (Figure 3.6). In general, the canyons decend from about 200 m to 4000 m below sea level along their length, on a slope 40-50 km wide west of Wilyanup Canyon (200-4000 m contours), and 60 km wide further east. Thus thalweg gradients are 6° (1:10) in the west and 4° (1:15) in the east.

The canyons do not run straight down the slope but appear to be structurally controlled along different segments. In the lower part of their course, the canyons frequently turn westward, possibly under the influence of the Coriolis force. Two structural directions are apparent: WNW-ESE (290-300°) and ENE-WSW (70-75°). These trends are likely to be related to the early structural accommodation zones and the strike of normal faults, respectively.

Maximum slopes of the canyons walls that lead down into the thalweg are generally between 1000 m and 2500 m depths. West of 118ºE, the maximum slope is around 6°, probably because the canyons are cutting through relatively soft sedimentary rocks. East of 118ºE, maximum slopes are generally between 10 and 30°, almost certainly because the canyons are cutting hard basement rocks (granites and gneisses) in their upper courses. The slopes in the canyon walls are generally much steeper than along the thalweg, reaching 45° where outcropping basement rocks are present.

Detailed mapping on the upper slope

Towards the end of Leg 1, an extensive 4.5 day swath mapping plan was developed on-board as a result of terminal failure of the seismic compressor. Over 1,500 km of swath mapping was undertaken from Vancouver Canyon, eastward to 40 km east of Whale Canyon (Figure 3.6), resulting in an additional 20 to 25 km wide swath of data covering the upper portion of the continental slope to the north of the existing the French data collected by the *Marion Dufresne* and *L'Atalante*.

The spatial resolution of the gridded swath data acquired ranges from 25 to 30 m, and the higher detail has illuminated new features not previously observed. Sub-horizontal linear structures observed along the canyon walls are likely to be outcropping sedimentary beds that have been differentially eroded as the canyons developed. Karst features (sink holes) have also been identified to the east of Whale Canyon in the upper slope.

Four canyon heads have been mapped where they incise the shelf-slope edge: an unnamed canyon between Vancouver and Wilyunup (35°06.6'S, 119°48.8'E), an unnamed canyon between Wilyunup and Bremer canyons (34°27.0'S, 119°19.8'E) and to a lesser degree, Hood and Vancouver canyons. These canyons are probably active and display sinuous incised valleys with mostly flat-bottomed thalwegs. A build up of sediments along the shelf edge, followed by mobilization by large storm conditions may drive canyon entrant erosion and down-slope deposition. The identification of active canyons allows scope for a swath mapping study of the shelf edge (palaeo-channels), characterization of canyon-fill sediments, and studies of climate change and associated variation of sedimentation rates.

Mapping of the upper slope during Survey 265 confirmed previous observations made during the AUSCAN study of seafloor mapping along other parts of the Australian southern margin (Hill and de Dekker, 2004). These observations include the presence of deep linear canyons that imply incision into soft sediments, and a rugged continental slope that is structurally and geomorphologically complex. The geometry of canyons may follow rift trends emplaced from the break-up of Australian and Antarctica (Willcox and Stagg, 1990).

SUMMARY OF ON-BOARD SURVEY RESULTS

The results of Geoscience Australia Survey 265 are summarised as follows:

- Successful swath-mapping of a large region using the new mid-range SIMRAD EM300 multibeam sonar system. About 5000 km^2 of the upper continental slope was mapped east of Albany, Western Australia. Along with existing swath and seismic data, the newly acquired bathymetric data proved critical in identifying successful dredge targets – in particular, to select the steepest canyon slopes and identify accessible outcrop. Accurate maps of the submarine canyon systems will also prove to be a useful dataset to evaluate the possible risks of trap and seal breach in the Bremer and Denmark sub-basins.

- Limited seismic acquisition due to equipment failure. A total of 1027 km of seismic data were acquired, well short of the intended 3000 km. Overall quality of the on-board processed seismic data was moderate, although one section was of poor quality. The three new profiles and pre-existing seismic data were used to plan the dredge sample sites. The magnetic data proved to be of poor quality and not likely to be a useful dataset.

- Successful basinwide dredge sampling program undertaken in the mapped canyons. Forty-five dredge hauls yielded 100s of individual rock samples and a diverse range of rock types and ages that will provide fundamental information to establish a tectonostratigraphic and petroleum systems framework for the Bremer and Denmark sub-basins. These rocks are the first successful recovery of rocks from the basinal succession, including two gravity cores that penetrated possible older sediments. The presence of coals and widespread black carbonaceous shales and mudstones of Cretaceous and Jurassic ages, indicates that potential petroleum source rocks exist in these depocentres. The presence of widespread, possibly coeval, clean quartz sandstones and arenites suggests that potential reservoir rocks are also present in the sub-basins.

- Gravity coring at 12 sites to establish the composition and character of surface and shallow subsurface sediment of likely Pleistocene and Holocene age. Further information on the formation of canyons systems that characterise the southern margin of Australia has also been collected.

Figure 3.1 *Bathymetric map of the Bremer and Denmark sub-basins based on the merged swath datasets. The basin outlines are shown in blue, along with locations of seismic lines acquired during Geoscience Australia Survey 265 (bold red). The existing Esso Survey R74A seismic (purple) and Shell Petrel N400 (green) lines are also shown.*

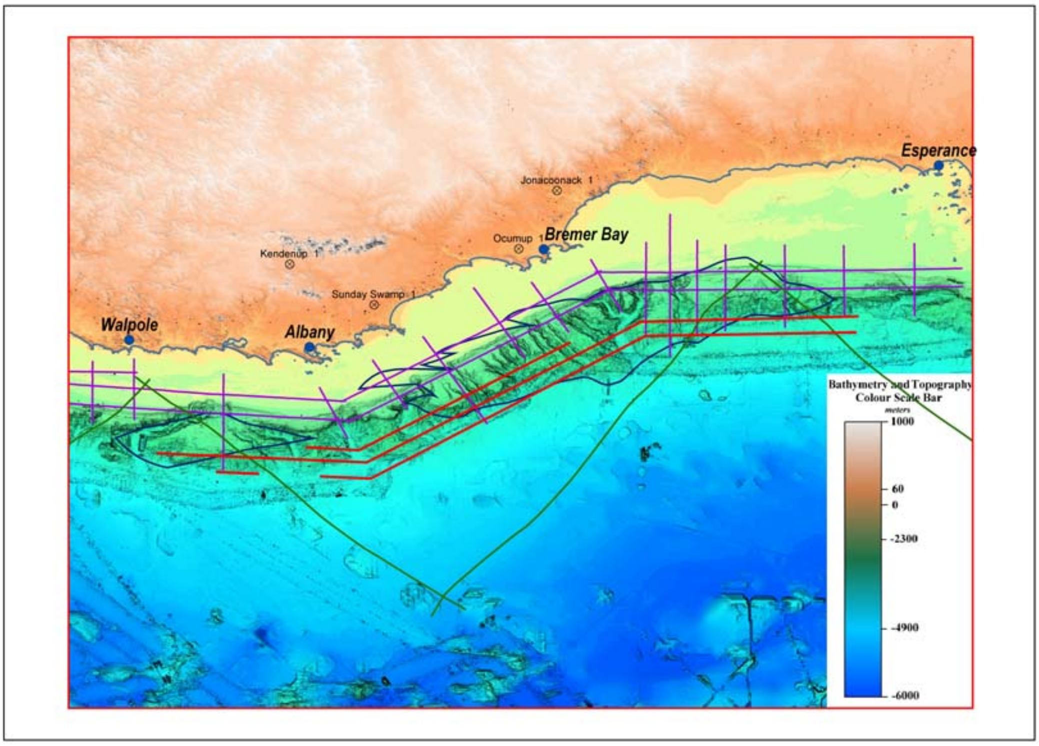

Figure 3.2 *An example of a target dredge site (265/15/DR15) shown on reprocessed Esso seismic line R74A-10A.*

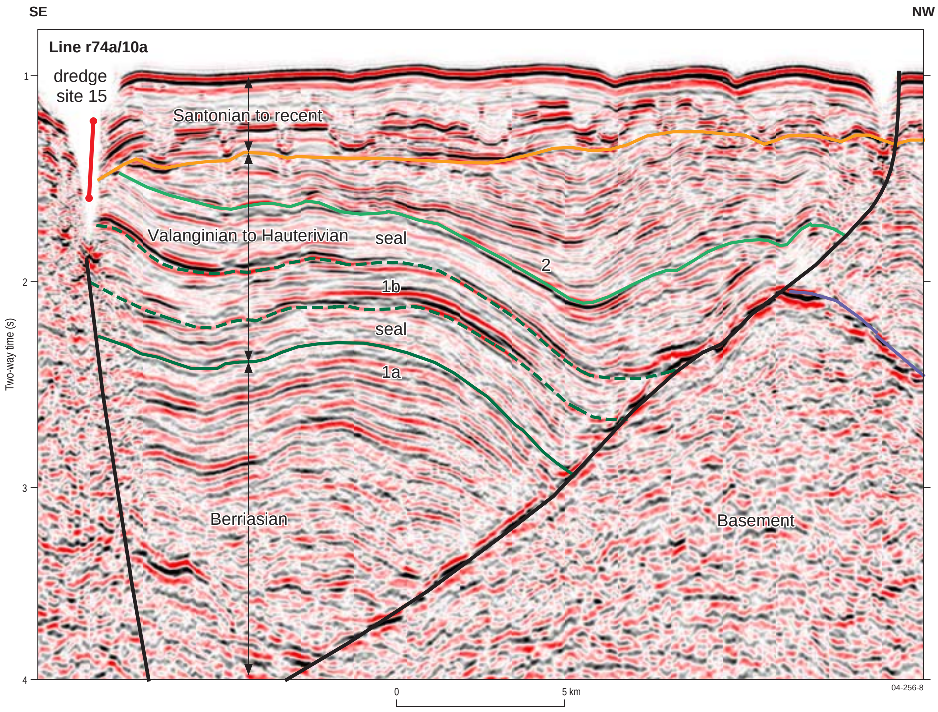

Figure 3.3 *Bathymetric map of the Bremer and Denmark sub-basins showing the locations of dredge sites (yellow dots) sampled during Survey 265.*

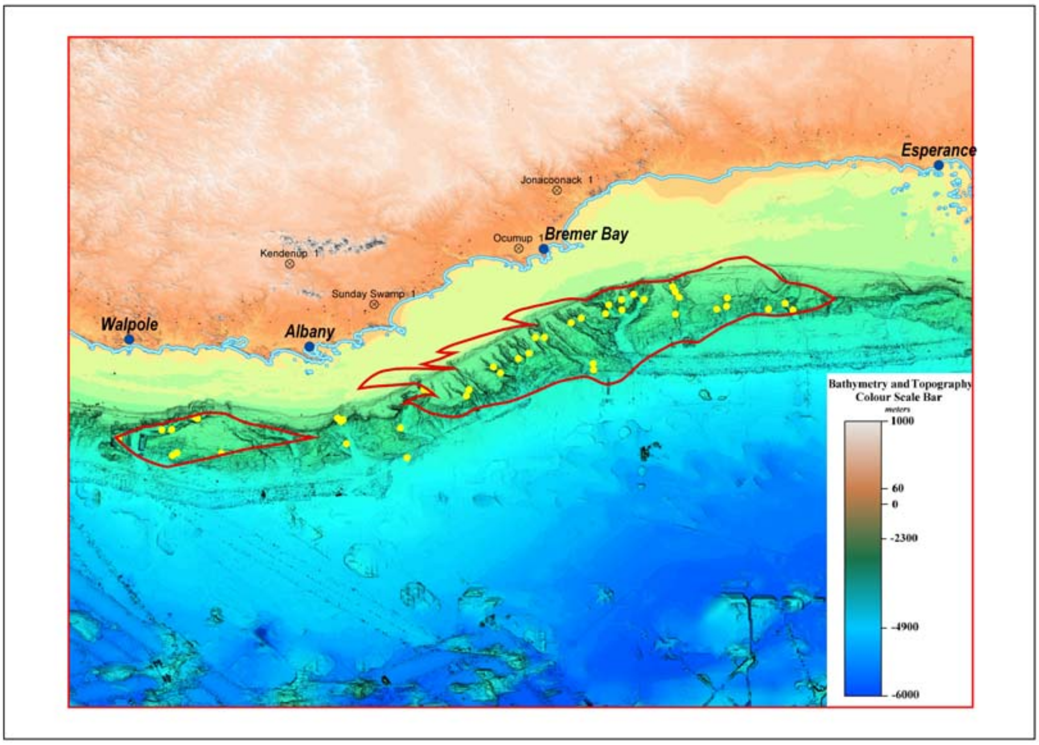

Figure 3.4 *A photograph showing the dredge equipment being recovered after a successful deployment during Survey 265 on the Southern Surveyor.*

Figure 3.5 *Location map of Van Veen (pink triangles) and gravity core (red dots) sites sampled during Survey 265.*

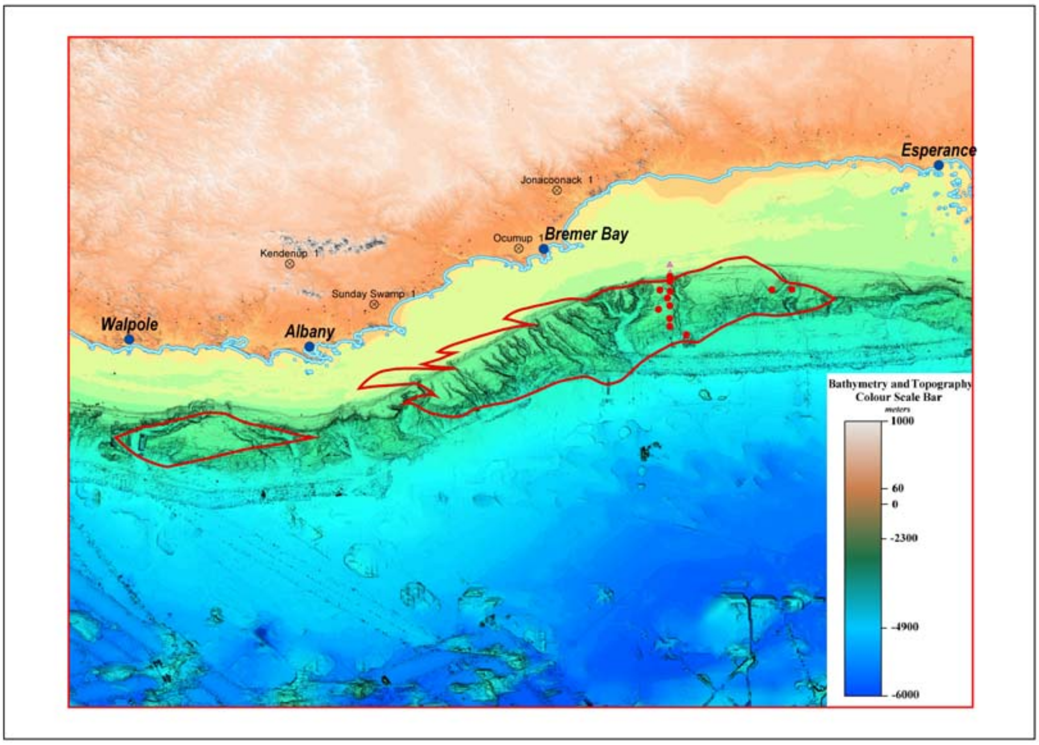

Figure 3.6 *Bathymetric map of the Bremer and Denmark sub-basins showing the locations and names of the major canyon systems.*

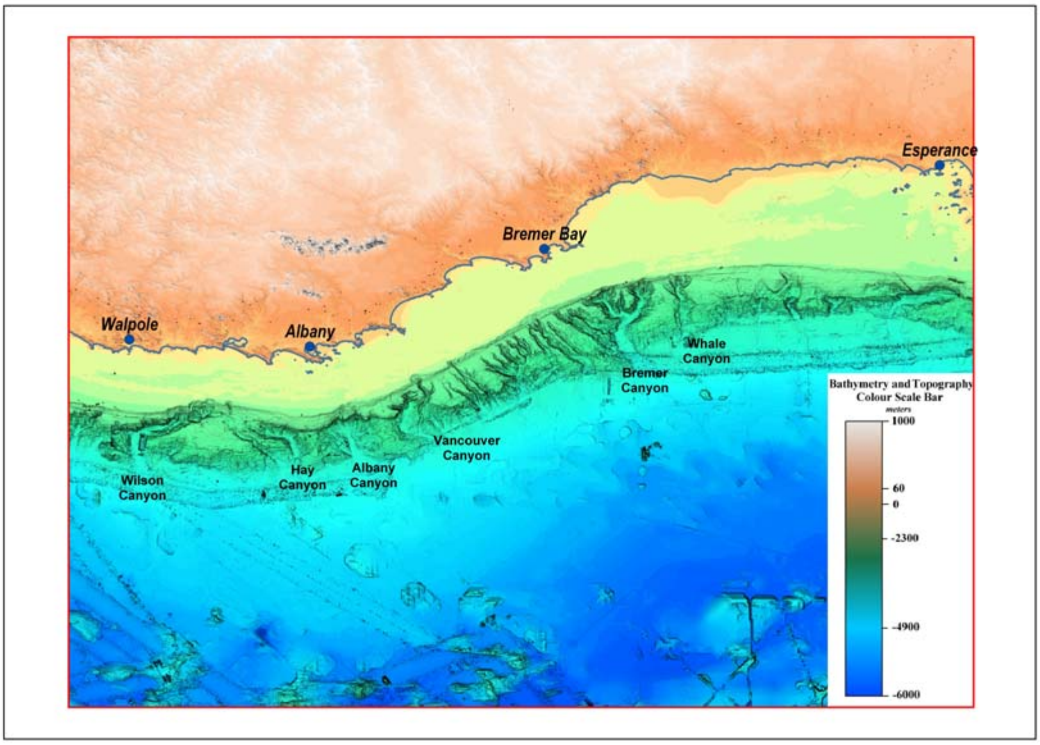

Table 3.1 *Itinerary of Geoscience Australia Survey 265, 9 February to 10 March 2004.*

ACTIVITY	PORT	DATE/DAY AND TIME
Depart *Commence Geophysical Data Acquisition, Leg 1*	**Fremantle**	**9 Feb 2004,Monday** **1045 hrs (WST)**
Arrive *Equipment Repair*	**Albany**	**12 Feb 2004,Thursday** **1030 hrs (WST)**
Depart *Recommence Geophysical Data Acquisition, Leg 1*	**Albany**	**12 Feb 2004, Thursday** **1200 hrs (WST)**
Arrive *Equipment Repair*	**Albany**	**17 Feb 2004, Tuesday** **0800 hrs (WST)**
Depart *Recommence Geophysical Acquisition, Leg 1*	**Albany**	**17 Feb 2004, Tuesday** **2000 hrs (WST)**
Arrive *Complete Geophysical Data Acquisition, Leg 1* *and scientific/technical crew change*	**Albany**	**24 Feb 2004, Tuesday,** **1000 hrs (WST)**
Depart *Commence Geological Sampling, Leg 2*	**Albany**	**24 Feb 2004, Tuesday,** **1600 hrs (WST)**
Arrive *Complete Geological Sampling, Leg 2*	**Hobart**	**10 Mar 2004, Wednesday,** **1000 hrs (EST)**

Table 3.2 *Summary of data and samples from Geoscience Australia Survey 265.*

DATA TYPE	RESULTS
Seismic profiles	1027 km of 24 channel, 3-fold data.
Magnetic profiles	852 km on seismic profiles 1 and 2. Approximately 1500 km total including transits.
Multibeam sonar lines	6200 km in study area (between 116ºE and 121ºE). Approximately 8500 km total including transits.
Bathymetric profiles	6200 km in study area. Approximately 9300 km total including transits.
Dredges	45 total attempted. 44 successful recovery.
Gravity cores	14 total attempted at 12 sites. 9 successful recovery, although several were very short. Maximum single core length recovered 335 cm. Total recovery 1190 cm.
Grabs	4 total attempted. 3 successful recovery.

Table 3.3 *Summary of seismic line statistics from Survey 265.*

LINE	START WAYPOINT		INTERMEDIATE WAYPOINT		END WAYPOINT		LENGTH (KM)
	LAT S	LONG E	LAT S	LONG E	LAT S	LONG E	
BREM1 (pt 1)	35°47.9'	116º51.4'	35°51.5'	118°16.2'	35°50.4'	117°48.1'	85
BREM1 (pt 2)	35°50.7'	117°56.8'	34°57.0' 34°51.6'	120°01.2' 119°59.6'	35°55.6'	121°22.5'	338
BREM2	34°49.5'	121°22.8'	35°45.4'	118°14.7'	35°41.9'	116°54.3'	429
BREM3	35°39.6'	117°51.5'	35°40.7'	118°11.6'	34°59.9'	119°31.7'	175
TOTAL KILOMETERS ACQUIRED: 1027 KMS							

Table 3.4 *Summary of the dredge haul recovery from Survey 265.*

Dredge No.	MARS [1] Sample No.	Water Depth [2], m	Calculated Dredge Start Location		Calculated Dredge Finish Location		Dredge Location [3] and Seismic Profiles [4]	Main Rock Types	Recovery Weight, Kg [5]	Date Acquired
			Latitude (South)	Longitude (East)	Latitude (South)	Longitude (East)				
265/01DR01	1393935	3363	35.6417	118.1227	35.6433	118.1117	Recherche Sub-basin, NNW trending ridge, western flank of Albany Canyon. Esso R74A-11	Quartzose fine-grained sandstone, calcareous ooze.	100	11 Feb 04
265/02DR02	n/a	2125	n/a	n/a	n/a	n/a	Northern margin of Albany Canyon. Esso R74A-6 and -11.	No recovery. Site abandoned.	0	11 Feb 04
265/03DR03	1393941	1370	35.4783	118.0600	35.4783	118.0600	Northern margin of Albany Canyon. Esso R74A-6 and -11.	Gneiss, schist, syenite, calcareous ooze.	4	16 Feb 04
265/04DR04	1393947	1722	35.4892	118.0950	35.4892	118.0950	Northern margin of Albany Canyon. Esso R74A-6 and -11.	Orthoclase-rich granite, calcareous ooze.	80	16 Feb 04
265/05DR05	1393951	2600	35.6033	116.6667	35.6033	116.6667	Denmark Sub-basin, N/S-trending spur west of Wilson Canyon.	Metasediments, syenite, limestone, chalk, foraminiferal sand.	1	18 Feb 04
265/06DR06	1394390	2237-1862	35.4717	117.1533	35.4850	117.1533	Denmark Sub-basin, head of Wilson Canyon, north of Parryville Spur. Shell N400.	Calcareous ooze	0	24 Feb 04
265/07DR07	1393966	1815-1803	35.4817	117.1683	35.4850	117.1683	Denmark Sub-basin, head of Wilson Canyon, north of Parryville Spur. Shell N400.	Silty glauconitic sandstone, chalk, calcareous ooze	13	25 Feb 04
265/08DR08	1393980	2279-2126	35.5517	117.0033	35.5567	117.0067	Denmark Sub-basin, south slope of Wilson Canyon.	Chalk, calcareous ooze.	10	25 Feb 04
265/09DR09	1393985	2921-2712	35.5533	116.9417	35.5600	116.9450	Denmark Sub-basin, south slope of Wilson Canyon.	Carbonaceous calcareous siltstone, black mudstone, calcareous mud and ooze.	2	25 Feb 04
265/10DR10	1393998	3169	35.7167	117.0083	35.7167	117.0083	Denmark Sub-basin, lower slope canyon. GA S265-02.	Calcareous ooze.	10	25 Feb 04
265/11DR11	1394005	2880-2694	35.7000	117.0383	35.7033	117.0383	Denmark Sub-basin, distal basin margin. GA S265-02.	Calcareous ooze.	0	26 Feb 04
265/12DR12	1394007	2343-2120	35.7017	117.3217	35.6917	117.3250	Denmark Sub-basin, distal basin margin, southern edge of Parryville Spur. Esso R74A-09, GA S265-02.	Calcareous ooze.	0	26 Feb 04

Table 3.4 (Continued) *Summary of the dredge haul recovery from Survey 265.*

265/13DR13	1394010	3944-3652	35.7317	118.5033	35.7250	118.5167	Recherche Sub-basin south of Albany Spur. GA S265-01.	Granite with vein quartz pebbles, arkose, very fine-grained sandstone, claystone, chalk, calcareous ooze.	30	26 Feb 04
265/14DR14	1394020	3087-2987	35.5417	118.4617	35.5500	118.4483	Western slope of Vancouver Canyon. GA S265-03.	Chalk, calcareous ooze.	40	26 Feb 04
265/15DR15	1394023	1411-1197	35.2967	118.6100	35.2933	118.6150	Bremer Sub-basin, feeder canyon east of Vancouver Canyon.	Early Cretaceous carbonaceous (black) shale and claystone, chalk, calcareous ooze.	50	27 Feb 04
265/16DR16	1394039	1523-1224	35.3150	118.6483	35.3100	118.6467	Bremer Sub-basin, feeder canyon east of Vancouver Canyon.	Arkose sandstone, quartzose sandstone, black shale, chalk, calcareous ooze.	50	27 Feb 04
265/17DR17	1394050	2116-1681	35.3367	118.8817	35.3450	118.8683	Bremer Sub-basin, Many Peaks Canyon. Esso R74A-15, GA S265-03.	Carbonaceous (black) shale, glauconitic sandstone, calcareous ooze.	200	27 Feb 04
265/18DR18	1394067	1967-1525	35.2967	118.8983	35.3000	118.8933	Bremer Sub-basin, Mermaid Canyon. Esso R74A-15, GA S265-03.	Dark-grey siltstone and claystone, lithic sandstone, basalt, calcareous ooze.	200	27 Feb 04
265/19DR19	1394088	1759-1434	35.1525	119.0533	35.1433	119.0600	Bremer Sub-basin, Wongerup Canyon. GA S280-27.	Lithic and quartzose sandstones, carbonaceous and micaceous siltstone, calcareous ooze.	120	27 Feb 04
265/20DR20	1394096	2212-1805	35.1900	119.0983	35.1933	119.0883	Bremer Sub-basin, Wongerup Canyon. GA S280-27.	Quartzose sandstone, carbonaceous (black) claystone, granite pebbles, calcareous ooze.	70	28 Feb 04
265/21DR21	1394104	2007-1611	35.0983	119.2117	35.0917	119.2033	Bremer Sub-basin, NE slope of Wilyunup Canyon, Esso R74A-17.	Carbonaceous (black) mudstone and shale, siltstone, breccia, calcareous ooze.	100	28 Feb 04
265/22DR22	1394122	2010-1577	35.0650	119.2800	35.0667	119.2900	Bremer Canyon, eastern flank of Richie Canyon. GA S280-17.	Quartzose sandstone, carbonaceous mudstone, phyllite, limestone, chalk, calcareous ooze.	100	28 Feb 04
265/23DR23	1394130	1637-1174	34.9633	119.3200	34.9600	119.3283	Bremer Sub-basin, Cheyne Canyon.	Quartzose sandstone, carbonaceous siltstone and mudstone, pale grey siltstone and mudstone, coal, calcareous ooze.	200	28 Feb 04

Table 3.4 (Continued) *Summary of the dredge haul recovery from Survey 265.*

265/24DR24	1394140	1800-1421	34.9633	119.3783	34.9667	119.3750	Bremer Sub-basin, Pallinup Canyon. GA S280-27.	Carbonaceous siltstone, glauconitic siltstone, quartz sandstone, limestone with *Inoceramus*, calcarenite, chalk, calcareous ooze.	200	28 Feb 04
265/25DR25	1394157	3454-3029	35.1717	119.6917	35.1667	119.7017	Recherche Sub-basin, lower slope of Pallinup Canyon. GA S280-19.	Grey siltstone and mudstone, soft green mudstone, yellow claystone, calcareous ooze.	150	28 Feb 04
265/26DR26	1394168	2635-2595	35.1284	119.6853	35.1229	119.6993	Recherche Sub-basin, lower slope of Pallinup Canyon. GA S280-19, S265-01.	Chalk, calcareous ooze.	20	28 Feb 04
265/27DR27	1394171	2047-1554	34.8700	119.5483	34.8750	119.5417	Bremer Sub-basin, Knob Canyon. Esso R74A-19.	Arkosic and quartzose sandstones, very fine-grained carbonaceous sandstone. Fine-medium-grained micaceous sandstone, minor coal, carbonaceous mudstone, glauconitic sandstone, calcareous ooze.	200	29 Feb 04
265/28DR28	1394184	2113-1466	34.8400	119.6133	34.8450	119.6017	Bremer Sub-basin, Henry Canyon. GA S280-19	Quartzose sandstone, grey siltstone, sandy mudstone, glauconitic sandstone, chert nodules with *Inoceramus*, calcareous ooze.	100	29 Feb 04
265/29DR29	1394203	2482-2057	34.8117	119.7683	34.8167	119.7617	Bremer Sub-basin, western slope of Hood Canyon.	Fine-to-very fine-grained micaceous and quartzose sandstone.	60	29 Feb 04
265/30DR30	1394207	2604-2346	34.7883	119.8717	34.7867	119.8750	Bremer Sub-basin, eastern slope of Hood Canyon. Esso R74A-21, GA S280-20.	Micaceous, bioturbated mudstone, quartzose sandstone, calcareous ooze.	100	29 Feb 04
265/31DR31	1394215	2505-2075	34.7567	119.7883	36.7517	119.7950	Bremer Sub-basin, eastern slope of Hood Canyon. Esso R74A-21, GA S280-20.	Fine-to-medium-grained quartzose and arkosic sandstones.	100	29 Feb 04
265/32DR32	1394220	2049-2130	34.7228	119.8697	32.7233	119.8683	Bremer Sub-basin, feeder canyon east of Hood Canyon. Esso R74A-21, GA S280-20.	Fine-to-medium-grained quartzose, arkosic and micaceous sandstones, carbonaceous mudstone, chalk, calcareous ooze.	100	01 Mar 04

Table 3.4 (Continued) *Summary of the dredge haul recovery from Survey 265. (Page 4)*

265/33DR33	1394228	2313-2089	34.7217	120.0133	37.7183	120.0200	Bremer Sub-basin, eastern slope of Bremer Canyon. Esso R74A-23.	Fine-to-medium-grained quartzose sandstone, muddy micaceous sandstone, carbonaceous mudstone, calcareous ooze.	150	01 Mar 04
265/34DR34	1394236	1991-1738	34.6883	119.9467	31.6850	119.9433	Bremer Sub-basin, northern slope of Bremer Canyon. Esso R74A-14.	Quartzose and micaceous sandstones, grey silty mudstone, 'red bed' quartzose sandstone, calcareous ooze.	50	01 Mar 04
265/47DR35	1394269	2395-1976	34.8155	120.2133	35.0000	120.0000	Bremer Sub-basin, western slope of Whale Canyon. Esso R74A-25A.	Bioclastic limestone, chalk, calcareous ooze.	10	02 Mar 04
265/48DR36	1394275	2099-1922	34.7067	120.2350	34.7067	120.2233	Western flank of Whale Canyon in Bremer Sub-basin. Esso R74A-25, GA S280-28.	Fine-grained micaceous quartzose sandstone and siltstone, carbonaceous mudstone, glauconitic quartz sandstone, calcareous ooze.	100	03 Mar 04
265/49DR37	1394288	1946-1720	34.6733	120.2117	34.6733	120.2050	Bremer Sub-basin, western and lower slope of Whale Canyon. Esso R74A-14, GA S280-25.	Micaceous quartzose siltstone, carbonaceous mudstone, calcareous ooze.	150	03 Mar 04
265/50DR38	1394295	1946-1802	34.6733	120.2117	34.6733	120.2067	Bremer Sub-basin, western and upper slope of Whale Canyon. Esso R74A-11 and -25, GA S280-28.	Quartzose siltstone, bioturbated muddy micaceous siltstone, calcareous ooze.	50	03 Mar 04
265/51DR39	1394305	1448-1401	34.6398	120.1970	34.6400	120.1950	Bremer Sub-basin, western slope of Whale Canyon. Esso R74A-25.	Brown mudstone, highly weathered brown siltstone and mudstone, limestone, calcareous ooze.	50	03 Mar 04
265/52DR40	1394320	2053-1913	34.7100	120.5433	34.7067	120.5450	Bremer Sub-basin, Powell Canyon. Esso R74A-29.	Coarse-grained quartzose sandstone (?quartzite), fine-grained quartzose sandstone, muddy siltstone, carbonaceous mudstone, green calcareous ooze.	50	03 Mar 04
265/53DR41	1394333	2537-2301	34.7817	120.4767	34.7850	120.4633	Bremer Sub-basin, unnamed lower slope canyon. GA S280-22.	Very-fine-grained bioturbated sandstone and siltstone, green calcareous ooze.	150	03 Mar 04

Table 3.4 (Continued) *Summary of the dredge haul recovery from Survey 265.*

265/54DR42	1394338	2745-2585	34.7650	120.5383	34.7617	120.5350	Bremer Sub-basin, Powell Canyon. Esso R74A-29.	Muddy siltstones, carbonaceous mudstone, trace coal, calcareous ooze.	125	03 Mar 04
265/55DR43	1394347	2988-2526	34.7833	120.8050	34.7767	120.8150	Bremer Sub-basin, unnamed lower slope canyon. GA S280-23.	Carbonaceous bioturbated mudstone and siltstone, silstone/mudstone, calcareous ooze.	70	04 Mar 04
265/56DR44	1394358	2955-2719	34.7467	120.9117	34.7450	120.9050	Bremer Sub-basin, eastern slope of Stokes Canyon. Esso R74A-31.	Coarse-grained, red quartzose sandstone, medium quartz sandstone, muddy siltstone, carbonaceous mudstone, siltstone, calcareous ooze.	50	04 Mar 04
265/57/DR45	139374	3375-3058	34.7880	120.9620	34.7850	120.9667	Bremer Sub-basin, western slope of Stokes Canyon. Esso R74A-31.	Angular cobbles of orthoclase-rich granite with biotite.	2	04 Mar 04

[1] MARS – A Geoscience Australia Oracle database of marine survey samples. The database can be accessed by the following link: http://www.ga.gov.au/oracle/mars/

[2] Water depths represent that range of the canyon slope that was sampled by the dredge. These depths have been recalculated (post-survey) using the swath bathymetry.

[3] Location includes the names of geological depocentres of the western Bight Basin and modern bathymetric features.

[4] Proximal seismic surveys include the Shell *Petrel* N-survey, Esso R74A, Geoscience Australia Surveys S265 (this report)
and S280.

[5] Recovery weight is estimated for the chain bag contents only.

Table 3.5. *Summary of the grab and gravity core recovery from Survey 265.*

Sample No.	Latitude, South	Longitude, East	Depth (m)	Recovery	Description/comments
265/35/GR1	34°29.66’	120°10.67’	78	1/4 grab	Coarse-grained bryozoan sand.
265/36/GR2	34°32.86’	120°10.68’	99	1/8 grab	Coarse-grained bryozoan sand with living corals.
265/37/GR3	34°34.75’	120°10.65’	467	1/2 grab	Light olive brown, clayey, foraminiferal and nannofossil ooze.
265/37/GC1	34°34.51’	120°10.63’	482	38 cm	Light olive brown, clayey, foraminiferal and nannofossil ooze.
265/38/GC2	34°36.43’	120°10.72’	1140	59 cm	Light olive brown, clayey, calcareous ooze coating lumps of quartzose silt.
265/39/GC3	34°39.63’	120°06.83’	1107	0	No recovery.
265/39/GC3A	34°39.65’	120°06.85’	1110	194 cm	Light olive brown, clayey, calcareous ooze. Hydrocarbon sample.
265/40/GC4	34°40.14’	120°10.78’	1570	25 cm	A 2 cm thick coating of calcareous ooze over dark grey carbonaceous and micaceous mudstone.
265/41/GC5	34°42.76’	120°09.70’	1374	14 cm	Foraminiferal and nannofossil ooze that becomes more consolidated at base.
265/41/GC5A	34°42.77’	120°09.76’	1372	0	Bent barrel. No recovery.
265/42/GC6	34°45.67’	120°10.66’	1805	65 cm	Very light grey, foraminiferal and nannofossil ooze. Hydrocarbon sample.
265/43GC7	34°47.05’	120°06.31’	1635	0	No recovery. Possible hard seabed.
265/43GR4	34°47.04’	120°06.27’	1641	0	No recovery. Grab did not trigger.
265/44GC8	34°50.59’	120°10.66’	1981	20 cm	Yellowish grey foraminiferal ooze.
265/45GC9	34°53.59’	120°10.64’	2550	335 cm	Light grey, consolidated, foraminiferal and nannofossil ooze. Hydrocarbon sample.
265/46GC10	34°56.79’	120°16.94’	3530	10 cc	Dark grey carbonaceous mudstone.
265/58/GC11	34°39.55’	120°49.63’	1950	334 cm	Light grey, foraminiferal and nannofossil ooze. Hydrocarbon sample.
265/59/GC12	34°39.44’	120°57.29’	2611	165 cm	Pale grey calcareous ooze with molluscs. Hydrocarbon sample.

4. Post-Survey 265 Analytical Results

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INTRODUCTION

At the conclusion of Survey 265, dredge samples and sediment cores were transported to Geoscience Australia in Canberra, where each sample was catalogued and photographed before being submitted to the National Petroleum Data Repository. The results of each dredge haul (Table 3.4) were also recorded in Geoscience Australia's MARS database and this information is available on-line via the following internet link: http://www.ga.gov.au/oracle/mars/. In the laboratory, a detailed description of each rock sample was confirmed against the on-board description and updated/supplemented where necessary (Appendix C). A summary of these descriptions is presented in Table 4.1. Thin sections were also made of selected sedimentary, volcanic and basement rocks to confirm petrological descriptions (Appendices D and E).

Representative rocks were separated by lithology into potential sample sets suitable for age (biostratigraphy) or geochemical analysis. A total of 59 samples were analysed for source rock characterisation, age (spore/pollen, nannofossil and foraminiferal components) and depositional environment, while a further 66 samples were analysed for age and depositional environment only (Appendices F to L). The results of these analyses are compiled in a chronostratigraphic correlation diagram along with explanatory notes in Appendix I. The results of the biostatigraphic and geochemical analyses are also compiled in the ArcGIS project supplied with this record (Appendix Volume II, CD-ROM). Metadata is supplied for the location and depth of each sample in the GIS Project.

Smaller subsets of representative samples were identified for fluid inclusion (QGF and GOI™; 10 samples) and reservoir/seal capacity analyses (Mercury Injection Capillary Pressure/MICP; 10 samples). These analyses were undertaken by CSIRO Petroleum and the Australian School of Petroleum, respectively. Full results of this work are included as Appendices M and N.

BIOSTRATIGRAPHIC RESULTS – PALYNOLOGY

A total of 96 samples from 28 dredge sites sampled during Survey 265 in the western Bight Basin were analysed under contract by Dr. Mike Macphail, Australian National University, for age determinations and depositional environments. The samples included 24 dredge hauls from the Bremer Sub-basin, and four dredge hauls from the Denmark Sub-basin. The dredges were analysed for preserved fossil pollen, spores and halophytic algae (dinocysts, acritarchs). Yields and preservation were adequate for determining the age of most of the samples submitted for palynostratigraphic analysis (Appendix F). In some instances, the low concentration of palynomorphs on the unoxidized/filtered and oxidized/filtered strew mounts meant that counting statistically significant numbers of spore/pollen (>250 grains) and locating zone index species was a lengthy process. Seventeen samples preserved significant numbers of spore/pollen as well as marine dinocysts, thus allowing the spore/pollen zonation scheme used in this study to be correlated against the international geological timescale.

In most instances, the oldest rocks dredged up a slope are presumed to be *in situ*. As most of the dredge hauls covered a depth range of <200 m across relatively flat-lying rocks, reasonable extrapolations can be made back to the seismic sequences (N. Exon, pers. comm.). Additional evidence was also derived from the samples on changes in kerogen influx controlled by regional and global climatic trends (Frakes, 1999, 2001), and changes in depositional environment related to breakup and separation during the Late Jurassic to Early Cretaceous. Potential limitations of analysing dredge samples are discussed in Appendix F.

Table 4.2 compares published age range data for spore-pollen species from southwest and central east Australia. This correlation was the basis for the present biostratigraphic interpretations that are summarised in Table 4.3. The individual results of the biostratigraphic analyses are summarised in Tables 4.4 to 4.11, with key findings highlighted as dot points below. The full (unedited) report supplied on these results is included as Appendix F (Macphail and Monteil, 2004). The results of further biostratigraphic work on younger components of the stratigraphic succession are presented in Appendices G (calcareous nannofossils analyses) and H (survey and post-survey foraminiferal analyses).

The biostratigraphic data from these analyses provide a preliminary chronostratigraphic framework for sediments deposited in the Bremer and Denmark sub-basin, and the overlying Eucla Basin during the Mesozoic and Cainozoic. The data also provide evidence towards the identification and characterisation of a petroleum system in the Bremer Sub-basin. These results suggest that rocks dredged from the submarine canyon walls have provided a cost-effective means of extracting critical chronostratigrpahic information from these undrilled depocentres.

Key results of the biostratigraphic analyses

- The oldest dredge samples yielding reliable palynostratigraphic ages are Callovian-Kimmeridgian *Murospora florida* Zone (Samples 265/20/DR20/C1.1, 265/28/DR28/B1.3, 265/54/DR42/C1.1, 265/56/DR44/E1.1).

- The youngest spore-pollen assemblage sample recorded in this study (265/15/DR15/A1.1) is Holocene, indicating that Recent estuarine sediments have been transported down the submarine canyons. Sample 265/05/DR05/C1.1 may also be Holocene. Maximum ages based on marine microfossils are Pliocene and Middle Miocene, respectively, for these samples.

- Dredges 265/28/DR28/F1.2, 265/48/DR36/A1.1, 265/48/DR36/C1.1 yielded mixed age palynofloras ranging in age from Late Eocene/earliest Oligocene (spore/pollen) to Late Maastrichtian/earliest Danian (dinocysts). The samples are suggested to come from condensed sections which correlate to the early stages of sediment accumulation on the Esperance Shelf of the Eucla Basin.

- Samples deposited in restricted to open marine environments during the Cretaceous range from Late Maastrichtian (265/09/DR09/A1.2, 265/09/DR09/A1.3) to early Early Aptian (265/51/DR23/A1.2) age. With one exception (sample 265/24/DR24/C1.1), which is dated as Cenomanian, these samples fall into two broad age classes - Maastrichtian to Turonian and Albian-Aptian. Many of the Maastrichtian to Turonian age samples are contaminated with Paleocene to Early Eocene dinocysts.

- The earliest unequivocal evidence for marine transgression is Late Hauterivian/Early Barremian Upper *Aprobolocysta alata*-Lower *Batioladinium jaegeri* Zone (265/27/DR27/B1.1). The sample was deposited under probable anaerobic (near-shore, shallow-water) conditions but subjected to a strong freshwater/lacustrine input. Geochemical data support a dual origin for the organic content, with marine-derived kerogen being responsible for the high TOC (8%) and HI (>250) values.

- Equivocal evidence exists for a strong saline influence in the Bremer Sub-basin during the Valanginian *Gagiella mutabilis* to Early Barremian *Batioladinium jaegeri* (dinoflagellate) Zones (265/17/DR17/A1.2, 265/23/DR23/G1.1, 265/51/DR39/C1.1). These samples broadly correlate with the earliest marine samples in the Perth Basin. They are also consistent with the proposal by Veevers et al. (1991) that marine environments extending southwards along the western Australian margin during the early Early Cretaceous had reached the area around Cape Leuwin and into the western Bight region by Valanginian time (approximately 140 Ma).

- The majority of non-marine samples can be assigned to the Valanginian-?Early Aptian *Balmeiopsis limbata* Zone or Berriasian-basal Valanginian *Biretisporites eneabbaensis* Zone. Assuming that these samples are representative of non-marine rock sequences exposed in the canyon walls, the data strongly support the conclusion of Bradshaw et al. (2003) that the Bremer Sub-basin contains a thick sequence of predominantly non-marine Late Jurassic to Early Cretaceous sediments that are unconformably overlain by thinner sequences of Late Cretaceous and Cenozoic marine strata.

- Acritarchs and the cysts of diverse but unidentified fresh-brackish algae indicate that the southwestern part of the Southern Rift System separating Australia and Antarctica was occupied by: a) fresh to brackish lakes during the Callovian-Kimmeridgian, b) freshwater lakes during the Tithonian; and, c) predominantly brackish water lakes during the Berriasian-Early Valanginian. In most cases, the high salinity levels are more likely to reflect discharge of salts into groundwater (or paralic environments) than seasonally dry climates because of the high palaeolatitude of the sub-basin during the Late Jurassic-Early Cretaceous. Leakage of saltwater upward along fault zones was also possible.

- The subdivision of the Early Cretaceous-Late Jurassic infill in the Bremer Sub-basin into marine and non-marine/lacustrine formations closely parallels the Warnbro Group and Parmelia Formation, respectively, in the Perth Basin – except that the *Balmeiopsis limbata* Zone Warnbro Group is wholly marine and can be independently dated by dinoflagellates as middle-late Valanginian to Barremian.

This raises the possibility that non-marine correlatives of the Early-Middle Valanginian *Systematophora areolata* Zone (sediments missing from the Perth Basin) may occur also in the Bremer Sub-basin.

- Many non-marine samples include a significant laminar kerogen component derived from algal cysts, including *Botryococcus*, or the 'ghosted' fragments of bisaccate gymnosperm pollen. As with Necomian dinocysts (e.g. 265/27/DR27/B1.1), these components may high-grade the potential of the host sediments to generate hydrocarbons. Otherwise the kerogen influx (structured terrestrial, semi-opaques) is dominated by material derived from dryland plants; in particular, austral conifers including araucarians (*Araucariacites*, *Callialasporites*) and pteridosperms (*Falcisporites*). Some of the terrestrial organic matter is reworked from Triassic-Early Jurassic sediments. Ferns, fern allies and possibly liverwort sources were usually of secondary significance until Late Cretaceous time.

- The majority of samples are thermally immature (TAI = 2- to 2). Exceptions (TAI = 2+ to 3+) which indicate the source rocks are within the mature main phase of liquid hydrocarbon generation include the following samples: 265/27/DR27/B1.1 (Late Hauterivian/Early Barremian), 265/27/DR27/A3.1 (*B. limbata* Zone), 265/21/DR21/C4.1 and 265/23/DR23/D1.1 (*B. eneabbaensis* Zone), 265/56/DR44/E1.1 (*M. florida* Zone), 265/52/DR40/C1.1 (<*C. turbatus* Zone) and 265/52/DR40/A1.1 (<*C. torosa* Zone). Samples 265/01/DR01/A1.1 (*B. limbata* Zone) and 265/15/DR15/A1.1 (Holocene) include possible reworked palynomorphs within the mature range. The highest value recorded is 4- to 4, i.e. within the range associated with generation of dry gas (265/21/DR21/E1.1)

- The combination of fresh-brackish and marine environments, and high TAI values suggest that rich potential source rocks of Late Jurassic to Neocomian age exist in the Bremer Sub-basin.

GEOCHEMICAL RESULTS – SOURCE ROCK CHARACTERISATION

Samples and Methods

Dredge samples were selected for source rock assessment based primarily on their dark colouration and fine-grained nature, resulting in a total of 59 samples from 25 dredge sites (Figure 4.1 and Appendix J). A 50g sub-sample was taken from the unexposed centre of the bulk specimen, washed with distilled water and air dried at 40^{o}C. After lightly crushing to pass through a 3 mm sieve, representative splits were taken for organic petrographic, organic geochemistry and palaeontological analyses. For the latter analysis, acid-resistant plant, marine and algal microfossils were extracted using standard oxidation and filtration techniques designed to eliminate fines with maximum diameters of less than 5 µm. Age determinations are summarised in Table 4.12.

Vitrinite reflectance (VR, reported as $R_o$max) and maceral descriptions were done under contract by Kieraville Konsultants (Appendix K). In order to positively identify normal vitrinite that would further constrain vitrinite reflectance and to document possible fluid alteration effects, a sub-set of 12 samples were analysed by Newman Research using the vitrinite and inertinite reflectance and fluorescence (VIRF) technique (Appendix L).

Rock Eval pyrolysis and total organic carbon (TOC) contents of powdered whole rock and kerogen isolate samples were determined using a Rock Eval 6 instrument and the results are listed in Table 4.13. Removal of mineral matter for kerogen isolation was done using a modification to the HF/BF_3 method of Robl and Davis (1993) whereby a saturated solution of boric acid was used instead of solid boric acid. The kerogen was thoroughly dried at 105^{o}C in an inert atmosphere and under a stream of nitrogen for three hours. The carbon isotopes of the kerogen were analysed at the School of Biological Sciences, Australian National University, and the results given in Table 4.13.

Based on the bulk geochemistry and VR results, twelve samples were high-graded for detailed molecular analysis(Table 4.14). All samples were extracted with dichloromethane:methanol 90:10 at 100^{o}C using the accelerated solvent extraction (ASE) technique and extract yields measured after removal of the solvent. The isolated extractable organic matter was separated into saturated hydrocarbons, aromatic hydrocarbons and polars (NSO compounds) by open column chromatography on solid silica gel support using hexane, dichloromethane:hexane (1:1) and dichloromethane:methanol (1:1) respectively. The saturated hydrocarbons were further purified by passing through a column of elemental Cu in order to remove elemental S. Silicalite molecular sieve was used to separate a silicalite-adduct (SA) and a silicalite-non-adduct (SNA) fraction from the saturated hydrocarbons. Gas chromatography (GC) of the saturated hydrocarbons followed the procedures outlined in Edwards et al. (2004).

Preservation of organic matter in sea-floor sediments

Prolonged exposure of potential source rocks in outcrop can degradation organic matter and thus adversely affect an assessment of the petroleum potential. Typically, oxidative weathering leads to loss of organic carbon and reduction in bulk petroleum potential (Copard et al., 2002). Fortunately, there is generally little change at the molecular level and detailed geochemical assessments (e.g. pyrolysis-GCMS) of original unaltered petroleum potential will remain valid (Petsch et al., 2000) even though bulk parameters can sometimes indicate a lower potential. Furthermore, vitrinite reflectance is only slightly affected by weathering, and Tmax and OI tend to show increases proportional to the degree of weathering (Copard et al., 2002).

The potential effects of sub-sea exposure of the dredge samples on the canyon walls of the Bremer and Denmark sub-basins was qualitatively assessed during organic petrographic analysis by observing the degree of alteration of various mineral phases (eg. pyrite; Cook, 2005; Appendix K). A scale from 1 to 4 was used to assess the effects of weathering and corrosion with ‘Grade 1’ representing no alteration, while ‘Grade 4’ was assessed as severely altered (Table 4.12). Encouragingly, the majority of the dredge samples appear to be either unaltered or only slightly affected (Figure 4.2). The sample with the best hydrocarbon potential 265/23/DR23/F1.1 showed a moderate degree of alteration (Tables 4.12 and 4.13), suggesting that bulk geochemistry parameters have been little influenced by sub-sea exposure. This is further supported by the lack of a relationship between Tmax and OI (Table 4.13). Therefore, the organic petrology and geochemistry results suggest that the Bremer dredge samples have been only mildly affected by oxidative weathering and this has had little impact on the source rock assessment.

Bulk Geochemistry and Petrology

Petroleum Potential

Since the majority of the samples are considered immature with average $R_o$max < 0.65% (Table 4.12 and see below), the present-day geochemical parameters can be considered as <u>initial</u> values and do not need to be adjusted for yield losses due to petroleum generation. Total Organic Carbon (TOC) contents range from 0.2 to 22.6%, with 20 of the samples showing good to excellent organic richness (TOC > 2%; Figure 4.3 and Table 4.13). The capacity of the organic matter to be converted to petroleum (gas and oil) was further assessed using the Rock Eval pyrolysis technique.

Pyrolysate yields (S2) range from extremely low 0.06 to extremely high 84.37 mg hydrocarbons/g rock, with six samples having good to excellent generative potential (S2 >5 in Figure 4.3). TOC-normalised pyrolysis yields, or Hydrogen Indices (HI), range from 11 to 373 mg hydrocarbons/g TOC, with the highest value representing potential conversion of up to 30% of the TOC into both gas and oil. However, only three samples, 265/23/DR23/F1.1, 265/23/DR23/G1.1 and 265/27/DR27/B1.1 are considered to have liquids potential with HIs greater than 200 mg hydrocarbons/g TOC (Figure 4.4). Additionally, the five samples with HI between 100 and 200 mg hydrocarbons/g TOC and TOC > 2% (Figure 4.4) are considered to have some potential for wet gas. However, the majority of the samples contain extremely hydrogen-deficient organic matter (HI<50 mg hydrocarbons/g TOC) and together with their poor organic richness (TOC<1%) have no potential to generate hydrocarbons (Figure 4.4).

However, even dredge samples with poor hydrocarbon potential have revealed evidence of oil migration and an active petroleum system (Herzer et al., 1999). Fluorescing oil under petrographic analysis suggests that this is migrated oil, which may have been generated as a result of thermal alteration of correlative units, or from deeper in the section (Newman Energy Research Ltd, 2004; Appendix L). This is further supported by the presence of oil inclusions in some Bremer Sub-basin sandstones attesting to mobile hydrocarbons in the subsurface (Kempton et al., 2004; Appendix M). The low hydrocarbon potential of the Bremer Sub-basin dredge samples is further supported by a dominant inertinte maceral group for the majority of the dredge samples (Figure 4.5). Encouragingly, samples with a high liptinite maceral group show elevated HIs (Figure 4.3). There is a strong positive correlation between the lamalginite maceral content and HI for HI > 120 mg hydrocarbons/g TOC (Figure 4.6), suggesting that the lacustrine organic facies has enhanced hydrocarbon potential.

Importantly, the S2 pyrolysate yields can be influenced by the mineral matrix, especially for samples with TOC< 4–5% (Boreham and Powell, 1987), resulting in a lower HI value for the whole rock. A more realistic measure of the hydrocarbon potential is gained after removal of the mineral matter with strong acids and Rock Eval of the organic concentrates (kerogen). Pyrolysis yields from the kerogen (Table 4.14) generally resulted in dramatic increases in $HI_{kerogen}$ of up to 160% over the HI_{whole} (Figure 4.7). For example, the five samples that have HI_{whole} between 100 and 200 mg hydrocarbons/g TOC (TOC between 2 and 5%; Figure 4.4) now show $HI_{kerogen}$ > 200 mg hydrocarbons/g TOC (Figure 4.7), confirming their liquid hydrocarbon potential.

There are also samples where $HI_{kerogen}$ < HI_{whole} (Figure 4.6). Here, both whole rock TOC and S2 are low, resulting in larger errors in calculated HI_{whole}. Furthermore, there is a high temperature contribution to the S2 peak (Figure 4.8a), which is eliminated following removal of the mineral matter (Figure 4.8b). It is likely this non-hydrocarbon-related high temperature detector response is a result of production of ions from mineral decomposition (eg. salts). The age-dependent change in $HI_{kerogen}$ is displayed in Figure 4.9 from Early Jurassic to latest Cretaceous. For the eight samples with liquids potential, all are of Early Cretaceous age with relative abundance, in decreasing order, from Berriasian (5 of 23; 22%) to Valanginian (2 of 10; 20%) to Hauterivian–Cenomanian (1 of 7; 14%).

Maturity

All samples, except 265/21/DR21/E1.1, are immature with VR < 0.64% (Figure 4.10 and Table 4.12). The older Jurassic to Berriasian samples have the largest proportion with the higher ranks, (Figure 4.10) with the Berriasian 265/21/DR21/C4.1 having VR = 0.64%, consistent with maturation related to depth of burial. The overmature sample 265/21/DR21/E1.1 gives an inertinite reflectance of 5.5% (Appendix K), which translates to a vitrinite reflectance of 4%. Assuming that 95% of the initial hydrocarbon potential has been lost through maturation (based on kinetic parameters), then using the present day values (Table 4.13) the calculated initial values $TOC_{initial}$, $S2_{initial}$ and $HI_{initial}$ are 3.8%, 7.2 mg hydrocarbons/g rock and 189 mg hydrocarbons/g TOC, respectively.

Sample 265/22/DR22/C1.1 shows a bimodal vitrinite reflectance distribution with a maximum at 0.47% and a less abundant population at 0.94% (Table 4.12, Appendix K), with the latter maturity within the main oil window. However, the molecular geochemistry (see below) is not overtly affected by this higher maturity subset. The immaturity of this sample is reflected by a Tmax of 400°C and low PI (Table 4.13). The higher VR in these two samples is attributed to the effects of igneous intrusions (Newman Energy Research Ltd, 2004; Appendix L). Sample 265/21/DR21/C4.1 shows textural relationships where intrusive igneous rocks have been explosively mixed with the sedimentary rocks they have intruded, resulting in an extremely high VR (4 %; Table 4.12 and Appendix K). Sample 265/22/DR22/C1.1 shows that the intrusion has induced varying degrees of thermal alteration (0.41 to 2.33 %; Table 4.12 and Appendix K), suggesting a position at the edge of the heating aureole of an intrusion.

The majority of the samples have Tmax < 440°C and PI < 0.1 confirming their immaturity (Table 4.13). Additionally, there are two small groups of samples that, at first, appear to be overmature with Tmax > 600°C (Table 4.13) and 460–520°C (Figure 4.4). A characteristic of the former group is a dominant high temperature contribution to the S2 profile, attributed to ionisation of salts, which monotonically increase at the higher pyrolysis temperature and never reaches a ‘peak’ (Figure 4.8a). Thus, the highest detector response is at the final pyrolysis temperature resulting in the maximum instrument value for Tmax (Figure 4.8a). Removal of the mineral matter results in a lower Tmax (<440°C), which is more representative of its inherent immaturity (Figure 4.8b). For the latter group, this mineral decomposition is of lower abundance and the Tmax is again taken at the greatest detector response, for example, a peak at Tmax 482°C for 265/49/DR37/B1.1 (Figure 4.11a). However, as the S2 peak is composed of multiple peaks that becomes simplified in the kerogen analysis, and results in a lower Tmax value of 421°C (Figure 4.11b).

Source facies and depositional environments

Molecular geochemical analysis of the extractable organic matter (equivalent to Rock Eval S1) combined with micropalaeontology and palynology analyses (Table 4.14) of the organic facies can prove fruitful in defining source inputs and depositional environments. Twelve dredge samples were chosen ranging in age from Tithonian to latest Hauterivian-earliest Barremian (Table 4.14), encompassing the range in petroleum potential as well as depositional environments from land plant to lacustrine to marine from biostratigraphic assessments. The low extract yields (HC/gTOC; Table 4.13) are further evidence of the lack of petroleum generation and the sample immaturity.

Gas chromotography

The most abundant compounds in the GC traces are the homologous series of *n*-alkanes from *n*-C_{15} to *n*-C_{33} with a strong bias towards the waxy (> *n*-C_{22}) homologues. Sample 265/21/DR21/E1.1 is devoid of *n*-alkanes, consistent with its extremely high maturity. The strong carbon preference (CPI) for odd-numbered waxy *n*-alkanes (Table 4.14) indicates a pronounced higher land plant input (Tissot and Welte, 1984). The waxy *n*-alkanes maximise between *n*-C_{23} to *n*-C_{31} (Figure 4.12), which suggests a progressive change in land plant source inputs. Lacustrine organic facies are associated with a *n*-C_{23} maxima whereas the coaly organic facies has a *n*-C_{31} maxima. This is most likely a reflection of the two end-member plant communities within the fluvio-lacustrine depositional environment, with the lacustrine organic facies closely associated with ferns (along the shoreline), and the coaly organic facies dominated by gymnosperms (Figure 4.12). Variable source inputs from the two end-member organic facies would account for the *n*-C_{25}, *n*-C_{27} and *n*-C_{29} maxima (Figure 4.12). The lower molecular weight *n*-alkanes ($<C_{22}$) show a very weak CPI (Table 4.14). This, together with the positive correlation between the proportion of algal palynomorphs and lower molecular weight *n*-alkanes (C_{14}–C_{22}/C_{23}–C_{31}; Table 4.14), indicates an algal origin for the $<C_{22}$ *n*-alkanes (Tissot and Welte, 1984). The high abundance of waxy *n*-alkanes, maximum at *n*-C_{29}, in the latest Hauterivian-earliest Barremian sample 265/27/DR27/B1.1 (Figure 4.12) indicates transport of significant gymnosperm plant remains into the marine depositional environment.

The isoprenoid hydrocarbons, pristine (Pr) and phytane (Ph), also have relatively high abundances (Figure 4.12). For the Tithonian to Valanginian fluvio-lacustrine facies the Pr/Ph ratio is between 1.0 and 4.75 (Table 4.14), suggesting dysoxic to oxic depositional environments. However, there is no apparent relationship between Pr/Ph and the varying land plant inputs since the Berriasian samples 265/15/DR15/B1.1 and 265/22/DR22/C1.1 with low and high Pr/Ph values (1.0 and 4.5, respectively) both have a *n*-C_{23} dominance (Table 4.14 and Figure 4.12). The poor correlation power of Pr/Ph is not unexpected since the very low maturity would require an account of the functionalised precursors to these isoprenoid hydrocarbons, which for the former become less relevant with increasing maturity (Tissot and Welte, 1984). Nevertheless, the very low Pr/Ph (0.25) of the latest Hauterivian-earliest Barremian marine sample 265/27/DR27/B1.1 is consistent with a reducing marine depositional environment.

Consideration of the biostratigraphic results gives further insights into the secular change in the distribution of the coaly and lacustrine organic facies. Figure 4.13 shows the relative abundance of gymnosperms, ferns and algae for Valanginian to older sediments, before the first marine incursion during the latest Hauterivian-earliest Barremian, and after which time marine algae also become abundant. There does not appear to be a strong age control on either of the two terrestrial organic facies during the Jurassic to Early Cretaceous, however the Berriasian contains the purest end-member organic facies (Figure 4.13). Although there was undoubtedly variation in the depositional environment during the initial stages of basin development, there appears to be a cyclicity in organic facies that oscillated between the two end-member terrestrial organic facies throughout this period. It was not until a marine incursion during the latest Hauterivian-earliest Barremian that variable amounts of allochthonous terrestrial organic matter could mix with marine algal source inputs. This period was followed by restricted marine conditions during the latest Hauterivian–Cenomanian that resulted in a large influx of terrestrial conifer detritus (Figure 4.14).

Carbon Isotopes

The carbon isotopic compositions of organic matter (kerogen) for six timeslices from Jurassic to Late Cretaceous are plotted in Figure 4.15, while Figure 4.16 displays the average $\delta^{13}C_{kerogen}$ ± one standard deviation for the same timeslices. The non-marine Jurassic to Early Cretaceous (Valanginian) showed moderate variation in $\delta^{13}C_{kerogen}$ with similar averages from -23.46 to -22.90‰ in $\delta^{13}C_{kerogen}$ (Figures 4.15 and 4.16); the Jurassic being the isotopically lighter (depleted in ^{13}C) compared to the Berriasian and Valanginian timeslices (Figure 4.16). However, there is no simple relationship between $\delta^{13}C_{kerogen}$ and the relative organic inputs to the coaly (gymnosperm) and lacustrine (ferns + algae) organic facies (Figure 4.17). This suggests that the carbon isotopic composition of the terrestrial and aquatic organic matter are similar, as previously seen for coaly and lacustrine organic facies from the non-marine Tertiary oil shales of Queensland (Boreham et al., 1994). On the other hand, there appears to be a weak positive relationship between $\delta^{13}C_{kerogen}$ and the percentage of inertinite maceral group (Figure 4.18) with samples having higher inertinite content being isotopically heavy (enriched in ^{13}C). Intuitively, oxidation and reworking will favour loss of ^{13}C-depleted, H-rich organic matter, preserving the more recalcitrant, ^{13}C-enriched organic matter. A similar plot of $\delta^{13}C_{kerogen}$ against % vitrinite and % liptinite maceral groups shows a weak negative relationship with the former but no significant trend with the latter. The extremely overmature 265/21/DR21/E1.1 is one of the most enriched in ^{13}C, consistent with the effect of increasing maturity on isotopic composition.

The latest Hauterivian–Cenomanian was the time of greatest carbon isotopic variability (Figures 4.15 and 4.16) with a range from -29.10 to -21.45‰. Here, the isotopic influence of the marine organic matter is the strongest but where isotopically heavy terrestrial land plant inputs were still significant. The anoxic marine facies is the most depleted in ^{13}C of any Bremer Sub-basin sediment. As conditions became more open marine during the Late Cretaceous, the carbon isotopic composition first showed enrichment in ^{13}C in the Coniacian–Santonian followed by an isotopic reversal to depletion in ^{13}C during the Maastrichtian–Campanian, possibly reflecting secular changes in the carbon isotopic composition of marine organic matter.

The overall wide range in $\delta^{13}C$ of 7.7‰ for the Jurassic to Late Cretaceous Bremer Sub-basin kerogens (Table 4.13) can provide a strong foundation for a carbon isotope stratigraphic approach that can be used to correlate a parental potential source rock to its daughter gas and oil (Boreham et al., 2001; Boreham et al., 2003). In order to understand carbon isotope correlations in southern Australia, a comparison is made between the average carbon isotopic composition of kerogens from the Denmark and Bremer sub-basins and kerogens from the most significant potential non-marine and marine source rocks from the Perth Basin in the west to the Gippsland Basin in the east (Figure 4.19), encompassing source rock ages from Permian to Early Eocene.

The Late Cretaceous marine organic matter in the Denmark and Bremer sub-basins is slightly enriched in ^{13}C by approximately 1‰ compared to marine organic matter from the Otway Basin. Non-marine kerogen from the Late Cretaceous Gippsland Basin and the Paleocene Bass Basin are further depleted in ^{13}C by approximately 2‰, with the Early Eocene coals from the Bass Basin isotopically the lightest (Boreham et al., 2003). The Early Cretaceous marine organic matter in the Bremer Sub-basin is depleted in ^{13}C by approximately 1‰ compared to Early Cretaceous non-marine kerogen from the Bremer Sub-basin and Otway Basin. The Late Jurassic was a time of maximum enrichment in ^{13}C in terrestrial organic matter from the southern Australian margin (Figure 4.19). However, there is little secular change in the average carbon isotopic composition of Early Cretaceous to Jurassic non-marine organic matter. Large depletion in ^{13}C is seen for Early Triassic marine organic matter in the Perth Basin returning to heavy isotopes for the non-marine Permian of the Perth Basin, although the latter are still more depleted in ^{13}C compared to Early Cretaceous to Jurassic non-marine kerogen.

Summary - source rock characterisation

Fifty-nine dredge samples from the Bremer Sub-basin survey were selected for assessment of the petroleum potential of the entrained organic matter. Total organic carbon contents ranged from 0.2 to 22.62% with twenty of the samples showing good organic richness with TOC contents > 2%. Rock Eval pyrolysate yields (S2) range from 0.06 to 84.37 mg hydrocarbons/g rock with six samples having good to excellent generative potential (S2 >5). TOC-normalised pyrolysis yields, or Hydrogen Indices (HI), range from 11 to 373 mg hydrocarbons/g TOC, representing potential conversion of up to 30% of the TOC into petroleum (gas and oil). However, only three samples are considered to have major liquids potential with HIs greater than 200 mg hydrocarbons/g TOC. Rock Eval of the isolated kerogen identified an additional five samples with liquids potential. The majority of samples analysed are immature for hydrocarbon generation, with Vitrinite reflectance (VR) < 0.65% (taken as the lower maturity limit for oil generation from non-marine organic matter). Higher thermal maturities of up to 4% occur in a few samples, but are associated with local igneous intrusions. The predominance of thermally immature rocks in dredge samples is consistent with the stratigraphic units sampled either being from the upper two kilometres of the main basin depocentres (Cretaceous–Cainozoic age rocks), or from thin basin successions deposited over shallow basement blocks (Jurassic age samples). Appropriate maturities for hydrocarbon generation are likely in the main basin depocentres where sediments are buried to depths of over three kilometres. While petrographic and fluid inclusion (GOI) analyses suggest the presence of migrated oil, the bulk (Rock Eval) and molecular geochemistry (GC) only identify an immature signature in all samples with (VR <0.64%), suggesting this trace ‘oil’ component is below bulk geochemical resolution. Biomarker analysis of the oil traces by GCMS could provide a more diagnostic tool.

Molecular and biostratigraphic assessments of the Tithonian to Valanginian sediments indicate a fluvio-lacustrine depositional environment with end-member lacustrine and coaly organic facies. The former is associated with subordinate low molecular weight C_{14}-C_{22} *n*-alkanes (freshwater algal input) and abundant waxy (>C_{22}) *n*-alkanes with a *n*-C_{23} dominance (fern input), while the latter has a *n*-C_{31} dominance (gymnosperm input). Intermediate *n*-alkane dominances at *n*-C_{25}, *n*-C_{27} and *n*-C_{29} are associated with variable inputs from the end-member organic facies. Anoxic marine conditions in the Bremer Sub-basin were evident in the latest Hauterivian-earliest Barremian, leading to the deposition of an oil-prone marine organic matter. However, significant dilution by allochthonous terrestrial land plant inputs has lowered the overall hydrocarbon potential. Source areas where the terrestrial input is reduced may provide oil-prone ‘sweet-spots’. In the Bremer Sub-basin, Cretaceous marine organic matter is isotopically lighter than corresponding Early Cretaceous to Jurassic non-marine kerogen. Similar isotopic discriminations are seen in organic matter of similar age along Australia’s southern margin, suggesting that carbon isotopes can provide a good stratigraphic correlation tool and diagnostic for gas-oil-source correlations.

FLUID INCLUSION ANALYSIS - GOI DATA

Oil inclusions were observed in trace abundance in five samples from dredge sites 265/19/DR19, 265/27/DR27, 265/31/DR31, 265/52/DR40 and 265/56/DR44 in the Bremer Sub-basin with GOI values of <0.1% (Table 4.15). Oil inclusions were not observed in the remaining samples and the GOI are reported as <0.1% to allow for the presence of oil inclusions, but being excluded from the small sub-samples used for the measurements. A full report on the GOI analyses (including photomicrographs of inclusions) is presented in Appendix M.

Inclusions containing liquid oil were identified by a fluorescing phase in the body of the inclusion that lacks internal structure and conforms to a spherical vapour bubble. The oil inclusions exhibit blue fluorescence colour under ultraviolet illumination (Table 4.16) and occur along healed fractures in detrital quartz. The presence of trace numbers of oil inclusions in some samples suggests that oil was present in the pore space at low saturation. This may indicate either local oil generation or secondary oil migration. The location of each dredge sample with respect to a potential trap is not known, therefore no palaeo-oil zones were anticipated.

Oil-bearing inclusions with a high proportion of vapour and a minor blue fluorescing liquid component were also observed in low abundance in the 265/19/DR19/B1.3 and 265/56/DR44/I1.2 samples. The 265/56/DR44/I1.2 sample also has rare oil inclusions in an adjacent fracture in the same detrital quartz grain. These inclusions may have resulted from trapping of gas and a minor amount of oil as separate phases. Inclusions of this type were not included in the GOI count.

Aqueous inclusions containing a vapour bubble and trace amounts of a fluorescing liquid phase were observed in low abundance in most samples except the 265/24/DR24/A1.1, 265/34/DR34/D1.2 and 265/56/DR44/I1.2 samples (Tables 4.15 and 4.16). These inclusions contain mostly aqueous phase with a thin annular shell of fluorescing liquid oil which completely, or partially, conforms to a vapour bubble. While inclusions of this type have been found in other petroleum provinces such as the Bass, Otway, Gippsland and Perth basins, they are generally not observed in samples from producing oil zones and there is no clear petrographic evidence that these inclusions trapped an immiscible oil phase. The presence of a small amount of oil leaves unresolved the possibility of un-mixing of oil from other phases in the inclusions on cooling from reservoir temperature. Inclusions of this type were not included in the GOI count.

RESERVOIR AND SEAL POTENTIAL ANALYSES

Mercury Injection Capillary Pressure (MICP) analysis was undertaken on ten dredge samples to determine the seal and reservoir potential of a representative set of lithologies from the Bremer Sub-basin. A full description of the rock samples and results are presented in Appendix N, and summarised in Table 4.17. The results need to be interpreted with caution as prolonged exposure at the seafloor has probably partially altered the samples. Seal capacity results probably represent minimum hydrocarbon heights as the samples analysed took a long time to dry and had porosities of 38 to 53% in three samples, indicating that there has been relaxation of the shales due to sea floor exposure. Sandstones have probably experienced significant dissolution (particularly of carbonate cements), decompaction, and clay modification also due to exposure. The measured porosities should therefore be used with caution, and probably represent maximum values.

At least one of the samples analysed (265/52DR40/A1.3) is from a thin Early-Middle Jurassic syn-rift or pre-rift section deposited over shallow basement (Figure 4.18). This silicified fluvial sandstone shows poor reservoir potential, with a maximum porosity of only 10.2%. However, this dredge sample is probably not representative of syn-rift deposits in the Bremer Sub-basin given the dredge sample location updip of the main half-graben depocentre, and its potential Early Jurassic age.

Six of the samples analysed (265/15/DR15/C1.5, 265/19/DR19/A1.2, 265/19/DR19/B1.3, 265/27/DR27A1.2, 265/34/DR34/D1.2 and 265/56/DR44/A1.1) were deposited during the

Tithonian–Valanginian. Two lacustrine shales analysed (265/15/DR15/C1.5 and 265/19/DR19/A1.2) show good seal capacity, with potential oil column heights of 36.3 to 70.7 m. Further interpretation of seismic data will be required to determine the lateral continuity and thickness of these lacustrine shales, and their potential to form regional seals. Fluvio-lacustrine sandstones of this age consistently show good reservoir potential, with maximum porosities of 24 to 34.2%. These high porosities may be partly due to the limited depths of burial for many dredge samples, as indicated by low thermal maturities in geochemical analyses and/or due to the potential dissolution of cements on the seafloor.

Two of the samples analysed (265/25/DR25/B1.2 and 265/55/DR43/B1.2) were deposited during the Late Albian to Santonian. Marine shales and claystones analysed show good seal capacity, with potential oil column heights of 51.2 to 146 m. Further interpretation of seismic data is required to determine the lateral continuity and thickness of these marine shales, and their potential to form a regional seal.

One of the samples analysed (265/24/DR24/E1.4) is from strata overlying the Santonian break-up unconformity. Although the MICP analysis shows reservoir potential in these calcarenites (maximum porosity of 27.4%), their potential to reservoir hydrocarbons in the Bremer Sub-basin is limited by the lack of sealing lithologies in overlying coarse grained, calcareous marine sediments.

Figure 4.1 *Location map showing dredge site samples for geochemistry.*

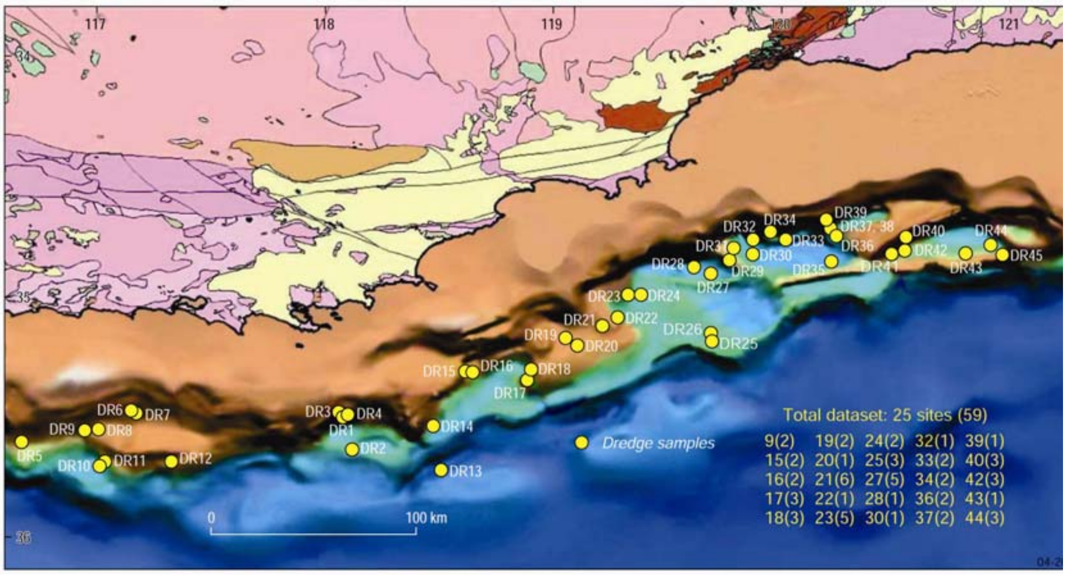


Figure 4.2 *Histogram showing the extent of weathering and corrosion of the dredge samples.*

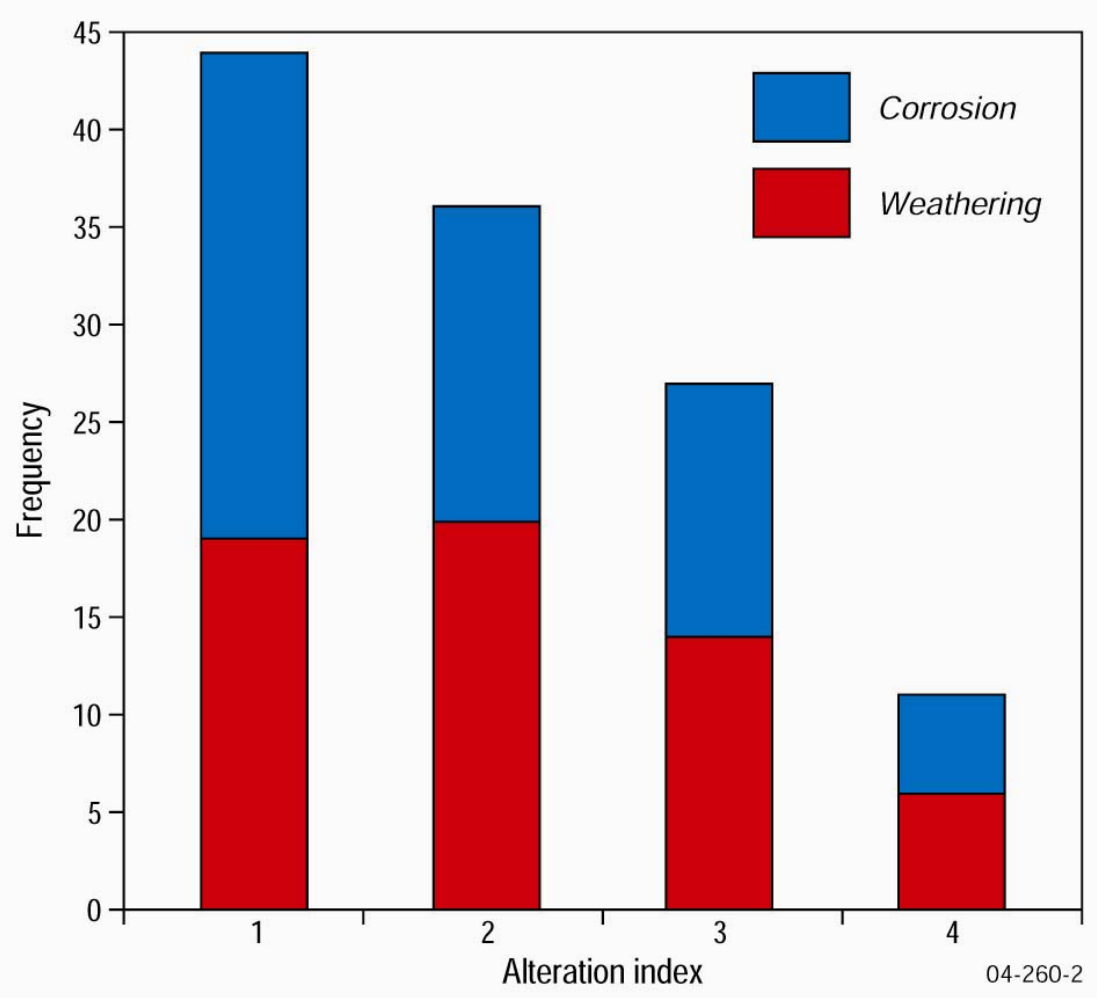


Figure 4.3 *Plot of total organic carbon (TOC %) versus Rock Eval pyrolysis S2 (data from Table 4.14). Note: HI = 100*S2/TOC with the various source richness and quality fields modified after Peters (1986) and Espitalié and Bordenave (1993).*

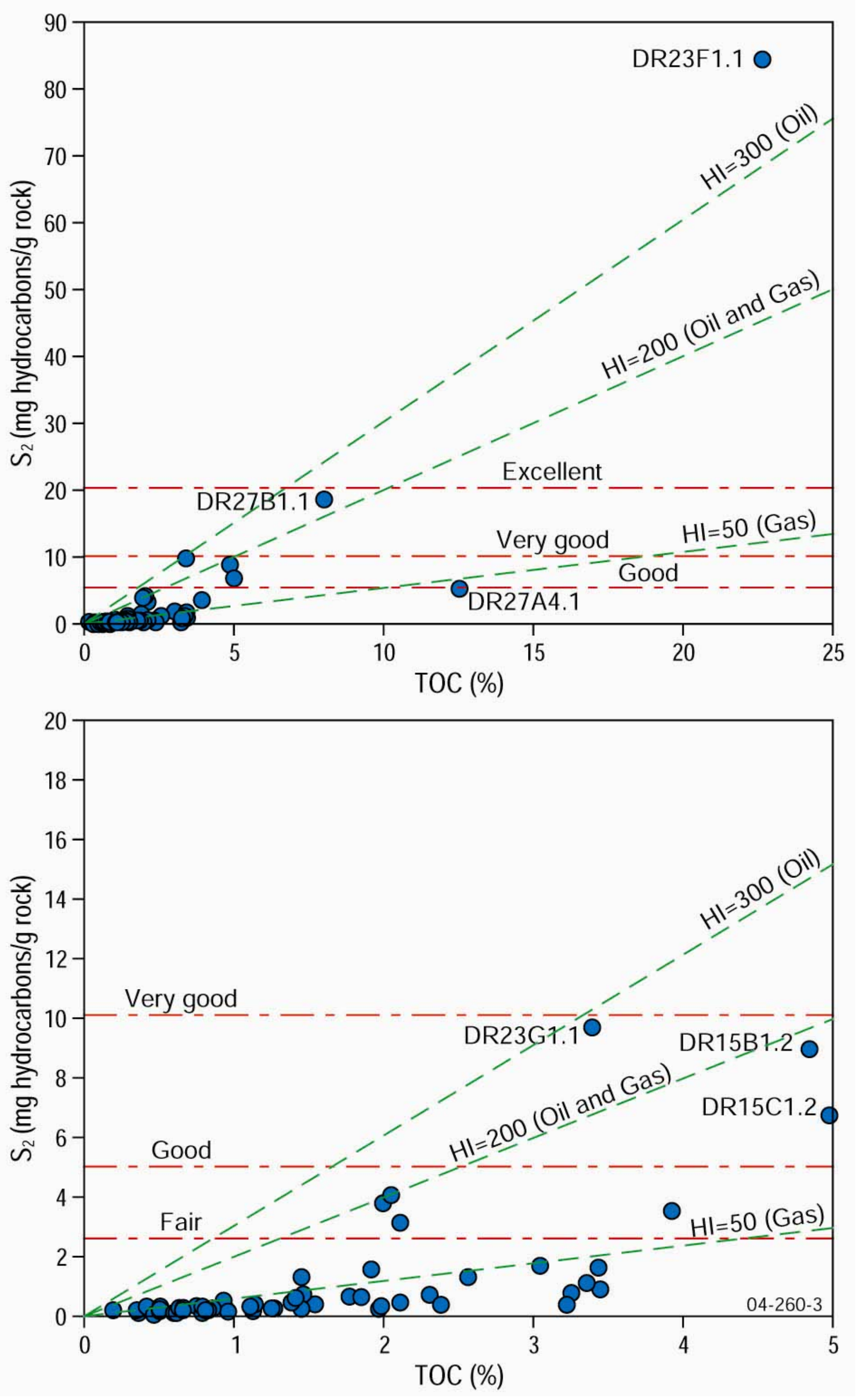


Figure 4.4 *Source quality-maturity plot of Hydrogen Index versus Tmax. The symbols are based on ranges in TOC (Table 4.14) and the colour coding depicts the extent of weathering (Table 4.13).*

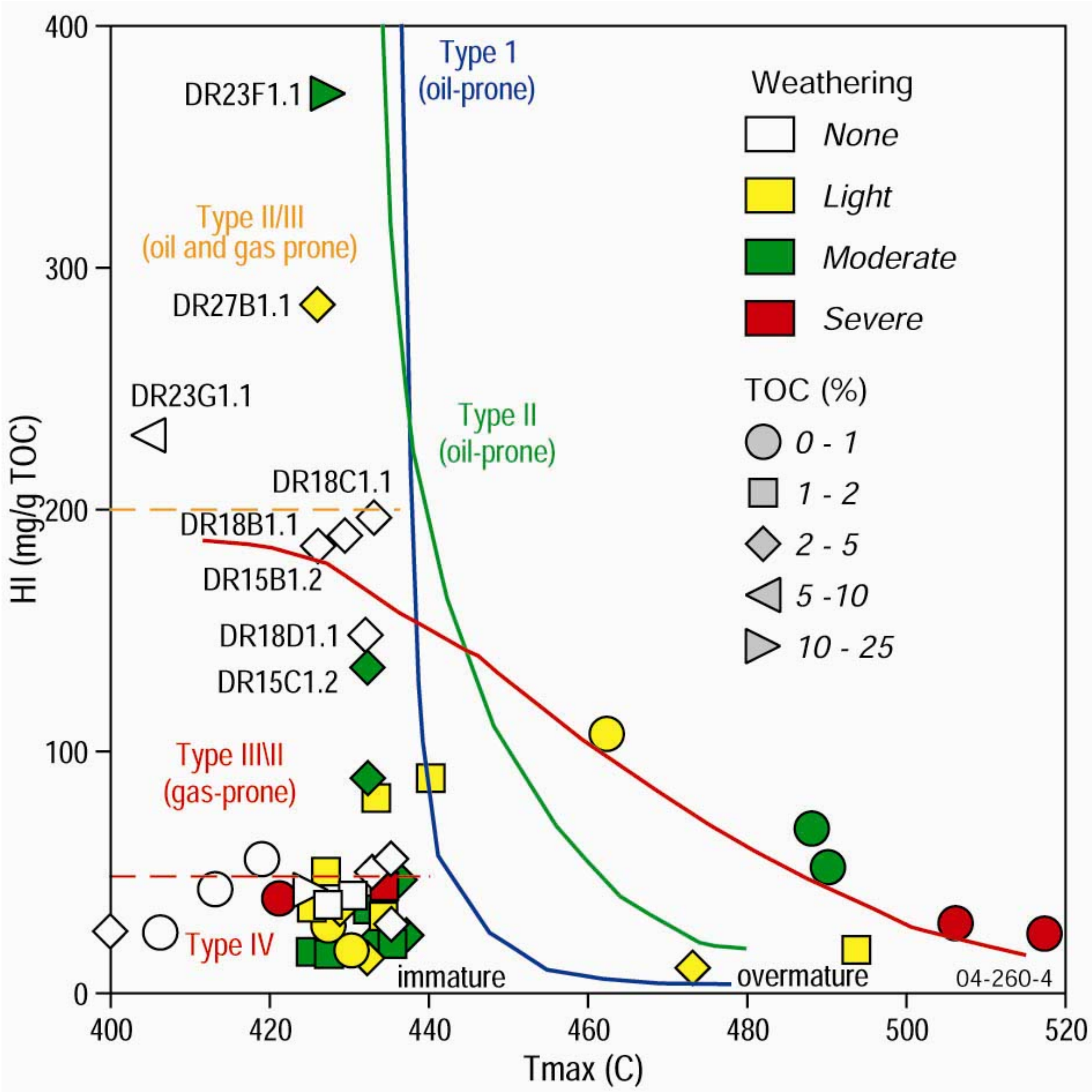


Figure 4.5 *Triangular plot of relative percentages of liptinite, vitrinite and inertinite maceral groups. The symbols are based on ranges in TOC (Table 4.14) and the colour coding on ranges in HI (Table 4.14).*

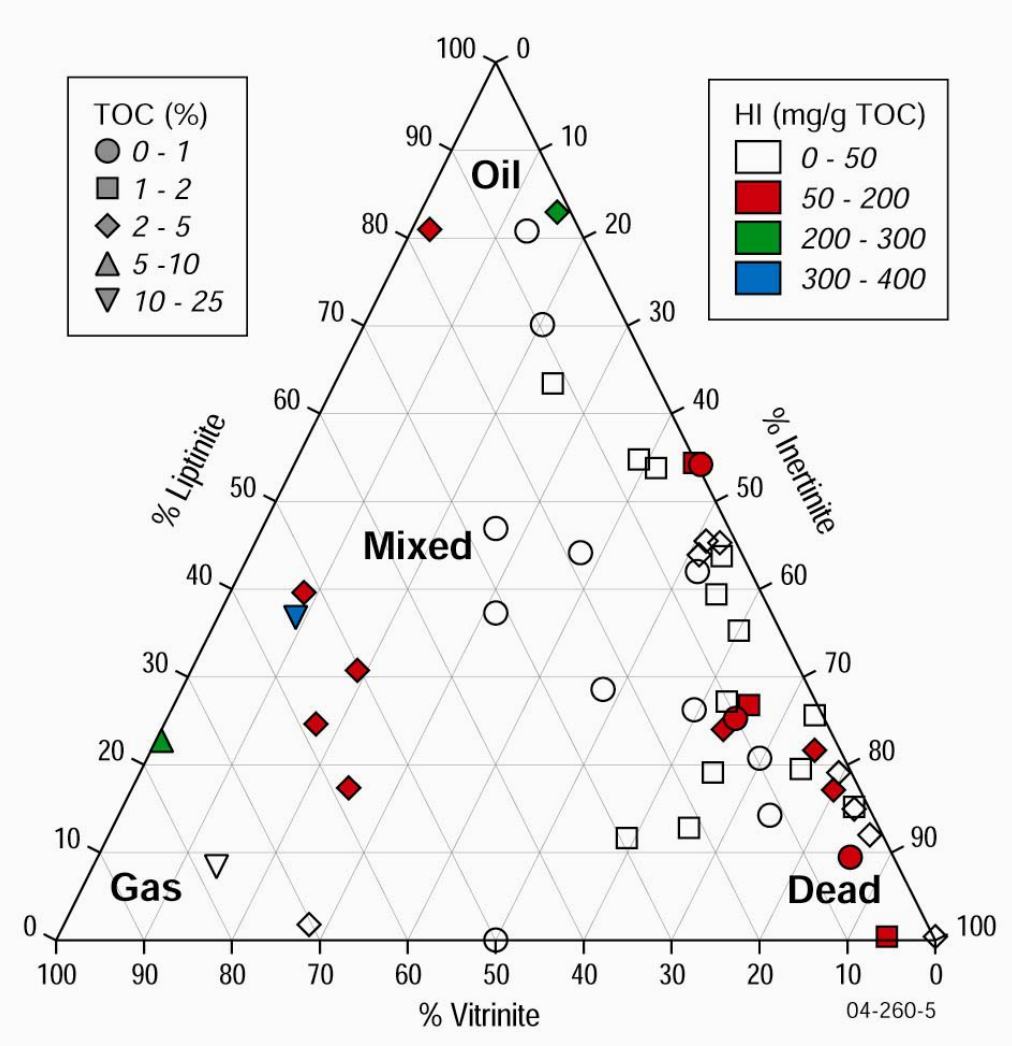


Figure 4.6. *Plot of HI verses relative proportion of lamalginite maceral in the liptinite maceral group.*

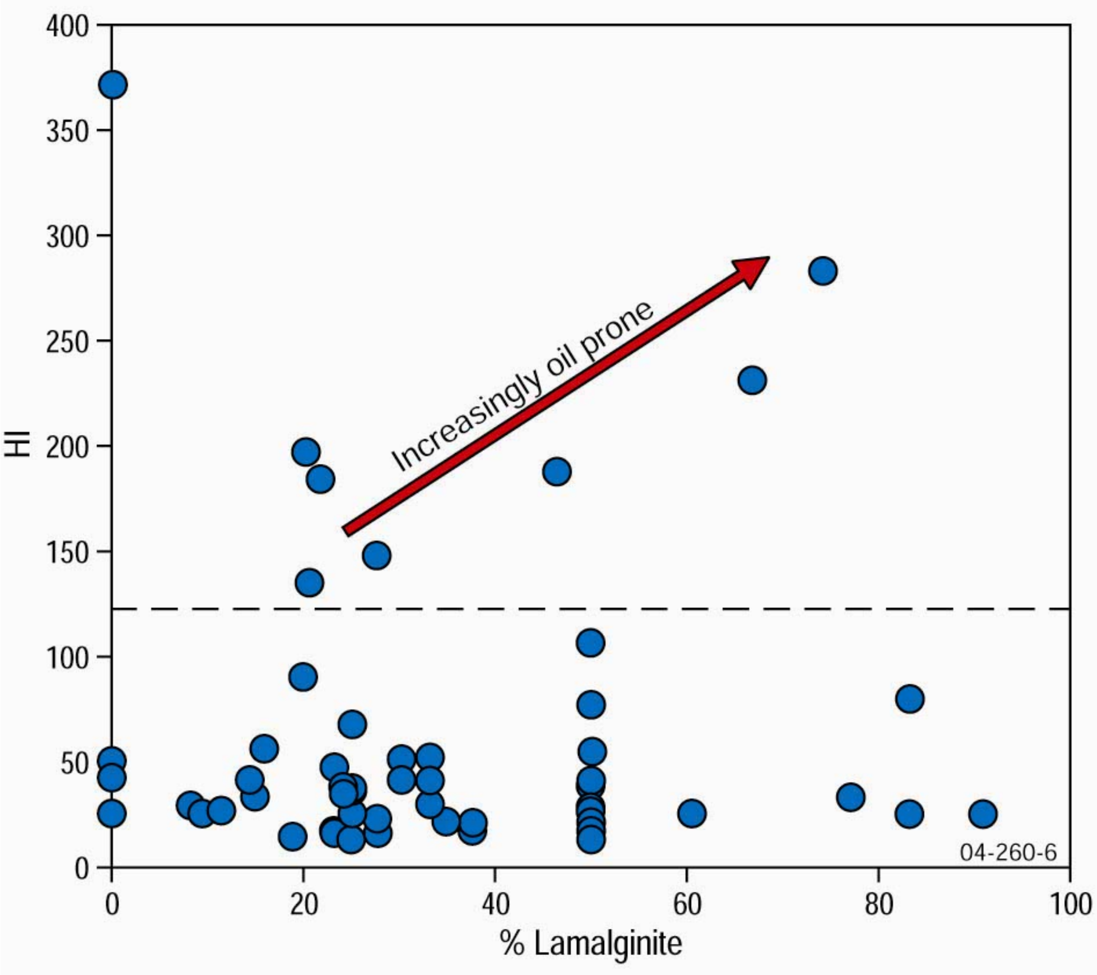


Figure 4.7 *Rock-Eval pyrolysis Hydrogen Index for whole rock versus kerogen.*

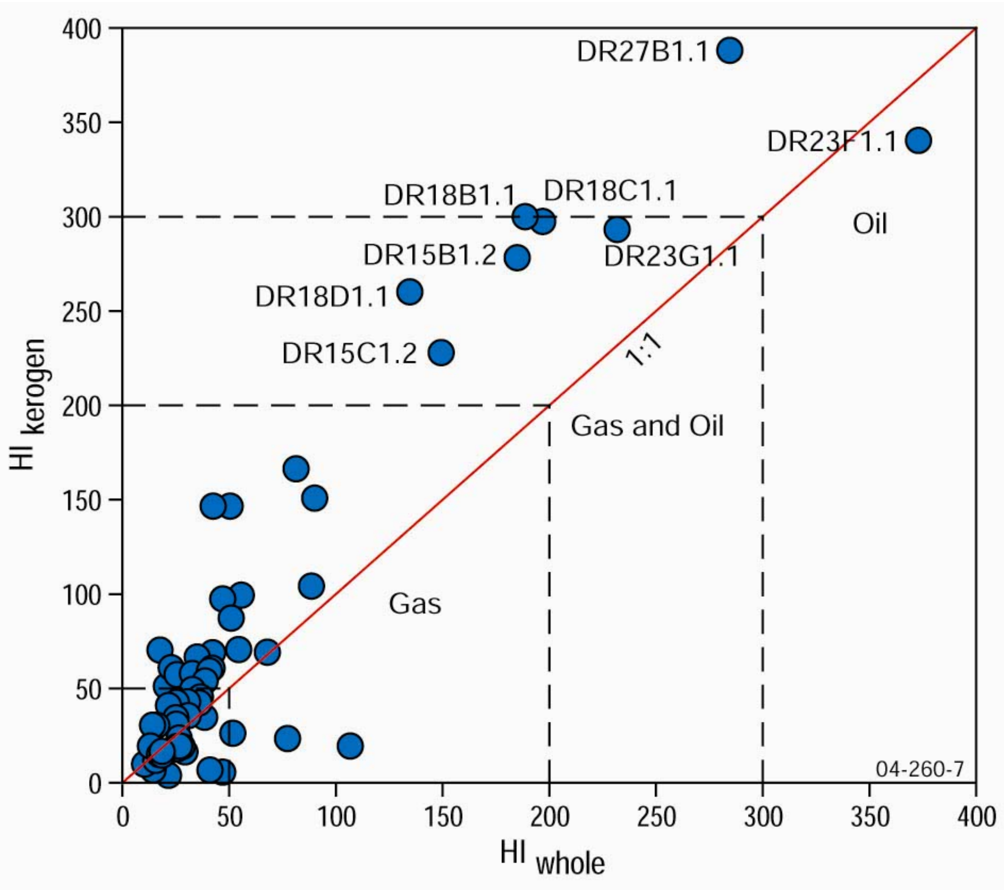


Figure 4.8 *Rock Eval pyrolysis trace for DR36D1.2 for a) whole rock, and b) kerogen. The temperature profile (red trace) tracks the temperature of the sample within the pyrolysis oven: a) 300°C for 3 minutes, b) 25°C/min to 650°C and c) oven cool down after 17 minutes. The area under the detector response (blue trace) corresponds to S1 (temperature region a) and S2 (temperature region b). Tmax is the largest detector response in temperature region b.*

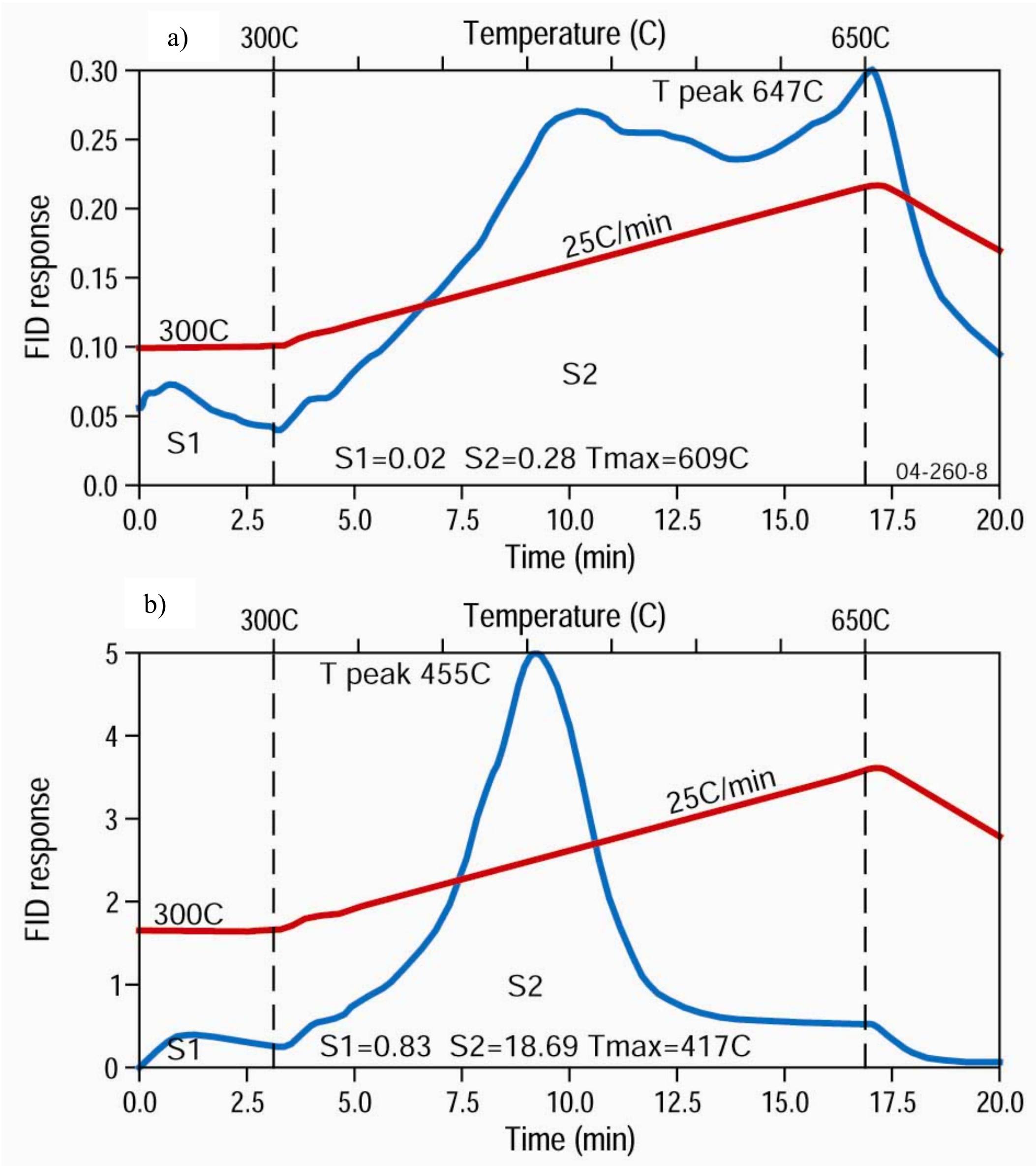


Figure 4.9 *Frequency distribution of $HI_{kerogen}$ for the six timeslices: Jurassic, Berriasian, Valanginian, Hauterivian-Cenomanian, Turonian-Santonian and Maastrichtian–Campanian.*

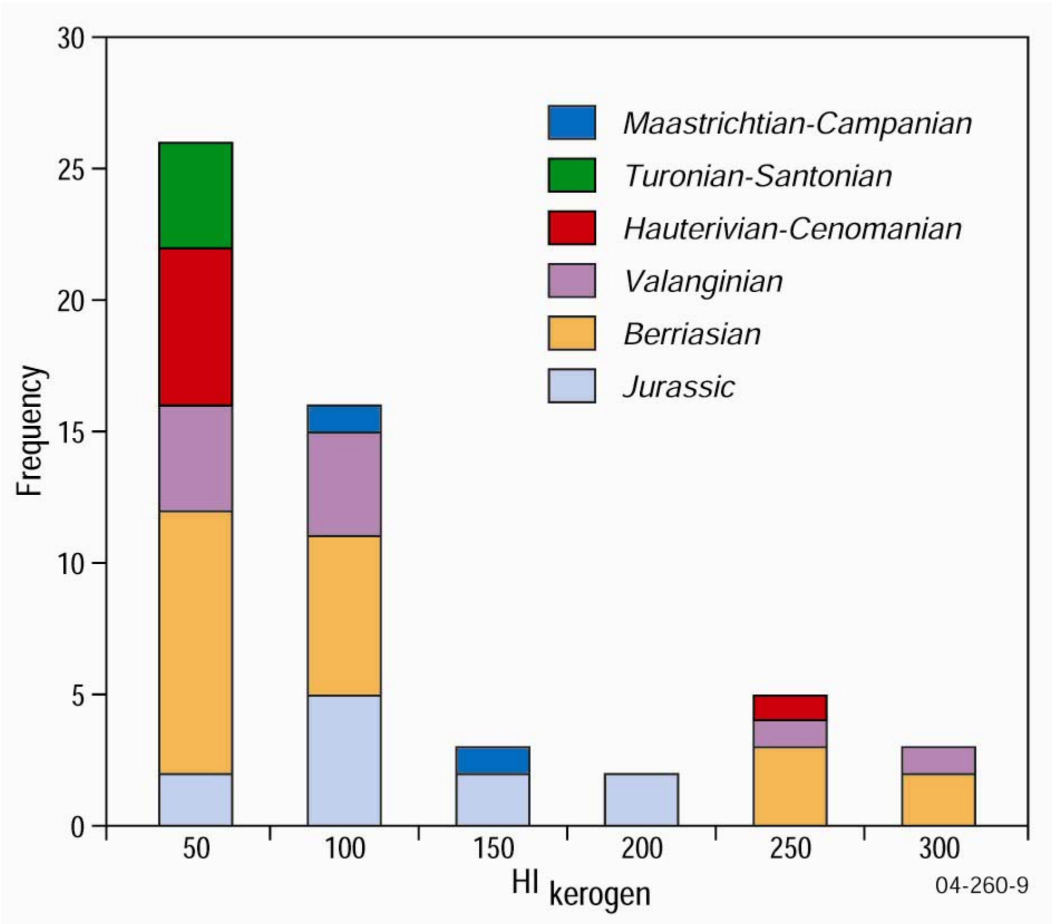


Figure 4.10 *Histogram of frequency distribution of vitrinite reflectance for samples of Jurassic, Berriasian, Valanginian, Hauterivian-Cenomanian, Turonian-Santonian and Maastrichtian-Campanian age.*

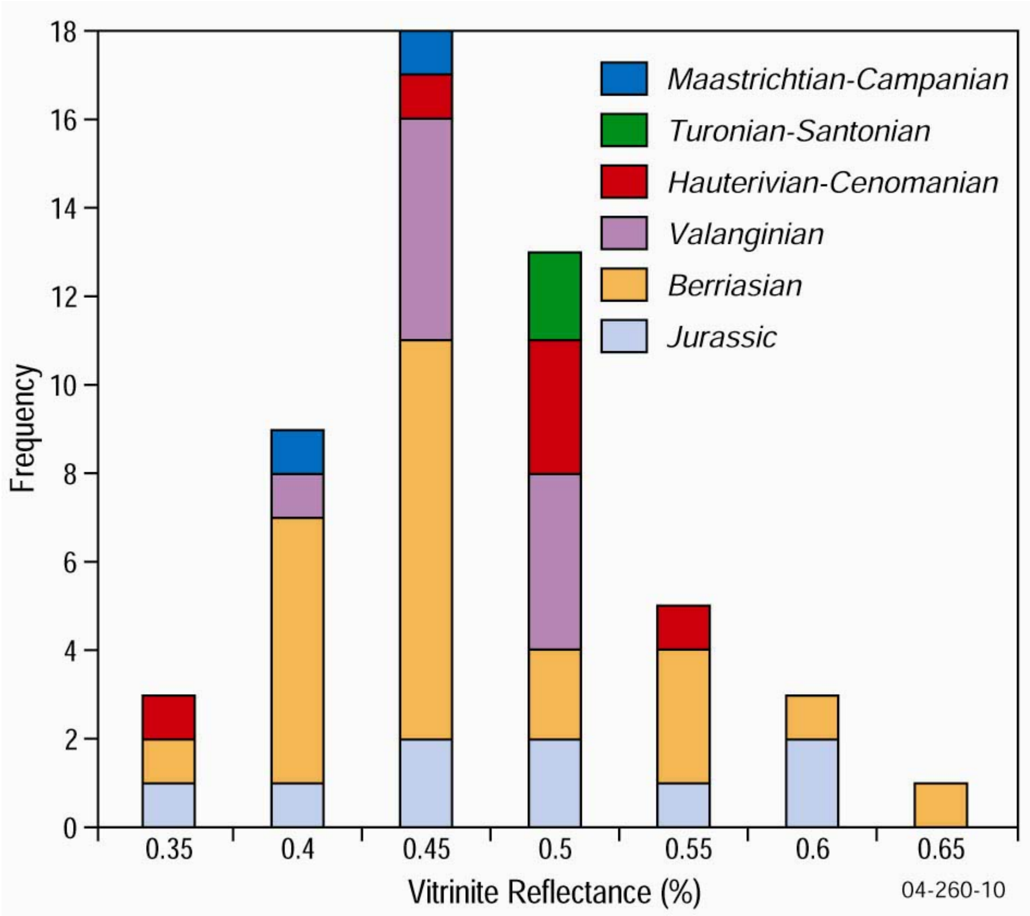
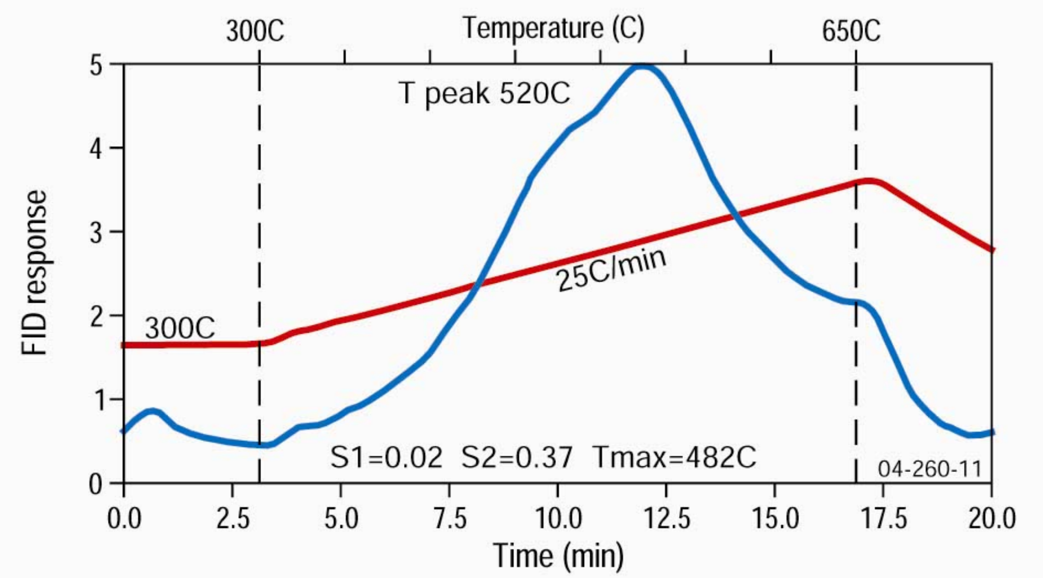


Figure 4.11 *Rock Eval pyrolysis trace for DR37B1.1 for a) whole rock, and b) kerogen. The temperature profile (red trace) tracks the temperature of the sample within the pyrolysis oven: a) 300°C for 3 minutes, b) 25°C/min to 650°C and c) oven cool down after 17 minutes. The area under the detector response (blue trace) corresponds to S1 (temperature region a) and S2 (temperature region b). Tmax is the largest detector response in temperature region b.*



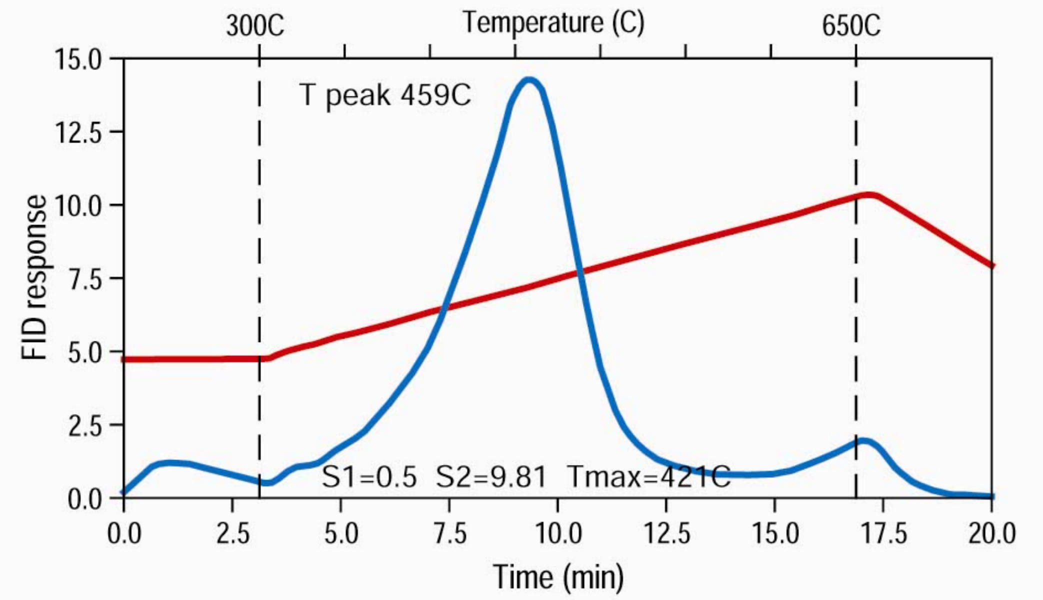


Figure 4.12 *Gas chromatography of saturated hydrocarbons in Bremer Sub-basin dredge samples. Annotations show n-alkane carbon number at maximum abundance and Pr and Ph. Sample information includes the dredge number, sample number, VR, TOC, HI, age and relative proportions of marine algae, fresh/brackish water algae, ferns and gymnosperms.*

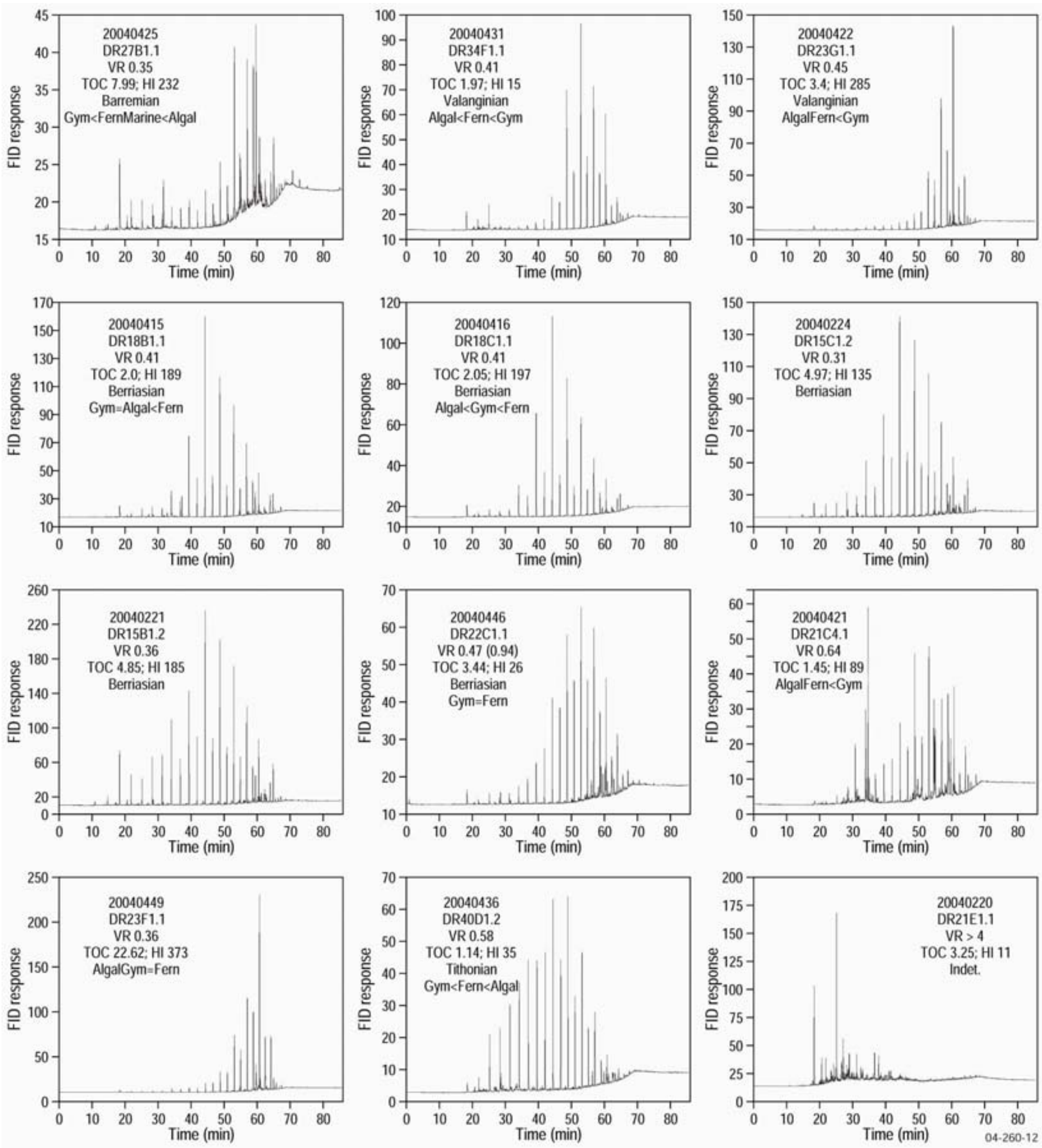


Figure 4.13 *Triangular plot of percentage of gymnosperm, ferns and lacustrine algae for the non-marine sediments of Early-Late Jurassic and Early Cretaceous age.*

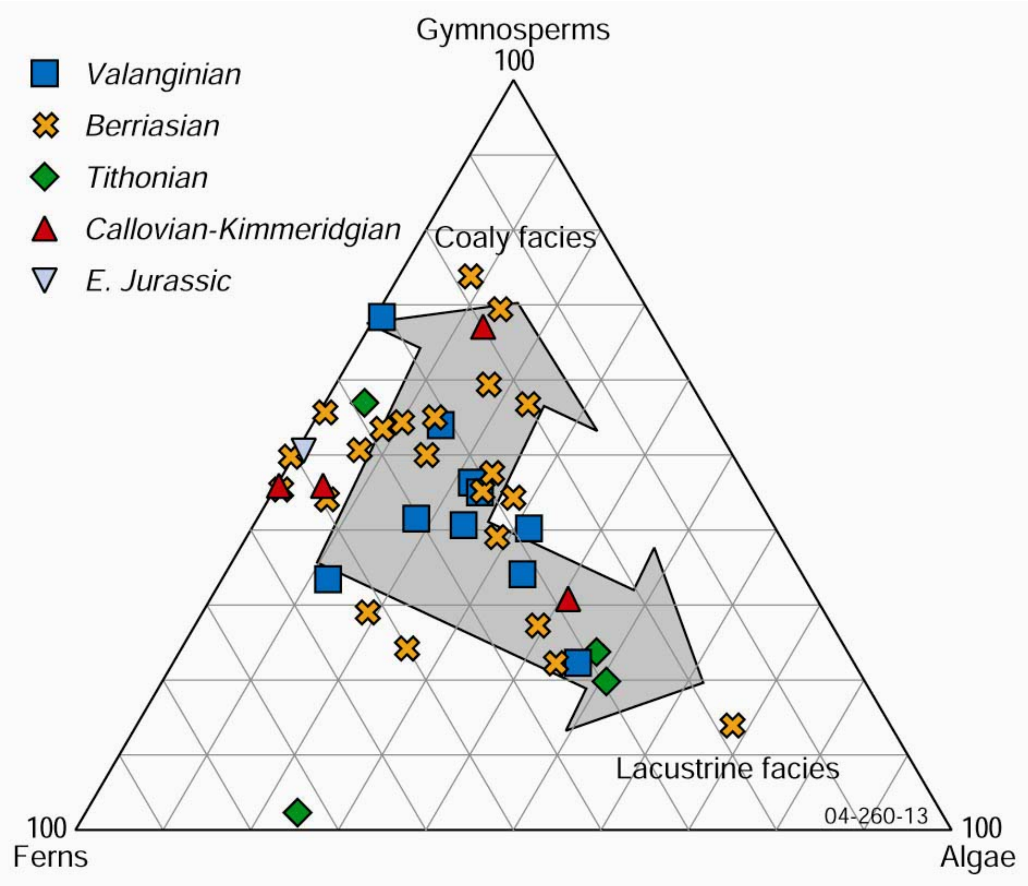


Figure 4.14 *Plot of percentages gymnosperm/fern versus percentages gymnosperm/ (percentages fresh and brackish water algae plus percentage marine algae) from biostratigraphic results of the Bremer Sub-basin samples.*

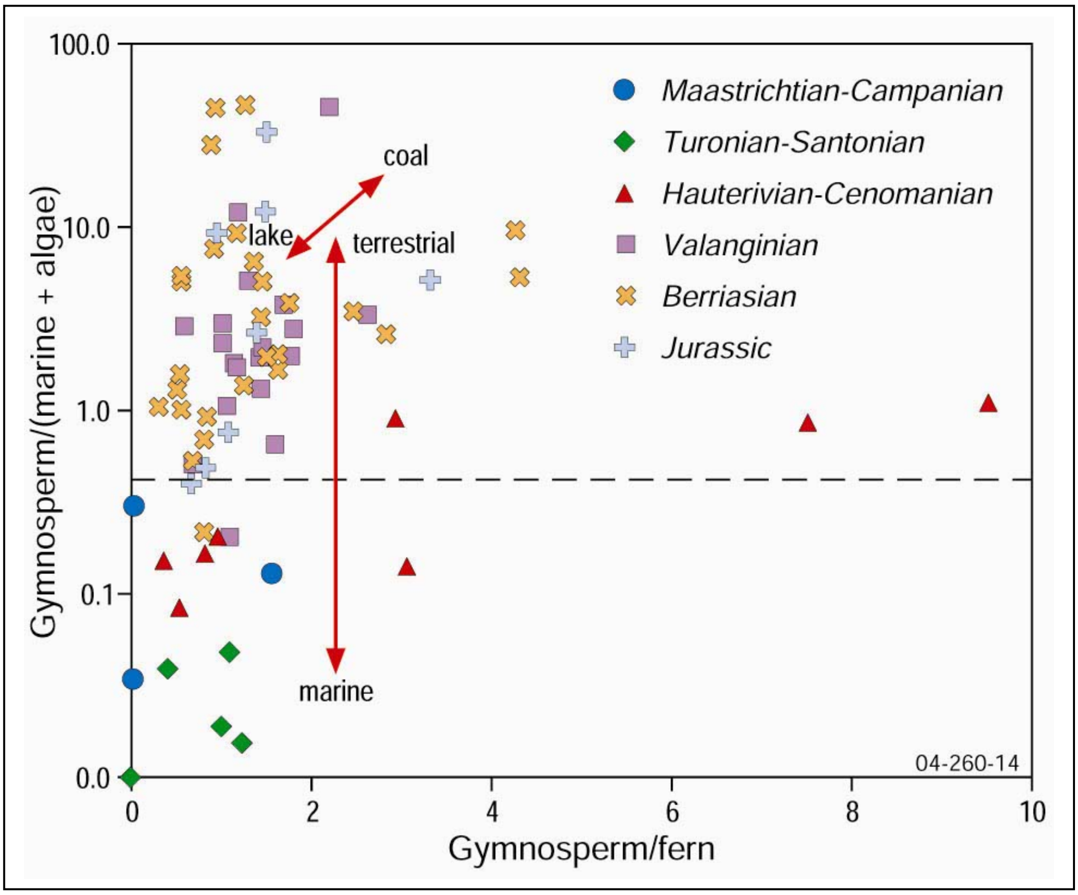


Figure 4.15 *Frequency distribution of $\delta^{13}C$ kerogen for the six time slices: Jurassic, Berriasian, Valanginian, Hauterivian-Cenomanian, Turonian-Santonian and Maastrichtian-Campanian.*

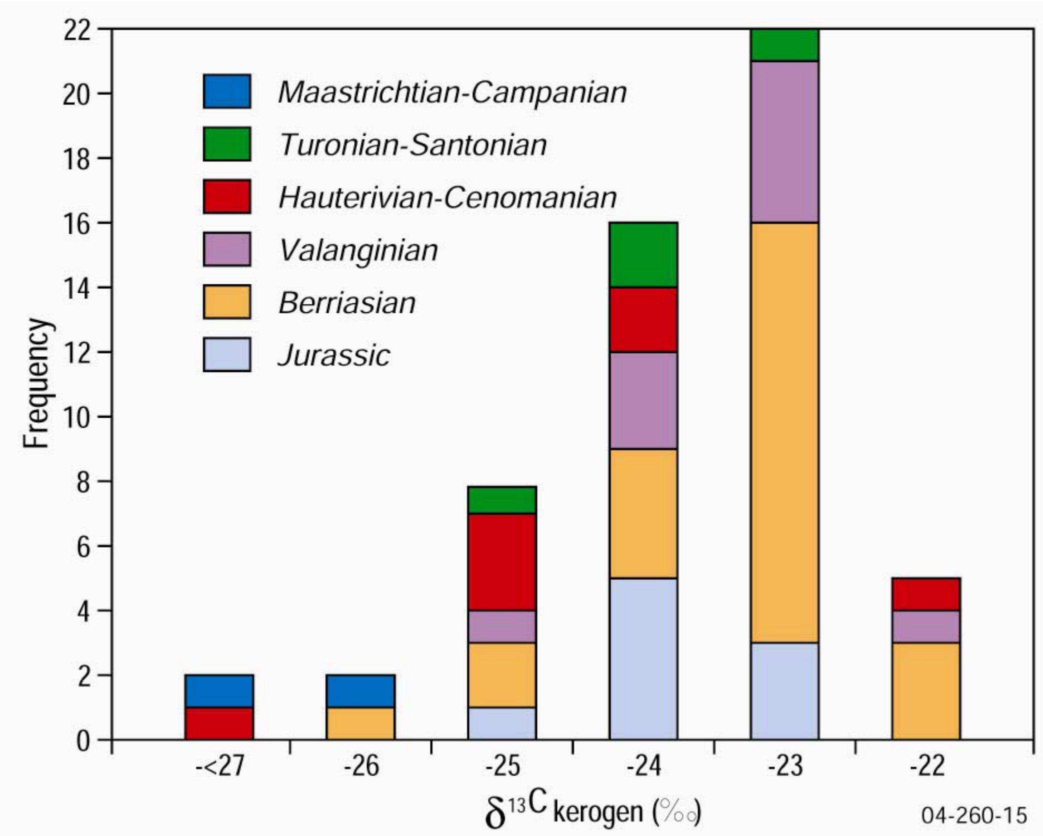


Figure 4.16 *Plot of average $\delta^{13}C$ kerogen ± one standard deviation for the six timeslices: Jurassic, Berriasian, Valanginian, Hauterivian-Cenomanian, Turonian-Santonian and Maastrichtian-Campanian.*

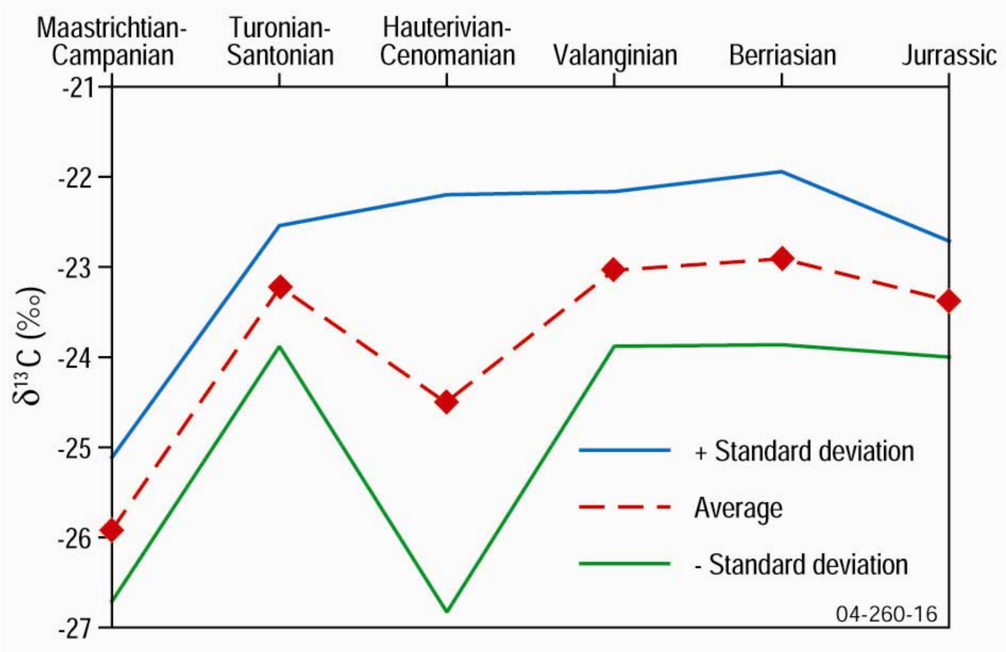


Figure 4.17 *Plot of $\delta^{13}C$ kerogen versus ratio of percentage gymnosperm to percentage ferns plus percentage lacustrine algae for the non-marine sediments of Early-Late Jurassic and Early Cretaceous age.*

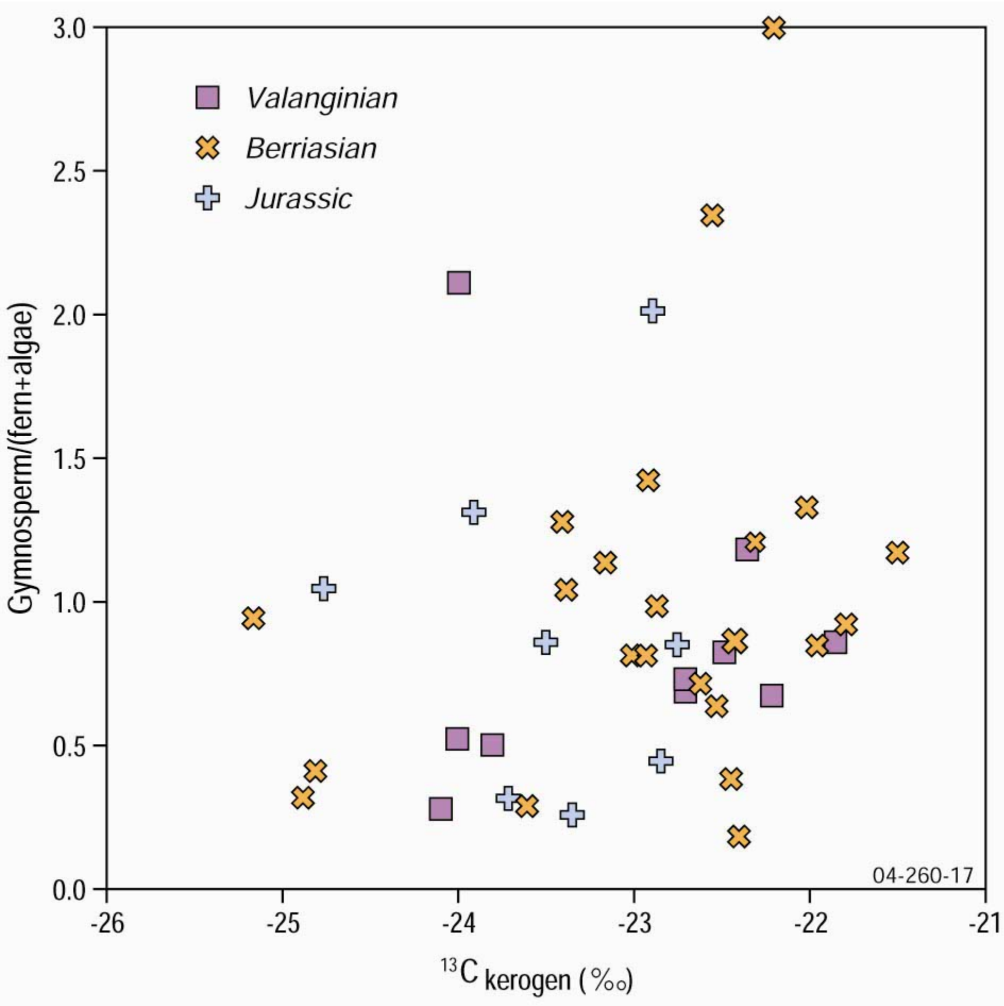


Figure 4.18 *Plot of δ^{13}C kerogen versus percentage inertinite maceral group for the non-marine sediments of Early-Late Jurassic and Early Cretaceous age.*

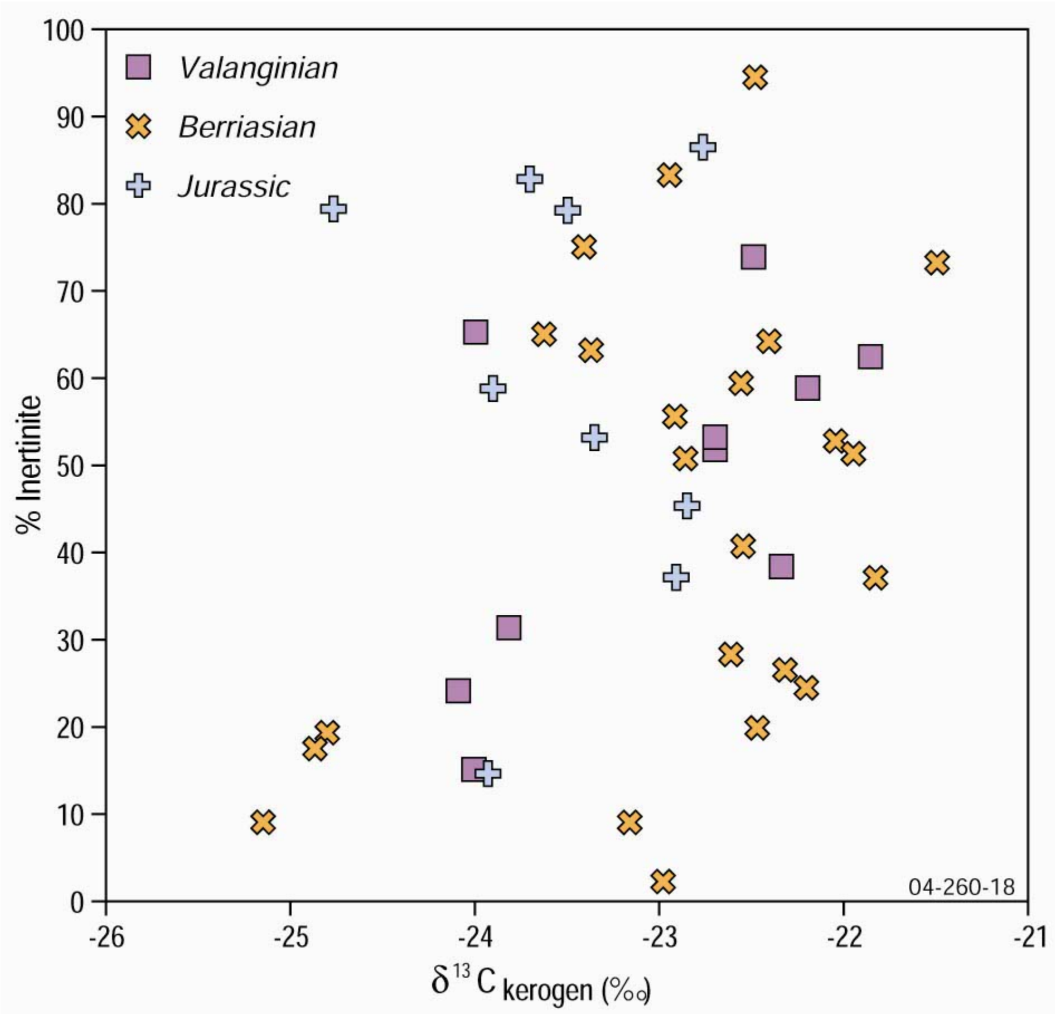


Figure 4.19 *Age plot of average carbon isotopic composition for disseminated organic matter (kerogen) in fine-grained sediments. Data for non-marine and marine kerogen from Bass, Gippsland, Otway and Perth basins (Boreham, unpublished data) and the Bremer Sub-basin.*

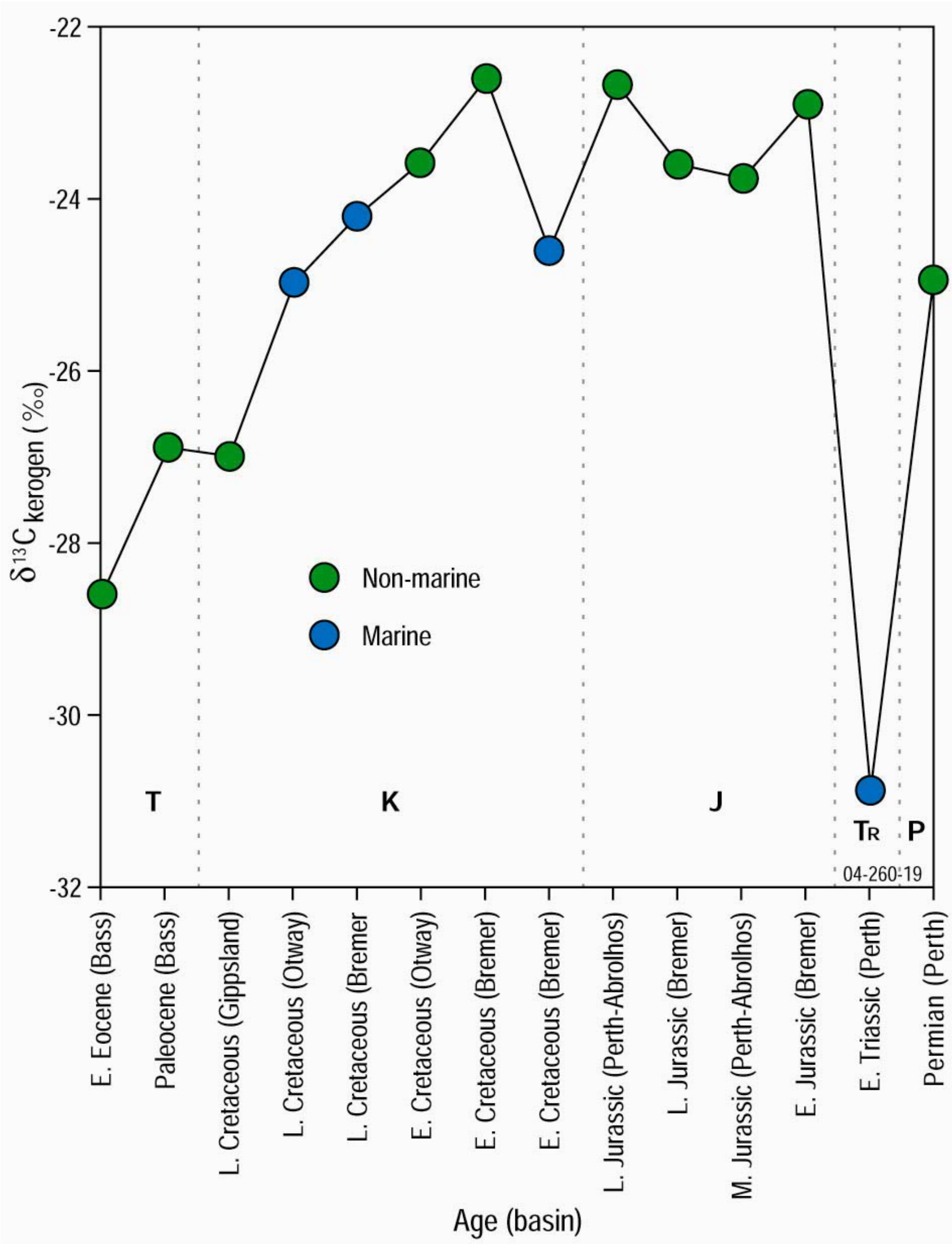


Table 4.1 *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/01DR01	**1393935**				
265/01/DR01/A1	1393936	pipe	11 Feb 04	sandstone, silty, fine to very fine-grained, quartz, lithics, feldspar, mica, subangular grains, friable sample	5Y 5/3
265/01/DR01/B1	1393939	pipe	11 Feb 04	nannofossil ooze	5Y 8/1
265/03/DR03	**1393941**				
265/03/DR03/A1	1393942	pipe	16 Feb 04	gneiss, porphyroblastic texture with quartz, feldspar, biotite	white to grey pink
265/03/DR03/B1	1393944	pipe	16 Feb 04	nannofossil ooze	5Y 6/2
265/03/DR03/C1	1393945	pipe	16 Feb 04	syenite, felsic with quartz, feldspar and some biotite, fine to medium-grained, equigranular texture	grey
265/04/DR04	**1393947**				
265/04/DR04/A1	1393948	pipe	16 Feb 04	granite, quartz, feldspar and biotite, fine-grained, equigranular	grey to black
265/04/DR04/B1	1393950	pipe	16 Feb 04	nannofossil ooze	5Y 6/2
265/05/DR05	**1393951**				
265/05/DR05/A1	1393952	chain bag	18 Feb 04	granite, quartz rich with feldspar and mica	not recorded
265/05/DR05/B1	1393954	chain bag	18 Feb 04	granite, medium grained, quartz rich with feldspar and mica	not recorded
265/05/DR05/C1	1393957	chain bag	18 Feb 04	limestone, forams and molluscan fragments	5Y 6/1
265/05/DR05/D1	1393959	chain bag	18 Feb 04	chalk, very fine-grained, forams, spicules, loosely consolidated	5Y 8/1
265/05/DR05/E1	1393963	pipe	18 Feb 04	nannofossil sand and ooze, with large forams, spicules and fine to medium-grained shell fragments	5Y 7/2
265/05/DR05/F1	1393964	chain bag	18 Feb 04	whale bone	not recorded
265/06/DR06	**1394390**				
265/06/DR06/A1	1393965	pipe	24 Feb 04	nannofossil ooze, silty, forams, spicules and quartz	5Y 7/2
265/07/DR07	**1393966**				
265/07/DR07/A1	1393967	chain bag	25 Feb 04	greensand, with fine-grained to silty quartz, mica, spicules, glacuonite, well sorted and sub-rounded grains, loosely consolidated sample	5YR 5/4
265/07/DR07/A2	1393969	chain bag	25 Feb 04	sandstone, very fine to fine-grained quartz and lithics, well-sorted, coarsely bedded, iron staining, semi-lithified	5YR 4/3
265/07/DR07/A3	1393970	chain bag	25 Feb 04	sandstone, very fine to fine-grained lithics, quartz, mica, with pebbles, coarsely bedded, semi-lithified, bored	5YR 4/3

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/07/DR07/B1	1393971	chain bag	25 Feb 04	chalk, silty, abundant spicules, loosely consolidated	5Y 8/1
265/07/DR07/C1	1393975	chain bag	25 Feb 04	limestone, very-fine to fine-grained sand and silt, bioclastic, some quartz grains	5Y 5/2
265/07/DR07/D1	1393978	pipe	25 Feb 04	mudstone, bioclastic, very fine to fine-grained sand and mud, loosely consolidated	5Y 7/2
265/08/DR08	**1393980**				
265/08/DR08/A1	1393981	chain bag	25 Feb 04	chalk, very fine to fine-grained sand and silt, burrowed, consolidated	5YR 8/1
265/08/DR08/B1	1393983	pipe	25 Feb 04	nannofossil ooze	5YR 8/1
265/08/DR08/C1	1393984	pipe	25 Feb 04	nannofossil ooze	5Y 7/1
265/09/DR09	**1393985**				
265/09/DR09/A1	1393986	chain bag	25 Feb 04	carbonaceous siltstone, calcareous, with some coarse to very fine-grained quartz sand and silt, well indurated	5Y 3/2
265/09/DR09/B1	1393990	pipe	25 Feb 04	carbonaceous mudstone, calcareous, very fine-grained quartz sand and silt, plastic and sticky, semi-consolidated	5Y 3/2
265/09/DR09/C1	1393994	pipe	25 Feb 04	mudstone, calcareous, very fine-grained quartz sand and silt, soft	5Y 3/2
265/09/DR09/D1	1393996	pipe	25 Feb 04	nannofossil ooze, with medium to coarse-grained bioclastic sand, forams and spicules	10Y 6/2
265/09/DR09/E1	1393997	pipe	25 Feb 04	nannofossil ooze, with silty quartz, forams and spicules	10YR 6/2
265/10/DR10	**1393998**				
265/10/DR10/A1	1393999	pipe	25 Feb 04	calcareous siltstone, very fine to fine-grained sand, spicules and forams, semi-consolidated sample	10YR 8/2
265/10/DR10/B1	1394001	pipe	25 Feb 04	nannofossil ooze, spicules and forams	5Y 7/2
265/10/DR10/C1	1394002	pipe	25 Feb 04	calcareous siltstone, spicules, forams and bioclastic material, semi-consolidated	5Y 7/2
265/10/DR10/D1	1394003	pipe	25 Feb 04	calcareous siltstone to chalk, spicules, forams and bioclastic material, semi-consolidated lumps	5Y 7/2
265/11/DR11	**1394005**				
265/11/DR11/A1	1394006	pipe	26 Feb 04	nannofossil ooze, spicules, forams and very fine sand to silty bioclastic material, massive	5Y 8/1
265/12/DR12	**1394007**				
265/12/DR12/A1	1394008	pipe	26 Feb 04	nannofossil ooze, spicules, forams and very fine sand to silty bioclastic material	5Y 8/1
265/12/DR12/B1	1394009	pipe	26 Feb 04	nannofossil ooze, massive nodules to semi-lithified, heavily bored sample	5Y 8/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/13/DR13	**1394010**				
265/13/DR13/A1	1394011	pipe	26 Feb 04	granitic pebbles, medium to coarse-grained, porphyritic quartz, feldspar, biotite, vein quartz	not recorded
265/13/DR13/B1	1394012	pipe	26 Feb 04	felsic to intermediate igneous pebbles, quartz, subangular to subrounded pebbles with black iron stain	not recorded
265/13/DR13/C1	1394013	chain bag	26 Feb 04	sandstone, arkosic, medium to coarse-grained, with quartz , mica, poorly sorted, subangular to subrounded grains, moderate to well lithified	10 YR 4/2
265/13/DR13/D1	1394014	chain bag	26 Feb 04	siltstone, micaceous, with very fine to fine-grained quartz, lithic frags, laminated and fining upward beds	5Y 5/2
265/13/DR13/E1	1394015	pipe	26 Feb 04	mudstone, mica, very fine to fine-grained quartz, lithic frags, very well sorted, burrows/bores, moderately consolidated	10 Y 6/2
265/13/DR13/F1	1394016	chain bag	26 Feb 04	mudstone, silty, carbonaceous, with very fine to fine-grained flecks of mica, some quartz, well sorted and moderately consolidated	5Y 3/2
265/13/DR13/G1	1394017	chain bag	26 Feb 04	chalk to calcareous mudstone, abundant forams, moderate to well lithified	5Y 7/2
265/13/DR13/H1	1394019	pipe	26 Feb 04	nannofossil ooze	5Y 7/2
265/14/DR14	**1394020**				
265/14/DR14/A1	1394021	pipe	26 Feb 04	nannofossil ooze	5Y 8/1
265/14/DR14/A2	1394022	chain bag	26 Feb 04	chalk to calcareous mudstone, semi-lithified, massive, heavily bored sample	5Y 7/2
265/15/DR15	**1394023**				
265/15/DR15/A1	1394024	chain bag	27 Feb 04	nannofossil ooze, very fine-grained sand and mud, firmly consolidated	5Y 7/2
265/15/DR15/A2	1394025	pipe	27 Feb 04	nannofossil ooze,spicules, very fine-grained sand and mud, semi-consolidated	5Y 8/1
265/15/DR15/A3	1394026	chain bag	27 Feb 04	nannofossil ooze, well consolidated	5Y 8/1
265/15/DR15/A4	1394027	chain bag	27 Feb 04	calcareous mudstone to chalk, some macrofossils, moderately well lithified, heavily bored	5Y 7/3
265/15/DR15/B1	1394030	chain bag	27 Feb 04	mudstone, carbonaceous, with fine-grained quartz, organic material and mica, massive, moderately lithified	5Y 2/1
265/15/DR15/C1	1394034	chain bag	27 Feb 04	shale, with carbonaceous clasts, mica, some fine-grained quartz, lithified, bored	5Y 2/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/16/DR/16	**1394039**				
265/16/DR16/A1	1394040	chain bag	27 Feb 04	sandstone, arkosic, medium to coarse-grained quartz, subrounded grains, poorly to moderately sorted, iron banding, moderately lithified sample	10YR 5/4
265/16/DR16/A2	1394041	chain bag	27 Feb 04	sandstone, quartzose, medium to fine-grained, some organics, well sorted, partially lithified	5Y 8/1
265/16/DR16/A3	1394042	chain bag	27 Feb 04	sandstone, quartzose, fine to medium-grained, micaceous beds, massive, well consolidated sample, iron stained	5Y 5/2
265/16/DR16/B1	1394044	chain bag	27 Feb 04	mudstone/shale, micaceous, microfoliated, iron stained, burrowed, lithified sample, soft (weathered)	5Y 4/1
265/16/DR16/C1	1394045	chain bag	27 Feb 04	silty mudstone, micaceous, moderately well lithified	5Y 4/1
265/16/DR16/D1	1394046	chain bag	27 Feb 04	chalk to calcareous siltstone, lithified and heavily bored, with solitary corals preserved on sample surface	5Y 8/1
265/16/DR16/D2	1394048	pipe	27 Feb 04	nannofossil ooze, spicules, forams, semi-consolidated	5Y 8/1
265/16/DR16/D3	1394049	pipe	27 Feb 04	nannofossil ooze, spicules, forams, semi-consolidated	5Y 7/2
265/17/DR17	**1394050**				
265/17/DR17/A1	1394051	chain bag	27 Feb 04	mudstone/shale, micaceous, laminated, bored, well indurated sample	5Y 3/2
265/17/DR17/B1	1394054	chain bag	27 Feb 04	mudstone, silty, with some mica, laminated, well lithified	5Y 4/2
265/17/DR17/C1	1394058	chain bag	27 Feb 04	mudstone, silty, micaceous, laminated, lithified	5Y 3/2
265/17/DR17/D1	1394062	chain bag	27 Feb 04	sandstone, glauconitic, medium-grained quartz, some mica, massive and moderately lithified sample	10Y 5/4
265/17/DR17/E1	1394066	pipe	27 Feb 04	nannofossil ooze	5Y 7/1
265/18/DR18	**1394067**				
265/18/DR18/A1	1394068	chain bag	27 Feb 04	limestone, muddy, zeolite, massive and well lithified sample	5Y 4/1
265/18/DR18/A2	1394069	chain bag	27 Feb 04	limestone, muddy, massive and well lithified sample	dark grey
265/18/DR18/A3	1394070	chain bag	27 Feb 04	limestone, muddy, massive and well lithified sample	dark grey
265/18/DR18/B1	1394071	chain bag	27 Feb 04	siltstone concretions, micaceous, well sorted, well lithified	5Y 3/2
265/18/DR18/C1	1394076	chain bag	27 Feb 04	mudstone, abundant fine to very fine-grained mica, poorly-formed cleavage that cross-cuts bedding planes, moderately well lithified and partially bored	5Y 3/2

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/18/DR18/D1	1394080	chain bag	27 Feb 04	mudstone, very fine-grained mica, massive, semi-consolidated, soft (weathered)	5Y 3/2
265/18/DR18/E1	1394085	chain bag	27 Feb 04	heavy red concretion, possible coprolite	
265/18/DR18/F1	1394086	chain bag	27 Feb 04	limestone to lithic sandstone, medium to coarse-grained, sub-angular to rounded quartz, poorly sorted, well lithified	5Y 7/6
265/18/DR18/G1	1394087	pipe	27 Feb 04	nannofossil ooze, spicules, forams	5Y 7/1
265/19/DR19	**1394088**				
265/19/DR19/A1	1394089	chain bag	27 Feb 04	sandstone with interbedded shale, medium to coarse-grained, rounded to subangular grains of lithics and quartz, moderately to poorly sorted, ripples, cemented, lithified	5Y 2.5/2
265/19/DR19/B1	1394090	chain bag	27 Feb 04	sandstone to pebble conglomerate, medium to very coarse-grained, minor shale and coaly fragments, moderately to poorly sorted, loosely cemented, well lithified	5Y 6/1
265/19/DR19/C1	1394092	chain bag	27 Feb 04	siltstone, micaceous, with fine-grained sandstone layers, carbonaceous, well sorted, cross-bedding, lithified	5Y 2/1
265/19/DR19/D1	1394094	chain bag	27 Feb 04	sandstone, quartzose, with carbonaceous-micaceous siltstone layers, fine to coarse-grained quartz and lithics, well sorted sand, thin micaceous layers, small scale cross-beds	10YR 7/4
265/19/DR19/E1	1394095	pipe	27 Feb 04	nannofossil ooze, forams, spicules	2.5Y 7/2
265/20/DR20	**1394096**				
265/20/DR20/A1	1394097	chain bag	28 Feb 04	granite, subhedral to anhedral phenocrysts of feldspar, quartz and biotite, weathered, iron-stained	grey green to weathered red
265/20/DR20/B1	1394098	chain bag	28 Feb 04	sandstone, quartzose, coarse to medium-grained quartz, mica and lithics, some small pebbles, poorly sorted, partly lithified, black weathering rind	5Y 5/2
265/20/DR20/B2	1394099	chain bag	28 Feb 04	sandstone, quartzose, coarse to fine-grained quartz, mica and lithics interbedded with organic-rich layers, strong bed contact, poorly sorted	pale olive
265/20/DR20/C1	1394100	chain bag	28 Feb 04	shale to mudstone, carbonaceous, with fine to medium-grained quartz, loosely lithified	5Y 2/1
265/20/DR20/D1	1394103	pipe	28 Feb 04	nannofossil ooze, spicules, forams	5Y 7/2
265/21/DR21	**1394104**				
265/21/DR21/A1	1394105	chain bag	28 Feb 04	basalt, porphyritic, randomly oriented phenocrysts, weathered	dark brown to black
265/21/DR21/B1	1394107	chain bag	28 Feb 04	limestone breccia, medium to very coarse-grained, angular lithic fragments in heavily cemented groundmass, poorly sorted, well lithified	10Y 6/2
265/21/DR21/C1	1394108	chain bag	28 Feb 04	mudstone/shale, carbonaceous with fine to very fine-grained mica and quartz layers, moderately consolidated, bored	5Y 2/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/21/DR21/C2	1394111	chain bag	28 Feb 04	mudstone/shale, carbonaceous with very fine-grained mica, quartz and coaly, massive, moderately consolidated, bored	5Y 2/1
265/21/DR21/C3	1394115	chain bag	28 Feb 04	mudstone, carbonaceous with abundant fine to very fine-grained mica, massive, loosely consolidated	5Y 2/1
265/21/DR21/C4	1394116	chain bag	28 Feb 04	siltstone, carbonaceous, abundant coaly material, micaceous, minor fine-grained quartz, massive, partly lithified	5Y 2/1
265/21/DR21/D1	1394118	chain bag	28 Feb 04	siltstone, interbedded with medium to very fine-grained quartz and abundant mica, coaly layers, iron-stained, consolidated, burrowed	5Y 4/1
265/21/DR21/E1	1394119	chain bag	28 Feb 04	lignitic or bituminous coal and carbonaceous mudstone, fine to very fine-grained mica, lithified, fractured	N1
265/21/DR21/F1	1394121	chain bag	28 Feb 04	nannofossil ooze, spicules	5Y 8/1
265/22/DR22	**1394122**				
265/22/DR22/A1	1394123	chain bag	28 Feb 04	mudstone, with micaceous laminations, fine to medium-grained quartz and minor coaly flecks, consolidated, soft	5Y 4/1
265/22/DR22/B1	1394124	chain bag	28 Feb 04	sandstone, quartzose, sub-rounded, fine to very fine-grained quartz with some mica, well sorted, massive, lithified, hard vitreous iron oxide weathered layers	5YR 5/2
265/22/DR22/C1	1394125	chain bag	28 Feb 04	mudstone, carbonaceous, coaly, with pyrite aggregrates, coal fragments, minor quartz and mica, massive, lithified	5Y 2/1
265/22/DR22/D1	1394126	chain bag	28 Feb 04	limestone, glauconitic, fossils, massive, burrowed, lithified with conchoidal fracture	5Y 8/1
265/22/DR22/D2	1394127	chain bag	28 Feb 04	chalk, silty, heavily bored, lithified	5Y 8/1
265/22/DR22/D3	1394128	chain bag	28 Feb 04	chalk, silty, unconsolidated to semi-consolidated	5Y 8/2
265/22/DR22/E1	1394129	chain bag	28 Feb 04	nannofossil ooze	5Y 8/1
265/23/DR23	**1394130**				
265/23/DR23/A1	1394131	chain bag	28 Feb 04	sandstone, quartzoze, rounded to subangular medium to coarse-grained quartz, with minor feldspar, moderately sorted, partly lithified, weathered	5Y 4/4
265/23/DR23/B1	1394132	chain bag	28 Feb 04	siltstone to carbonaceous mudstone, fossiliferous, minor coal and plant material, fine to very fine-grained mica, massive, moderately lithified	5Y 6/1
265/23/DR23/C1	1394133	chain bag	28 Feb 04	mudstone to greensand, micaceous, minor quartz, well sorted, unconsolidated	5Y 4/4
265/23/DR23/D1	1394134	chain bag	28 Feb 04	mudstone, fine to very fine-grained mica with minor coal, consolidated, conchoidal fracture	5Y 6/1
265/23/DR23/E1	1394135	chain bag	28 Feb 04	sandstone, quartzoze and micaceous, fine-grained, moderately well sorted, massive, loosely consoldiated	5Y 6/1
265/23/DR23/F1	1394136	pipe	28 Feb 04	mudstone, carbonaceous with mica and fine to coarse clasts (up to 2.5 cm) of shiny black coal and woody fragments, poorly sorted, moderately consolidated	5Y 6/1
265/23/DR23/G1	1394137	chain bag	28 Feb 04	mudstone, carbonaceous and micaceous, with coal, coarser interbeds are moderately sorted, massive, consolidated	5Y 6/1
265/23/DR23/H1	1394139	pipe	28 Feb 04	nannofossil ooze	5Y 8/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/24/DR24	**1394140**				
265/24/DR24/A1	1394141	chain bag	28 Feb 04	sandstone, quartz arenite, micaceous, fine to medium-grained quartz and other dark grains, well-sorted, partly lithified, weathered, displays high visual porosity	5R 6/2
265/24/DR24/B1	1394142	chain bag	28 Feb 04	mudstone, with fine-grained glauconite and mica, consolidated	5Y 4/4
265/24/DR24/C1	1394143	chain bag	28 Feb 04	mudstone, black carbonaceous, with fine to very fine-grained quartz and mica, well sorted, moderately to well lithified	5Y 6/1
265/24/DR24/D1	1394145	chain bag	28 Feb 04	mudstone, with very fine-grained to silty mica and quartz, possible glauconite, massive, slightly bored	5Y 2.5/2
265/24/DR24/E1	1394146	chain bag	28 Feb 04	calcarenite, abundant glauconite, *Inoceramus* fragments, massive, burrowed	5Y 7/2
265/24/DR24/F1	1394149	chain bag	28 Feb 04	sandstone, quartz arenite, some fine-grained mica, subrounded quartz and possible glauconite, moderately to well sorted, lithified	5Y 7/2
265/24/DR24/G1	1394150	chain bag	28 Feb 04	calcarenite to calcirudite, bryozoal, some forams, echinoid, possible glauconite, coarse-grained, poorly sorted, massive, partly lithified, displays high visual porosity	2.5Y 8/4
265/24/DR24/H1	1394153	chain bag	28 Feb 04	chalk, spicules, forams, semi-consolidated	2.5Y 8/2
265/24/DR24/I1	1394155	chain bag	28 Feb 04	nannofossil ooze, sandy with semi-lithified terrigenous nodules within the unconsolidated mud., spicules, forams	5Y 3/2
265/25/DR25	**1394157**				
265/25/DR25/A1	1394158	chain bag	28 Feb 04	chert (possibly silicified claystone), sub-conchoidal fracture, cryptocrystalline silicification	N2
265/25/DR25/B1	1394159	chain bag	28 Feb 04	shale/mudstone, fractured, indurated	N2/N4
265/25/DR25/C1	1394161	chain bag	28 Feb 04	mudstone, with very fine-grained mica and quartz, semi-lithified, soft	5Y 2.5/1
265/25/DR25/D1	1394162	chain bag	28 Feb 04	mudstone, with very fine-grained mica and quartz, semi-lithified, friable, bored surface that has been partially infilled and oxidised	5Y 5/3
265/25/DR25/E1	1394163	chain bag	28 Feb 04	mudstone, slightly calcareous, heavily burrowed	5Y 8/4
265/25/DR25/F1	1394165	chain bag	28 Feb 04	chalk, forams, spicules, massive	5Y 8/1
265/25/DR25/G1	1394167	chain bag	28 Feb 04	nannofossil ooze	5Y 7/2
265/26/DR26	**1394168**				
265/26/DR26/A1	1394169	chain bag	28 Feb 04	chalk, spicules, lithified, heavily bored	5Y 7/2
265/26/DR26/B1	1394170	pipe	28 Feb 04	nannofossil ooze	5Y 8/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/27/DR27	**1394171**				
265/27/DR27/A1	1394172	chain bag	29 Feb 04	sandstone, sub-arkosic, medium to coarse-grained with sub-angular to sub-rounded quartz, feldspar, biotite and lithic fragments, pebbles, moderately sorted, loosely lithified	N5
265/27/DR27/A2	1394173	chain bag	29 Feb 04	sandstone, sub-angular, fine to medium-grained quartz with mica and lithics, well sorted, heavily iron stained and diagenetic rim, partly lithified	5Y 5/6
265/27/DR27/A3	1394174	chain bag	29 Feb 04	sandstone, fine to very fine-grained, with interbeds of silty carbonaceous mudstone, mica, lithics and plant frags, moderately lithified	N2
265/27/DR27/A4	1394175	chain bag	29 Feb 04	sandstone, micaceous-quartzose, fine to medium-grained, with organic material and pyrite, moderately well sorted, moderately lithified	N1
265/27/DR27/B1	1394177	chain bag	29 Feb 04	mudstone, carbonaceous, with very coal and fine-grained mica, moderately lithified, prominent cleavage	N1
265/27/DR27/C1	1394179	chain bag	29 Feb 04	mudstone, carbonaceous with coaly layers, very fine-grained quartz and abundant mica, consolidated, prominent mica foliation	5Y 2/1
265/27/DR27/C2	1394181	chain bag	29 Feb 04	mudstone, carbonaceous, very fine to fine-grained mica layers, abundant organic material, massive, semi-consolidated	5Y 4/1
265/27/DR27/D1	1420093	chain bag	29 Feb 04	mudstone, sandy, calcareous with some carbonate clasts (up to 1 cm), possible glacuonite, burrowed	5Y 4/1
265/27/DR27/E1	1394183	chain bag	29 Feb 04	nannofossil ooze	5Y 8/1
265/28/DR28	**1394184**				
265/28/DR28/A1	1394185	chain bag	29 Feb 04	sandstone, quartz arenite, sub-rounded, medium to coarse-grained quartz, with lithic fragments, mica and feldspar, moderately sorted, coarsely bedded, moderately iron stained, partly lithified	5Y 6/2
265/28/DR28/B1	1394186	chain bag	29 Feb 04	mudstone, silty, with very fine to fine-grained mica, quartz, feldspar, coaly layers, micaeous layers (possible foliation), semi-consolidated	5YR 3/1
265/28/DR28/C1	1394190	chain bag	29 Feb 04	mudstone, coaly, micaceous, with medium to coarse-grained, poorly sorted sandy interbeds and small pebbles, semi-consolidated	5YR 5/1
265/28/DR28/D1	1394193	chain bag	29 Feb 04	sandstone, calcarenite, fine-grained, partly consolidated	5GY 7/2
265/28/DR28/E1	1394195	chain bag	29 Feb 04	nannofossil ooze	2.5Y 8/2
265/28/DR28/F1	1394197	pipe	29 Feb 04	nannofossil ooze to calcarenite, spicules, semi-consolidated	5GY 7/3
265/28/DR28/G1	1394199	pipe	29 Feb 04	nannofossil ooze, semi-consolidated	2.5Y 8/2
265/28/DR28/H1	1394200	chain bag	29-Feb 04	calcarenite, nodular, with *Inoceramus* fragment, some glauconite, cherty diagenetic centre, minor sandy interbeds, amorphous texture, mottled, well lithified	2.5Y 8/2

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

265/29/DR/29	**1394203**				
265/29/DR29/A1	1394204	chain bag	29 Feb 04	sandstone, quartz arenite, with very fine to medium-grained quartz, with mica and other dark grains, micaceous layers, well sorted, subangular to subrounded grains, some cross-bedding, partly lithified, weathered	5Y 5/6
265/29/DR29/B1	1394206	pipe	29 Feb 04	nannofossil ooze	2.5Y 7/2
265/30/DR30	**1394207**				
265/30/DR30/A1	1394208	chain bag	29 Feb 04	sandstone, quartz arenite, medium to course-grained, with minor mica, feldspar and dark grains, moderately sorted, sub-rounded grains, massive, moderately to well lithified	N4
265/30/DR30/B1	1394209	chain bag	29 Feb 04	sandstone, quartz arenite, fine to medium-grained, micaceous, with feldspar and possible glacuonite, moderatly to well sorted, well layered, massive, moderately to well lithified	10YR 6/6
265/30/DR30/C1	1394210	chain bag	29 Feb 04	mudstone with some very fine to fine-grained micaceous layers, bioturbated, semi-consolidated	N4
265/30/DR30/D1	1394214	pipe	29 Feb 04	nannofossil ooze with some coarse-grained lithic fragments	5Y 6/1
265/31/DR31	**1394215**				
265/31/DR31/A1	1394216	chain bag	29 Feb 04	sandstone, medium to very coarse-grained quartz, feldspar, lithics and mica, very poorly sorted, sub-rounded to well-rounded grains, coaresly bedded, iron staining, partly lithified	5Y 4/4
265/31/DR31/A2	1394217	chain bag	29 Feb 04	sandstone, fine to medium-grained quartz, feldspar, lithics and mica, well sorted, with quartz and mica layers, possible foliations parallel to bedding planes, iron stained, well lithified	10 YR 5/4.
265/31/DR31/A3	1394218	chain bag	29 Feb 04	sandstone, fine to course-grained quartz, feldspar, lithics, cross-bedding and pebbles, moderate to poorly sorted, sub-angular to well-rounded quartz grains, lithified	N6
265/31/DR31/B1	1394219	chain bag	29 Feb 04	nannofossil ooze, spicules	5Y 6/1
265/32/DR32	**1394220**				
265/32/DR32/A1	1394221	chain bag	01 Mar 04	sandstone, fine to coarse-grained quartz, feldspar, lithics, mica, with pebbles (up to 4 cm long), very poorly sorted, sub-rounded to rounded grains, coarsely bedded, heavily iron stained, partly lithified	5Y 5/6
265/32/DR32/A2	1394222	chain bag	01 Mar 04	sandstone, fine to medium-grained quartz, feldspar, lithics, mica, sub-angular grains, moderately well sorted, micaeous layers, massive, heavily iron stained, moderately lithified	5Y 5/6
265/32/DR32/A3	1394223	chain bag	01 Mar 04	sandstone, fine to medium-grained quartz, mica, lithics, well sorted, sub-angular grains, minor cross-bedding and micaceous and organic-rich layers, gravelly base to sample, partly lithified	5Y 4/4
265/32/DR32/A4	1394224	chain bag	01 Mar 04	sandstone, quartzose, fine to medium-grained sand and mud, with micaceous layers, carbonaceous and minor lithics, sub-angular to sub-rounded quartz, prominent bedding, well sorted, lithified	10YR 6/2
265/32/DR32/B1	1394225	chain bag	01 Mar 04	mudstone, carbonaceous, with very fine to fine-grained quartz, mica with plant material and coaly flakes, massive, semi-consolidated	5Y 2/1
265/32/DR32/C1	1394226	chain bag	01 Mar 04	chalk, fine-grained lithic sand and glacuonite, cherty, possible glauconite, massive, burrowed, lithified	5Y 6/4
265/32/DR32/D1	1394227	pipe	01 Mar 04	nannofossil ooze, spicules with fine to medium-grained shell fragments	5Y 6/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/33/DR33	**1394228**				
265/33/DR33/A1	1394229	chain bag	01 Mar 04	sandstone, quartz arenite with subrounded, fine to medium-grained quartz, mica, feldspar and lithics, moderately well sorted, strong iron staining, thinnly bedded, partly lithified	5YR 4/4
265/33/DR33/A2	1394230	chain bag	01 Mar 04	sandstone, muddy, very fine to fine-grained quartz, mica and lithic fragments, sub-angular to sub-rounded grains, finely bedded with micaceous and organic-rich layers, moderately sorted, lithified	5YR 4/4
265/33/DR33/B1	1394231	chain bag	01 Mar 04	mudstone, carbonaceous, very fine-grained quartz, mica, organics, finely bedded with micaceous layers, consolidated.	5Y 4/1
265/33/DR33/B2	1394233	chain bag	01 Mar 04	mudstone, carbonaceous, very fine-grained quartz, mica, organics, massive, consolidated	5Y 4/1
265/33/DR33/C1	139435	chain bag	04 Mar 04	nannofossil ooze	5Y 6/1
265/34/DR34	**1394236**				
265/34/DR34/A1	1394237	chain bag	01 Mar 04	sandstone, quartz arenite, fine to medium-grained quartz, mica and minor lithic fragments, with thin muddy and micaceous layers, rounded grains, moderately well sorted, cross-bedded, lithified	10R 3/4
265/34/DR34/B1	1394238	chain bag	01 Mar 04	mudstone, red clay matrix with minor very fine to medium-grained quartz and mica, well sorted, micaceous layers, moderately to well lithified	5R 4/6
265/34/DR34/C1	1394239	chain bag	01 Mar 04	sandstone, quartzose, coarse to very coarse-grained quartz, with mica and feldspar, sub-angular grains, poorly sorted, cross-bedded, partly lithified	10YR 4/2
265/34/DR34/D1	1394240	chain bag	01 Mar 04	sandstone, quartz arenite, fine-grained quartz, mica and feldspar, moderately to well sorted, subangular to subrounded quartz grains, thinnly bedded, moderately to well lithified	5YR 6/1
265/34/DR34/E1	1394241	chain bag	01 Mar 04	mudstone with fine-grained sand and silty mica and quartz, well sorted, micaceous layers, moderately to well consolidated	10YR 3/2
265/34/DR34/F1	1394242	chain bag	01 Mar 04	mudstone with fine to medium-grained quartz, abundant micaceous interbeds, moderately sorted in parts, loosely consolidated, soft	10YR 3/1
265/34/DR34/G1	1394244	chain bag	01 Mar 04	nannofossil ooze, plastic texture	5Y 7/2
265/34/DR34/H1	1394246	pipe	01 Mar 04	nannofossil ooze	5Y 7/2
265/47/DR35	**1394269**				
265/47/DR35/A1	1394270	chain bag	02 Mar 04	limestone, calcarenite, bioclastic, with coarse-grained forams, nannofossils, rounded shells, minor quartz and mica, poorly sorted, loosely cemented, high visual porosity	5Y 8/1
265/47/DR35/A2	1394272	chain bag	02 Mar 04	chalk, nannofossils and spicules, moderately consolidated, massive, soft	5Y 8/2
265/47/DR35/A3	1394274	pipe	02 Mar 04	nannofossil ooze	2.5Y 7/2

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/48/DR36	**1394275**				
265/48/DR36/A1	1394276	chain bag	03 Mar 04	sandstone, fine to very fine-grained, sub-rounded quartz with glacuonite, mica and lithic fragments, well sorted, bioturbated, finely bedded with some cross-beds, massive, well lithified	5Y 5/2
265/48/DR36/A2	1394277	chain bag	03 Mar 04	sandstone, very fine-grained to silty, quartz-rich with fine-grained glauconite, mica and lithics, massive, bioturbated, loosely to semi-consolidated	10Y 6/2
265/48/DR36/B1	1408119	chain bag	03 Mar 04	mudstone, quartz-rich, with very fine to fine-grained mica and mud, iron stained, massive, bioturbated, moderately to well lithified	5YR 4/1
265/48/DR36/C1	1394279	chain bag	03 Mar 04	chalk, cherty in parts, nannofossils, massive, lithified with conchoidal fracture	5Y 7/2
265/48/DR36/D1	1394280	chain bag	03 Mar 04	mudstone, fine to medium-grained sand and silty mica, quartz and minor coaly fragments, moderately sorted in parts, iron stained, semi-consolidated	10YR 4/2
265/48/DR36/D2	1394283	chain bag	03 Mar 04	mudstone, fine-grained and silty quartz, with some mica, well sorted, massive, burrowed, semi-consolidated	5Y 2/1
265/48/DR36/E1	1394286	chain bag	03 Mar 04	mudstone, calcareous, abundant spicules, heavily bored, semi-consolidated ooze, massive	5Y 7/2
265/48/DR36/F1	1394287	chain bag	03 Mar 04	nannofossil ooze, with fine to coarse bioclastic and some lithic fragments	5Y 6/1
265/49/DR37	**1394288**				
265/49/DR37/A1	1394289	chain bag	03 Mar 04	mudstone, with fine to medium-grained and silty quartz, mica and organic material, moderately sorted in parts, iron staining, bioturbated with burrows filled with nannofossil ooze, moderately to well lithified	10YR 5/4
265/49/DR37/B1	1394290	chain bag	03 Mar 04	mudstone, carbonaceous, with very fine to fine-grained and silty quartz, mica and organic material, burrowed, moderately to well consolidated	5Y 3/2
265/49/DR37/B2	1394292	chain bag	03 Mar 04	mudstone, carbonaceous, very fine to medium quartz, mica, and lithic frags, micaceous layers, semi-consolidated	5YR 2/2
265/49/DR37/B3	1394293	chain bag	03 Mar 04	mudstone, very fine to fine quartz and mica, with lithic and coaly fragments, micaceous layers, heavily burrowed, loosely consolidated	5YR 2/2
265/49/DR37/C1	1394294	pipe	03 Mar 04	nannofossil ooze	5Y 6/1
265/50/DR38	**1394295**				
265/50/DR38/A1	1394296	chain bag	03 Mar 04	mudstone, silty, abundant fine to medium-grained quartz, with mica, massive, loosely consolidated	10YR 4/2
265/50/DR38/B1	1394298	chain bag	03 Mar 04	mudstone, silty, fine to medium-grained quartz, mica and organic frags, bioturbated, moderately to well consolidated	N4
265/50/DR38/C1	1394301	chain bag	03 Mar 04	mudstone, silty, with fine to medium-grained quartz, mica and lithics, massive, bioturbated, moderately lithified	5Y 4/1
265/50/DR38/D1	1394304	pipe	03 Mar 04	nannofossil ooze	5Y 6/1

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/51/DR39	**1394305**				
265/51/DR39/A1	1394306	chain bag	03 Mar 04	sandstone, fine to medium-grained, subangular quartz and mica, moderately sorted, massive, moderately lithified	5Y 3/2
265/51/DR39/B1	1394307	chain bag	03 Mar 04	mudstone, silty, fine-grained mica and quartz, laminated, well consolidated	5YR 4/6
265/51/DR39/C1	1394309	chain bag	03 Mar 04	mudstone, silty, abundant very fine to fine-grained mica, quartz and lignitic frags, laminated, moderately consolidated	5YR 3/4
265/51/DR39/D1	1394310	chain bag	03 Mar 04	mudstone, silty, with minor very fine to fine-grained mica, laminated, massive, weathered, moderately to well consolidated	5YR 4/6
265/51/DR39/E1	1394312	chain bag	03 Mar 04	mudstone, with minor very fine-grained mica, soft, massive	5 YR 3/2
265/51/DR39/F1	1394313	chain bag	03 Mar 04	calcarenite, chalky, bioclastic, massive, well lithified, partially burrowed	
265/51/DR39/G1	1394315	chain bag	03 Mar 04	nannofossil ooze, plastic texture	5Y 7/2
265/51/DR39/H1	1394317	chain bag	03 Mar 04	nannofossil ooze, chalky, calcareous, plastic texture, massive	
265/51/DR39/I1	1394319	pipe	03 Mar 04	nannofossil ooze	5Y 8/2
265/52/DR40	**1394320**				
265/52/DR40/A1	1394321	chain bag	03 Mar 04	sandstone, quartz arenite, coarse grained feldspar with possible glauconite, mica-absent, iron stained, subangular to moderately well rounded quartz grains, moderately sorted in parts, highly indurated, high visual porosity	N6 – N7
265/52/DR40/B1	1394322	chain bag	03 Mar 04	shale/mudstone, carbonaceous, with very fine-grained mica, well lithified	5YR 2/2
265/52/DR40/C1	1394325	chain bag	03 Mar 04	sandstone, silty, with fine to very fine-grained quartz, mica, feldspar and lithic frags, dark shale intraclasts, moderately sorted, lithified	N3 – N4
265/52/DR40/D1	1394329	chain bag	03 Mar 04	mudstone, silty, with very fine to fine-grained mica, quartz and minor lignitic frags, micaceous layers, soft, well consolidated	N3 – N4
265/52/DR40/E1	1394332	pipe	03 Mar 04	nannofossil ooze, plastic texture	5Y 8/2
265/53/DR41	**1394333**				
265/53/DR41/A1	1394334	chain bag	03 Mar 04	siltstone to sandstone, very fine to fine-grained quartz with carbonate fragments, moderately sorted, finely layered, semi-consolidated	5Y 4/4
265/53/DR41/A2	1394336	chain bag	03 Mar 04	mudstone, silty, with very fine to fine-grained mica, quartz and possible glauconite, shell frags, massive, burrowed, semi-consolidated	5Y 5/2
265/53/DR41/B1	1394337	pipe	03 Mar 04	nannofossil ooze	5Y 6/1
265/54/DR42	**1394338**				
265/54/DR42/A1	1394339	chain bag	03 Mar 04	siltstone to sandstone, very fine-grained quartz, mica and feldspar, with medium to coarse lignitic fragments, minor cross-bedding, well sorted, finely layered, lithified	10YR 4/2

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265.*

Dredge and Sub-sample No.	GA No.	Dredge Sample Type	Date Acquired	Sample Description	Colour
265/54/DR42/B1	1394340	chain bag	03 Mar 04	mudstone, carbonaceous, with very fine-grained mica and minor lignitic frags, massive, moderately to well consolidated	5Y 2/2
265/54/DR42/B2	1394342	chain bag	03 Mar 04	mudstone, carbonaceous, with layers of very fine-grained mica and minor lignitic frags, massive, plastic texture, moderately to well consolidated	10YR 2/2
265/54/DR42/C1	1394345	chain bag	03 Mar 04	coaly shale, very fine to medium-grained mica, quartz and lignitic frags, well consolidated	N1
265/54/DR42/D1	1394346	pipe	03 Mar 04	nannofossil ooze	2.5Y 7/2
265/55/DR43	**1394347**				
265/55/DR43/A1	1394348	chain bag	04 Mar 04	mudstone, carbonaceous, silty and very fine to fine-grained quartz and mica, well rounded grains, bioturbated, moderately to well consolidated	N4
265/55/DR43/B1	1394352	chain bag	04 Mar 04	mudstone, carbonaceous, silty and very fine-grained quartz and mica layers, bioturbated, well consolidated	N4 – N5
265/55/DR43/B2	1394354	chain bag	04 Mar 04	mudstone, carbonaceous, silty and very fine-grained quartz, mica with lithic frags, bioturbation absent, finely layered, well consolidated	N4
265/55/DR43/B3	1394356	chain bag	04 Mar 04	mudstone, silty, cherty in parts, with minor very fine-grained mica and carbonaceous zones, well consolidated	N4
265/55/DR43/C1	1394357	pipe	04 Mar 04	nannofossil ooze, with forams and other coarse carbonaceous grains	5Y 7/2
265/56/DR44	**1394358**				
265/56/DR44/A1	1394359	chain bag	04 Mar 04	sandstone, muddy, oxidised bright red, medium to coarse-grained quartz, mica and minor feldspar, moderately sorted, subangular grains quartz grains, prominent iron staining, well bedded, well lithified	10YR 3/6
265/56/DR44/B1	1394360	chain bag	04 Mar 04	sandstone, fine to medium-grained quartz, subrounded grains, with minor mica and feldspar, occasional coarse-grained interbeds, friable, moderately lithified	5YR 6/1
265/56/DR44/C1	1394361	chain bag	04 Mar 04	sandstone, quartz arenite, medium-grained with minor mica and possible glauconite, sub-rounded quartz grains, moderately sorted, moderately lithified	10YR 5/4
265/56/DR44/D1	1394362	chain bag	04 Mar 04	mudstone, sandy, interbedded, very fine to medium-grained quartz, mica and carbonaceous fragments, micaceous layers, prominent bedding on cut suface (3 cm thick), moderately lithified	N4 – N5
265/56/DR44/E1	1394365	chain bag	04 Mar 04	mudstone/shale, fine-grained quartz and mica, micaceous layers, consolidated	2.5Y 3/1
265/56/DR44/F1	1394367	chain bag	04 Mar 04	mudstone with very fine to fine-grained mica, quartz and minor carbonaceous frags, micaceous layers, moderately consolidated	10YR 3/1
265/56/DR44/G1	1394370	chain bag	04 Mar 04	chalk, with minor medium to very fine-grained mica, massive, partly consolidated	5Y 8/1
265/56/DR44/H1	1394371	pipe	04 Mar 04	nannofossil ooze	2.5Y 7/2
265/56/DR44/I1	1394372	chain bag	04 Mar 04	sandstone, silty, fine to very fine-grained quartz, mica and minor feldspar, micaceous layers, possile preserved ripples, lithified	2.5Y 7/2
265/56/DR44/J1	1394373	chain bag	04 Mar 04	sandstone, cherty, non-calcareous, fine to very fine-grained quartz and feldspar, nodules, amorphous texture, well lithified	5Y 5/4

Table 4.1 (Continued) *Summary rock descriptions for the dredge hauls on Survey 265*

265/57/DR45	**1394374**				
265/57/DR45/A1	1394375	chain bag	04 Mar 04	granite, medium to coarse-grained, mostly equigranular texture, some alteration, partly covered with manganese crust	not recorded
265/57/DR45/B1	1394377	pipe	04 Mar 04	nannofossil ooze	5Y 6/1

Table 4.2 *Comparison of published age range data for spore-pollen species in southwest and central east Australia.*

FO = FIRST OCCURRENCE, LO = LAST OCCURRENCE.
ZONES IN PARENTHESES REPRESENT INCONSISTENT/SPORADIC OCCURRENCES.

FOSSIL SPECIES	PERTH BASIN		WEST		CENTRAL-EAST	
	FO	LO	FO	LO	FO	LO
Aequitriradites acusus	A. acusus	B. limbata	R. watherooensis	<C. striatus	R. watherooensis	< C. striatus
Aequitriradites hispidus	A. acusus	B. eneabbaensis	C. australiensis	F. wonthaggiensis	C. australiensis	F. wonthaggiensis
Aequitriradites sp. A	?No record	?No record	M. florida (C. cooksoniae)	R. watherooensis (C. australiensis)	M. florida (C. cooksoniae)	R. watherooensis (C. australiensis)
Antulsporites saevus	M. florida	R. watherooensis	C. torosa	M. florida (C. australiensis)	C. torosa	M. florida (C. australiensis)
Balmeiopsis limbata	B. limbata	<B. limbata	?No records	?No record	?No record	?No record
Balmeiopsis robusta	B. limbata	B. limbata	?No records	?No record	?No record	?No record
Biretisporites eneabbaensis	B. eneabbaensis	B. eneabbaensis	C. australiensis	F. wonthaggiensis	C. australiensis	C. hughesii
Callialasporites spp. ACME			C. turbatus	M. florida	C. turbatus	M. florida
Ceratosporites equalis	B. eneabbaensis	<B. limbata	R. watherooensis (M. florida)	<C. striatus	R. watherooensis (M. florida)	<C. striatus
Clavatipollenites hughesii	No record (B. limbata #)	No record (?C paradoxa)	C. striatus	<C. striatus	C. striatus	<C. striatus
Concavissimisporites crassatus	B. limbata	B. limbata	?No record	?No record	?No record	?No record
Concavissimisporites penolaensis	?Not recorded	?Not recorded	?	?	F. wonthaggiensis	F. wonthaggiensis
Concavissimisporites Variverucatus	R. watherooensis	B. eneabbaensis	M. florida (C. cooksoniae)	C. australiensis (F. wonthaggiensis)	M. florida (C. cooksoniae)	C. australiensis (F. wonthaggiensis)
Contignisporites cooksoniae	>M. florida	B. limbata	C. cooksoniae (C. turbatus)	C. hughesii (C. striatus)	C. cooksoniae (C. turbatus)	C. hughesii (C. striatus)
Contignisporites multimuratus	R. watherooensis	B. eneabbaensis	?	?	?	?
Cooksonites variabilis	B. limbata	B. limbata	?	?	C. australiensis	C. striatus
Crybelosporites striatus	?No record	?No record	C. striatus	<C. striatus	C. striatus	<C. striatus
Cyclosporites hughesii	?No record	?No record	C. australiensis	< C. striatus	C. hughesii (C. australiensis)	<C. striatus
Cyclosporites stylosus	B. eneabbaensis	B. limbata	C. australiensis (R. watherooensis)	C. hughesii (C. striatus)	C. australiensis (R. watherooensis)	C. hughesii (C. striatus)
Densoisporites velatus	?M. florida	<B. limbata	?	?	C. australiensis	C. striatus
Dictyotosporites complex	>M. florida	B. limbata	D. complex	<C. striatus	D. complex	<C. striatus

Table 4.2 (Continued) *Comparison of published age range data for spore-pollen species in southwest and central east Australia.*

FOSSIL SPECIES	PERTH BASIN		WEST		CENTRAL-EAST	
	FO	LO	FO	LO	FO	LO
Dictyotosporites filosus	?No record	?No record	?	?	*F. wonthaggiensis*	*C. striatus*
Dictyotosporites speciosus	*B. eneabbaensis*	*B. limbata*	?	?	*F. wonthaggiensis*	*<C. striatus*
Foraminisporis asymmetricus	?No record	?No record	*C. hughesii*	*<C. hughesii*	*C. hughesii*	*<C. hughesii*
Foraminisporis wonthaggiensis	?No record	?No record	*C. australiensis*	*<C. striatus*	*F. wonthaggiensis*	*<C. striatus*
Foveosporites canalis	*B. limbata*	*B. limbata*	?	?	*C. australiensis*	*C.hughesii*
Gleicheniidites spp.	*>M. florida*	*<C. striatus*	*C. torosa*	*<C. striatus*	*C. torosa*	*<C. striatus*
Januasporites spinulosus	*B. eneabbaensis*	*B. limbata*	?	?	*F. wonthaggiensis*	*C. hughesii*
Laevigatosporites belfordii	*B. eneabbaensis*	*B. limbata*	?	?	?	?
Matonisporites crassiangulatus = M. sp. A of Helby et al. 1987	*?M. florida*	*B. limbata*	*C. cooksoniae*	*M. florida*	*C. cooksoniae*	*M. florida*
Microcachrydites antarcticus	*M. florida*	*<B. limbata*	*M. florida*	*<C. striatus*	*M. florida*	*<C. striatus*
M. antarcticus ACME	*R. watherooensis*	*B. limbata*	*R. watherooensis*	*C. striatus*	*R. watherooensis*	*C. striatus*
Murospora florida	*M. florida*	*B. limbata*	*M. florida*	*<C. striatus*	*M. florida*	*<C. striatus*
Nevesisporites dailyii	*B. eneabbaensis*	*<B. limbata*	?	?	*?C. australiensis*	*C. hughesii?*
Nevesisporites harleyi	*B. eneabbaensis*	*B. eneabbaensis*	?Not recorded	?Not recorded	?Not recorded	?Not recorded
Nevesisporites undulatus	*B. eneabbaensis*	*B. eneabbaensis*	?Not recorded	?Not recorded	?Not recorded	?Not recorded
Pilosisporites ingramii	*B. eneabbaensis*	*B. eneabbaensis*	?No record	?No record	?No record	?No record
Pilosisporites notensis	?No record	?No record	*C. australiensis*	*<C. striatus*	*C. hughesii*	*<C. striatus*
Polypodiidites horridus	*B. eneabbaensis*	*B. eneabbaensis*	?No record	?No record	?No record	?No record
Reticuloidaesporites arcus	*B. eneabbaensis*	*B. limbata*	?	?	?	?
Retitriletes circolumenus	*<M. florida*	*B. limbata*	*D. complex*	*<C. striatus*	*D. complex*	*C. striatus*
Retitriletes facetus	*B. eneabbaensis*	*B. limbata*	*M. florida*	*<C. striatus*	*M. florida*	*<C. striatus*
Retitriletes nodosus	*B. eneabbaensis*	*B. limbata*	?	?	*C. australiensis*	*<C. striatus*
Retitriletes watherooensis	*R. watherooensis*	*B. limbata*	*R. watherooensis*	*C. australiensis (C. hughesii)*	*R. watherooensis*	*C. australiensis (C. hughesii)*
Ruffordiaspora australiensis	*B. eneabbaensis*	*B. limbata*	*C. australiensis*	*<C. striatus*	*C. australiensis*	*C. striatus*
Ruffordiaspora hughesii	*B. eneabbaensis*	*B. limbata*	*C. australiensis*	*<?C. striatus*	*C. australiensis*	*<?C. striatus*
Ruffordiaspora ludbrookiae	*B. eneabbaensis*	*B. limbata*	*C. australiensis*	*<C. striatus?*	*C. australiensis*	*<?C. striatus*
Trilobosporites trioreticulosus	?No record	?No record	*C. striatus (C. hughesii)*	*<C. striatus*	*C. striatus (C. hughesii)*	*<C. striatus*

Table 4.3 *Summary of palynological analyses for samples from Survey 265.*

DREDGE NO. [1]	SAMPLE NO.	LAB SAMPLE NO. [2]	AGE	BIOSTRATIGRAPHIC ZONE	DEPOSITIONAL ENVIRONMENT
DENMARK SUB-BASIN					
01/DR01	A1.1	1393937	Valanginian-?Early Aptian	*Balmeiopsis limbata*	?marginal marine
05/DR05	C1.1	1393958	Middle Miocene-Holocene	-	outer neritic-oceanic
07/DR07	A2.1	1415929	L. Santonian-E. Campanian (mixed with Early Eocene)	*Nelsoniella aceras*	inner /?middle shelf
	C1.1	1393976	Early Campanian	*Xenikoon australis*	inner /?middle shelf
	D1.1	1393979	Early Campanian	*Xenikoon australis*	inner /?middle shelf
09/DR09	A1.2	1393988	Late Maastrichtian	*Manumiella druggii*	inner-middle shelf
	A1.3	1393989	Late Maastrichtian	*Manumiella druggii*	inner-middle shelf
	B1.3	1393993	Early Campanian	*Xenikoon australis*	inner shelf
BREMER SUB-BASIN					
13/DR13	D1.1	1415934	indeterminate	-	?fluvial
	F1.1	1415935	indeterminate	-	?marine
15/DR15	A1.1	1415936	Holocene	-	estuary
	A3.1	1415937	indeterminate	-	?marine
	B1.2	1394032	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C1.2	1394036	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C1.3	1394037	Valanginian-?Early Aptian	*Balmeiopsis limbata*	fresh-?brackish lake
16/DR16	A2.1	1408074	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	A2.2	1408075	indeterminate	-	inner neritic
	B1.1	1408076	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	C1.1	1408077	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
17/DR17	A1.2	1394053	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	B1.3	1394057	Valanginian-?Early Aptian	*Balmeiopsis limbata*	brackish lake
	C1.3	1394061	Valanginian-?Early Aptian	*Balmeiopsis limbata*	brackish lake
	D1.1	1394063	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
18/DR18	B1.1	1394072	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	C1.1	1394077	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	D1.1	1394081	Valanginian-?Early Aptian	*Balmeiopsis limbata*	brackish lake
19/DR19	A1.1	1408080	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	indeterminate
	C1.1	1394093	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake

20/DR20	B1.1	1408082	indeterminate	-	?fluvial
	C1.1	1394101	Callovian-Kimmeridgian	*Murospora florida*	fresh-brackish lake
21/DR21	C1.1	1394109	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C2.2	1394113	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C3.1	1408085	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C4.1	1394117	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	D1.1	1415942	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	E1.1	1394120	indeterminate	-	-
22/DR22	C1.1	1408088	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	?fluvial
	D1.1	1408089	indeterminate	-	open marine
23/DR23	A1.1	1415943	Santonian (?Early Santonian)	*Odontochitina porifera-* *Isabelidinium cretaceum*	inner shelf
	B1.1	1408090	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	brackish lake
	C1.1	1408091	Late Aptian	*Diconodinium davidii*	inner shelf
	D1.1	1408092	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	E1.1	1408093	indeterminate	-	?marginal marine
	F1.1	1408094	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	?fluvial
	G1.1	1408138	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	?marginal marine
	G1.2	1408095	Late Aptian	*Diconodinium davidii*	inner shelf
24/DR24	B1.1	1408097	indeterminate	-	?marine
	C1.1	1394144	Cenomanian	*D. multispinum*	inner shelf
	D1.1	1415944	Late Aptian	*Diconodinium davidii*	inner/?middle shelf
	E1.2	1394148	Santonian (?Early Santonian) and L. Paleocene-E. Eocene	*Odontochitina porifera-* *Isabelidinium cretaceum*	inner/?middle shelf
	G1.2	1394152	Late Aptian	*Diconodinium davidii*	inner shelf
25/DR25	A1.1	1415946	Latest Turonian- basal Santonian	*Conosphaeridium* *striatoconus*	inner shelf
	B1.1	1394160	Latest Turonian- basal Santonian	*Conosphaeridium* *striatoconus*	inner shelf
	C1.1	1408098	Latest Turonian- basal Santonian	*Conosphaeridium* *striatoconus*	inner shelf
	D1.1	1408099	indeterminate	-	inner neritic
27/DR27	A1.1	1408100	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh brackish lake
	A3.1	1408102	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	A4.1	1394176	No older than Tithonian	*Retitriletes watherooensis*?	?freshwater lake
	B1.1	1394178	Late Hauterivian- Early Barremian	upper *Aprobolocysta alata-* lower *Batioladinium jaegeri*	marginal marine- innner shelf (restricted)
	C1.1	1394180	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	freshwater lake
	C2.2	1394182	Tithonian	*Retitriletes watherooensis*	?freshwater lake
	D1.2	1416190	Santonian (?Early Santonian) + L. Paleocene-E. Eocene	*Odontochitina porifera-* *Isabelidinium cretaceum*	inner/?middle shelf

28/DR28	B1.3	1394189	Callovian-Kimmeridgian	*Murospora florida*	fresh-brackish lake
	C1.1	1394191	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	F1.2	1415947	latest Maastrichtian- E. Danian + E.-M. Eocene	*Manumiella druggii-* *Trithyrodinium evittii.*	inner-middle shelf
29/DR29	A1.1	1408104	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	?fluvial
30/DR30	B1.1	1408107	indeterminate	-	?fluvial
	C1.1	1394211	indeterminate	-	-
32/DR32	A3.1	1408110	indeterminate	-	fresh-?brackish lake
	A4.1	1408111	indeterminate	-	?fluvial
	B1.1	1408113	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
33/DR33	B1.1	1394232	indeterminate	indeterminate	-
	B2.1	1394234	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
34/DR34	E1.1	1408117	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	F1.1	1394243	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
48/DR36	A1.1	1408118	latest Maastrichtian- Early Danian + Early Eocene	*Manumiella druggii-* *Trithyrodinium evittii*	inner-middle shelf
	B1.1	1408120	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	C1.1	1415952	latest Maastrichtian -Early Danian + Early-Middle Eocene	*Manumiella druggii-* *Trithyrodinium evittii*	inner-middle shelf
	D1.2	1394282	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	D2.2	1394285	earliest Late Albian	Uppermost *Endoceratium* *ludbrookiae*	inner shelf
49/DR37	B1.1	1394291	Berriasian- basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
49/DR37	B2.1	1408123	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
50/DR38	A1.1	1394297	Albian	*Muderongia tetracantha-* *Endoceratium ludbrookiae*	inner shelf
	B1.1	1394299	latest Aptian- early Late Albian	upper *Diconodinium davidii-* *Endoceratium ludbrookiae*	inner shelf
	C1.1	1394302	earliest Albian	lower *Muderongia* *tetracantha*	inner/?middle shelf
51/DR39	A1.1	1415953	early Early Aptian	Lowermost *Odontochitina* *operculata*	marginal marine- innner shelf (restricted)
	B1.1	1394308	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	C1.1	1408124	mid-Valanginian and ?Early Aptian	*Gagiella mutabilis* and *Batioladinium jaegeri*	fresh-brackish lake
	D1.1	1394311	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	E1.1	1408125	Valanginian- ?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake

52/DR40	A1.1	1408126	?Early Jurassic	no older than *C. torosa* Zone	?fluvial
	B1.2	1394324	Tithonian	*Retitriletes watherooensis*	?freshwater lake
	C1.1	1394326	?Early Jurassic	no older than *C. turbatus*	?fluvial
	D1.2	1394331	Tithonian	*Retitriletes watherooensis*	?freshwater lake
54/DR42	B1.1	1394341	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	brackish lake
	B2.1	1394343	Berriasian-basal Valanginian	*Biretisporites eneabbaensis*	fresh-brackish lake
	C1.1	1408132	Callovian-Kimmeridgian	*Murospora florida*	fresh-brackish lake
55/DR43	A1.2	1394350	Early Santonian	lower *Odontochitina porifera*	inner/?middle shelf
	B2.2	1408133	Early-Middle Albian - Early Campanian	*Canninginopsis denticulata-Xenikoon australis*	inner shelf
56/DR44	C1.1	1408134	Indeterminate	-	?fluvial
	D1.1	1394363	Indeterminate	-	-
	E1.1	1394366	Callovian-Kimmeridgian	*Murospora florida*	?fluvial
	F1.1	1394368	Valanginian-?Early Aptian	*Balmeiopsis limbata*	fresh-brackish lake
	I1.1	1415954	Indeterminate	-	-

[1] All dredge numbers should include the prefix 265 as a designation of the Survey number.
[2] A unique number is assigned to all samples processed in laboratories of Geoscience Australia.

Table 4.4 *Survey 265 samples preserving Cyclosporites hughesii and Distyotosporites.*

SAMPLE	ZONE	*Balmeiopsis*	*Ruffordiaspora*	*C. hughesii*	*D. speciosus*
265/15/DR15/C1.3	*B. limbata*	•	•		•
265/17/DR17/B1.3	*B. limbata*	•	•		•
265/17/DR17/C1.3	*B. limbata*	•	•		•
265/18/DR18/D1.1	*B. limbata*	•	•		•
265/23/DR23/G1.1	*B. limbata*		•	•	•
265/34/DR34/F1.1	*B. limbata*	•		•	•
265/48/DR36/B1.1	*B. limbata*	•	•	•	•
265/48/DR36/D1.2	*B. limbata*	•	•		•
265/51/DR39/B1.1	*B. limbata*	•		•	•
265/51/DR39/C1.1	*G. mutabilis and B. jaegeri*	•		•	
265/51/DR39/D1.1	*B. limbata*	•		•	
265/51/DR39/E1.1	*B. limbata*			•	•
265/56/DR44/F1.1	*B. limbata*	•			
265/16/DR16/B1.1	*B. enneabbaensis*		•		•
265/16/DR16/C1.1	*B. enneabbaensis*		•		•
265/17/DR17/A1.2	*B. eneabbaensis*		•		•
265/18/DR18/C1.1	*B. eneabbaensis*		•		•
265/21/DR21/C1.1	*B. eneabbaensis*				•
265/21/DR21/C2.2	*B. eneabbaensis*		•		•
265/21/DR21/C3.1	*B. eneabbaensis*		•		cf
265/21/DR21/C4.1	*B. eneabbaensis*				•
265/21/DR21/D1.1	*B. eneabbaensis*		•		cf
265/23/DR23/D1.1	*B. eneabbaensis*				•
265/32/DR32/B1.1	*B. eneabbaensis*				•

Table 4.5 *Survey 265 samples preserving foraminiferal trochospiral liners and spore-pollen..*

DREDGE SAMPLE NO.	ZONE/AGE	ABUNDANCE
265/01/DR01/A1.1	*B. limbata*	Frequent
265/07/DR07/A2.1	*N. aceras*	Trace
265/07/DR07/C1.1	*X. australis*	Abundant
265/09/DR09/A1.2	*M. druggii*	Frequent
265/15/DR15/A1.1	Holocene	Frequent
265/16/DR16/A2.2	Indeterminate	Frequent
265/22/DR22/D1.1	Indeterminate	Frequent
265/23/DR23/A1.1	*O. porifera-I. cretaceum*	Trace
265/23/DR23/G1.2	*D. davidii*	Trace
265/25/DR25/D1.1	Indeterminate	Trace
265/27/DR27/A1.1	*B. eneabbaensis*	Trace
265/27/DR27/D1.2	*O. porifera-I. cretaceum* (plus Late Paleocene-Early Eocene)	Frequent
265/29/DR29/A1.1	*B. eneabbaensis?*	Trace
265/51/DR39/C1.1	*G. mutabilis and B. jaegeri*	Trace

Table 4.6 *Cenozoic to Late Cretaceous marine samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-Pollen		Maximum	Minimum
DENMARK SUB-BASIN										
265/05/DR05/C1.1	1393958	low	high	outer neritic-oceanic	Middle Miocene-Holocene	-	-	med	Mid. Miocene	Holocene
265/28/DR28/F1.2	1415947	low	high	inner-middle shelf	latest Maastrichtian-Early Danian (mixed with Early-Middle Eocene)	Late *M. druggii*-*T. evittii*	-	high	Late *M. druggii*	T. evittii
265/48/DR36/A1.1	1408118	low	high	inner-middle shelf	latest Maastrichtian-Early Danian (mixed with Early Eocene)	Late *M. druggii*-*T. evittii*	-	high	Late *M. druggii*	T. evittii
265/48/DR36/C1.1	1415952	low	high	inner-middle shelf	latest Maastrichtian-Early Danian (mixed with Early-Middle Eocene)	Late *M. druggii*-*T. evitii*	-	high	Late *M. druggii*	T. evittii
265/09/DR09/A1.2	1393988	low	high	inner-middle shelf	Late Maastrichtian	*M. druggii*	-	high	*M. druggii*	*M. druggii*
265/09/DR09/A1.3	1393989	medium	high	inner-middle shelf	Late Maastrichtian	*M. druggii*	-	high	*M. druggii*	*M. druggii*
265/07/DR07/C1.1	1393976	high	high	inner/?middle shelf	Early Campanian	*X. australis*	*N. senectus*	high	*X. australis*	*X. australis*
265/07/DR07/D1.1	1393979	medium	high	inner/?middle shelf	Early Campanian	*X. australis*	-	high	*X. australis*	*X. australis*
265/09/DR09/B1.3	1393993	medium	high	inner shelf	Early Campanian	*X. australis*	-	high	*X. australis*	*X. australis*
265/07/DR07/A2.1	1415929	high	high	inner/?middle shelf	Late Santonian-Early Campanian	*N. aceras*	Lower *N. senectus*	high	*N. aceras*	*N. aceras*

Table 4.6 (Continued) *Cenozoic to Late Cretaceous marine samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-Pollen		Maximum	Minimum
BREMER SUB-BASIN										
265/15/DR15/A1.1	1415936	very low	high	estuary	Holocene	-	-	med	Pliocene	Pliocene
265/23/DR23/A1.1	1415943	low	high	inner shelf	Santonian (?E. Santonian)	*O. porifera- I. cretaceum*	-	high	*O. porifera*	*I. cretaceum*
265/24/DR24/E1.2	1394148	low	high	inner/?middle shelf	Santonian (?E. Santonian) mixed with latest Paleocene-Early Eocene	*O. porifera- I. cretaceum*	-	high	*O. porifera*	*I. cretaceum*
265/27/DR27/D1.2	1416190	low	high	inner/?middle shelf	Santonian (?E. Santonian) mixed with latest Paleocene-Early Eocene	*O. porifera- I. cretaceum*	N. senectus	low	*O. porifera*	*I. cretaceum*
265/55/DR43/A1.2	1394350	low	low	inner/?middle shelf	Early Santonian	lower *O. porifera*	-	high	*O. porifera*	*O. porifera*
265/25/DR25/A1.1	1415946	high	medium	inner shelf	Turonian-basal Santonian	*C. striatoconum*	*T. apoxyexinus*	high	*C. striatoconum*	*T. apoxyexinus*
265/25/DR25/B1.1	1394160	high	high	inner shelf	Turonian-basal Santonian	*C. striatoconum*	-	high	*C. striatoconum*	*C. striatoconum*
265/25/DR25/C1.1	1408098	high	high	inner shelf	Turonian-basal Santonian	*C. striatoconum*	-	high	*C. striatoconum*	*C. striatoconum*

Table 4.7 *Cenomanian to Late Hauterivian/Early Barremian marine samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	**Spore-Pollen**		**Maximum**	**Minimum**
265/24/DR24/C1.1	1394144	low	low	inner shelf	Cenomanian	*D. multispinum*	*?B. limbata*	Med	*D. multispinum*	*D. multispinum*
265/48/DR36/D2.2	1394285	low	medium	inner shelf	earliest Late Albian	*Uppermost E. ludbrookiae*	-	High	*P. ludbrookiae*	*H. uniforma*
265/50/DR38/A1.1	1394297	medium	medium	inner shelf	Albian	*M. tetracantha-E.ludbrookiae*	B. limbata	Med	*M. tetracantha*	*E. ludbrookiae*
265/55/DR43/B2.2	1408133	low	low	inner shelf	Early-Middle Albian-Early Campanian	*C. denticulata-* X. *australis*	-	High	*C. denticulata*	*X. australis*
265/50/DR38/B1.1	1394299	low	low	inner shelf	latest Aptian-early Late Albian	Upper *D. davidii-E. ludbrookiae*?	-	Med	Upper *D. davidii*	E. ludbrookiae
265/50/DR38/C1.1	1394302	low	low	Inner/ ?middle shelf	earliest Albian	Lower *M. tetracantha*	-	High	M. tetracantha	*M. tetracantha*
265/23/DR23/C1.1	1408091	low	medium	inner shelf	Late Aptian	*D. davidii*	-	Med	*D. davidii*	*D. davidii*
265/23/DR23/G1.2	1408095	Low	low	inner shelf	Late Aptian	*D. davidii*	-	High	*D. davidii*	*D. davidii*
265/24/DR24/D1.1	1415944	high	medium	Inner/ ?middle shelf	Late Aptian	*D. davidii*	*B. limbata*	med	*D. davidii*	*D. davidii*
265/24/DR24/G1.2	1394152	low	low	inner shelf	Late Aptian	*D. davidii*	-	low	*B. limbata*	*D. davidii*
265/51/DR39/A1.1	1415953	medium	medium	Marginal marine-inner shelf (restricted)	early Early Aptian	*O. operculata*	*?B. limbata*	high	*O. operculata*	*O. operculata*
265/27/DR27/B1.1	1394178	high	high	Marginal marine-inner shelf (restricted)	Late Hauterivian/ Early Barremian	upper *A. alata-* lower B. jaegeri	-	high	upper *A. alata*	lower *B. jaegeri*

Table 4.8 *Valanginian to ?Early Aptian possible marginal marine and non-marine samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-Pollen		Maximum	Minimum
DENMARK SUB-BASIN										
265/01/DR01/A1.1	1393937	low	low	?marginal marine	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. limbata*	*B. limbata*
BREMER SUB-BASIN										
265/15/DR15/C1.3	1394037	low	med	fresh-brackish ?lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*B. eneabbaensis*	*B. limbata*
265/17/DR17/B1.3	1394057	high	high	brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*B. eneabbaensis*	*B. limbata*
265/17/DR17/C1.3	1394061	med	high	brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. eneabbaensis*	*B. limbata*
265/18/DR18/D1.1	1394081	high	high	brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*B. eneabbaensis*	*B. limbata*
265/23/DR23/B1.1	1408090	high	med	brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. eneabbaensis*	*B. limbata*
265/23/DR23/G1.1	1408138	high	med	marginal marine?	Valanginian-?Early Aptian	*K. scrutillinum -B. jaegeri*	*B. limbata*	low	*B. eneabbaensis*	*B. limbata*
265/27/DR27/A3.1	1408102	low	low	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. limbata*	*B. limbata*
265/28/DR28/C1.1	1394191	low	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	high	*B. limbata*	*B. limbata*
265/34/DR34/F1.1	1394243	low	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	high	*B. limbata*	*B. limbata*
265/48/DR36/B1.1	1408120	high	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. limbata*	*B. limbata*
265/48/DR36/D1.2	1394282	med	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. limbata*	*B. limbata*
265/49/DR37/B2.1	1408123	high	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	high	*B. limbata*	*B. limbata*

Table 4.8 (Continued) *Valanginian to ?Early Aptian possible marginal marine and non-marine samples from Survey 265*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-pollen		Maximum	Minimum
265/51/DR39/B1.1	1394308	low	low	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	med	*B. limbata*	*B. limbata*
265/51/DR39/C1.1	1408124	med	low	fresh-brackish lake	Middle Valanginian and Early Barremian	*G. mutabilis and B. jaegeri*	*B. limbata*	high	*G. mutabilis/A. alata*	*B. jaegeri*
265/51/DR39/D1.1	1394311	low	low	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*B. eneabbaensis*	*B. limbata*
265/51/DR39/E1.1	1408125	med	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*B. eneabbaensis*	*C. hughesii*
265/56/DR44/F1.1	1394368	low	med	fresh-brackish lake	Valanginian-?Early Aptian	-	*B. limbata*	low	*R. watherooensis*	*B. limbata*

Table 4.9 *Berriasian to basal Valanginian samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	**Spore-Pollen**		**Maximum**	**Minimum**
265/15/DR15/B1.2	1394032	high	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. limbata*
265/15/DR15/C1.2	1394036	med	high	fresh-brackish lake	Berriasian-basal Valanginian	*F. tumida*-G. *mutabilis*	*B. eneabbaensis*	high	*B. eneabbaensis*	*B. eneabbaensis*
265/16/DR16/A2.1	1408074	low	med	brackish lake	Berriasian-basal Valanginian	*F. tumida*-G. *mutabilis*	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/16/DR16/B1.1	1408076	high	high	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	high	*B. eneabbaensis*	*B. eneabbaensis*
265/16DR/16/C1.1	1408077	med	med	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/17/DR17/A1.2	1394053	high	high	brackish lake	Berriasian-basal Valanginian	*F. tumida*-G. *mutabilis*	*B. eneabbaensis*	high	*F. tumidas*	*G. mutabilis*
265/17/DR17/D1.1	1394063	low	low	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*B. eneabbaensis*	*B. eneabbaensis*
265/18/DR18/B1.1	1394072	low	med	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/18/DR18/C1.1	1394077	med	med	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	high	*B. eneabbaensis*	*B. eneabbaensis*
265/19/DR19/A1.1	1408080	low	low	indeterminate	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/19/DR19/C1.1	1394093	high	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*M. florida*	*B. limbata*
265/21/DR21/C1.1	1394109	low	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/21/DR21/C2.2	1394113	high	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/21/DR21/C3.1	1408085	med	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	high	*B. eneabbaensis*	*B. eneabbaensis*
265/21/DR21/C4.1	1394117	low	low	?fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*M. florida*	*B. limbata*

Table 4.9 (Continued) *Berriasian to basal Valanginian samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-Pollen		Maximum	Minimum
265/21/DR21/D1.1	1415942	low	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. limbata*
265/22/DR22/C1.1	1408088	low	low	?fluvial	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*B. eneabbaensis*	*B. limbata*
265/23/DR23/D1.1	1408092	high	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*M. florida*	*B. eneabbaensis*
265/23/DR23/F1.1	1408094	med	low	?fluvial	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*M. florida*	*B. limbata*
265/27/DR27/A1.1	1408100	low	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/27/DR27/C1.1	1394180	med	med	freshwater lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/29/DR29/A1.1	1408104	trace	low	?fluvial	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*?B. eneabbaensis*	*?B. eneabbaensis*
265/32/DR32/B1.1	1408113	low	low	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/33/DR33/B2.1	1394234	low	med	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	med	*B. eneabbaensis*	*B. eneabbaensis*
265/34/DR34/E1.1	1408117	med	low	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/49/DR37/B1.1	1394291	high	high	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. limbata*
265/54/DR42/B1.1	1394341	high	med	brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/54/DR42/B2.1	1394343	low	low	fresh-brackish lake	Berriasian-basal Valanginian	-	*B. eneabbaensis*	low	*R. watherooensis*	*B. limbata*

Table 4.10 *Early Jurassic to Tithonian samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	**Spore-Pollen**		**Maximum**	**Minimum**
265/27/DR27/A4.1	1394176	low	med	?freshwater lake	Tithonian	-	*R. watherooensis*	low	*R. watherooensis*	*B. limbata*
265/27/DR27/C2.2	1394182	low	low	?freshwater lake	Tithonian	-	*R. watherooensis*	low	*R. watherooensis*	*B. eneabbaensis*
265/52/DR40/B1.2	1394324	high	med	?freshwater lake	Tithonian	-	*R. watherooensis*	high	*R. watherooensis*	*R. watherooensis*
265/52/DR40/D1.2	1394331	med	low	?freshwater lake	Tithonian	-	*R. watherooensis*	high	*R. watherooensis*	*R. watherooensis*
265/20/DR20/C1.1	1394101	high	med	fresh-brackish lake	Callovian-Kimmeridgian	-	*M. florida*	med	*M. florida*	*M. florida*
265/28/DR28/B1.3	1394189	med	low	fresh-brackish lake	Callovian-Kimmeridgian	-	*M. florida*	low	*M. florida*	*M. florida*
265/54/DR42/C1.1	1408132	low	low	fresh-brackish lake	Callovian-Kimmeridgian	-	*M. florida*	low	*M. florida*	*R. watherooensis*
265/56/DR44/E1.1	1394366	low	low	?fluvial	Callovian-Kimmeridgian		*M. florida*	low	*M. florida*	*R. watherooensis*
265/52/DR40/C1.1	1394326	low	low	?fluvial	Indeterminate	-	-	-	*C. turbatus*	-
265/52/DR40/A1.1	1408126	low	low	?fluvial	Indeterminate		-	-	*C. torosa*	-

Table 4.11 *Indeterminate samples from Survey 265.*

DREDGE NO.	GA LAB NO.	YIELD	DIVERSITY	DEPOSITIONAL ENVIRONMENT	GEOLOGIC AGE	ZONE		CONF RATE	AGE LIMITS	
						Dinoflagellate	Spore-Pollen		Maximum	Minimum
265/13/DR13F/1.1	1415935	trace	-	?marine	indeterminate	-	-	n/a	*A. distocarinatus*	Upper *L. balmei*
265/15/DR15/A3.1	1415937	trace	-	?marine	indeterminate	-	-	n/a	*M. florida*	Late Early Cretaceous
265/16/DR16/A2.2	1408075	low	low	inner neritic	indeterminate	-	-	n/a	*?B. eneabbaensis*	?Aptian
265/22/DR22/D1.1	1408089	-	-	open marine	indeterminate	-	-	n/a	Late Cretaceous	Oligo-Miocene
265/23/DR23/E1.1	1408093	med	low	?marginal marine	indeterminate	-	-	n/a	*M. florida*	Paleocene
265/24/DR24/B1.1	1408097	trace	-	?marine	indeterminate	-	-	n/a	*Muderongia* Superzone	*Heterosphaeridium* Superzone
265/25/DR25/D1.1	1408099	low	low	inner neritic	indeterminate	-	-	n/a	*Muderongia* Superzone	*Heterosphaeridium* Superzone
265/33/DR33/B1.1	1394232	trace	-	-	indeterminate	-	-	n/a	-	-
265/13/DR13/D1.1	1415934	trace	-	?fluvial	indeterminate	-	-	n/a	-	-
265/20/DR20/B1.1	1408082	trace	-	?fluvial	indeterminate	-	-	n/a	-	-
265/21/DR21/E1.1	1394120	trace	-	-	indeterminate	-	-	n/a	-	-
265/30/DR30/B1.1	1408107	trace	-	?fluvial	indeterminate	-	-	n/a	-	-
265/30/DR30/C1.1	1394211	-	-	-	indeterminate	-	-	n/a	-	-
265/32/DR32/A3.1	1408110	low	low	?fresh-brackish lake	indeterminate	-	-	n/a	*M. florida*	-
265/32/DR32/A4.1	1408111	trace	-	?fluvial	indeterminate	-	-	n/a	*E. Jurassic-Triassic*	*Early Cretaceous*
265/56/DR44/C1.1	1408134	trace	-	?fluvial	indeterminate	-	-	n/a	-	-
265/56/DR44/D1.1	1394363	trace	-	-	indeterminate	-	-	n/a	-	-
265/56/DR44/I1.1	1415954	trace	-	-	indeterminate	-	-	n/a	-	-

Table 4.12 *Vitrinite reflectance and maceral abundances for Survey 265 dredge samples.*

Dredge	Age	Rv[1]	Maceral Group			Liptinite Maceral						Weath[2]	Corr[3]
		%	% Vitrinite	% Inertinite	% Liptinite	% Sporinite	% Cutinite	% Resinite	% Suberinite	% Liptodetrinite	% Lamalginite		
265/09/DR09/A1.3	Late Maastrichtian	0.39	26.3	26.3	47.4	33.3	0.0	0.0	0.0	33.3	33.3	1	1
265/09/DR09/B1.3	Early Campanian	0.41	16.1	64.5	19.4	0.0	0.0	0.0	0.0	50.0	50.0	1	1
265/15/DR15/B1.2	Berriasian-basal Valanginian	0.36 (0.35)	51.7	8.6	39.7	43.5	6.5	6.5	0.0	21.7	21.7	1	1
265/15/DR15/C1.2	Berriasian-basal Valanginian	0.31	16.7	2.1	81.3	51.3	5.1	0.0	0.0	23.1	20.5	3	1
265/16/DR16/B1.1	Berriasian-basal Valanginian	0.56	5.1	40.8	54.1	56.6	0.0	0.0	0.0	5.7	37.7	3	4
265/16/DR16/C1.1	Berriasian-basal Valanginian	0.52	9.8	19.6	70.6	55.6	8.3	0.0	0.0	8.3	27.8	2	2
265/17/DR17/A1.2	Berriasian-basal Valanginian	0.42	8.1	65.0	26.8	60.6	0.0	0.0	0.0	9.1	30.3	2	1
265/17/DR17/B1.3	Valanginian-?Early Aptian	0.50	3.2	51.9	44.8	72.5	4.3	4.3	0.0	4.3	14.5	4	2
265/17/DR17/C1.3	Valanginian-?Early Aptian	0.50	2.7	53.2	44.1	60.2	3.6	0.0	0.0	12.0	24.1	2	1
265/18/DR18/B1.1	Berriasian-basal Valanginian	0.41	57.8	17.3	24.9	23.3	7.0	0.0	0.0	23.3	46.5	1	1
265/18/DR18/C1.1	Berriasian-basal Valanginian	0.41	50.3	18.9	30.8	61.2	6.1	6.1	0.0	6.1	20.4	1	1
265/18/DR18/D1.1	Valanginian-?Early Aptian	0.43	58.3	24.3	17.5	55.6	8.3	0.0	0.0	8.3	27.8	1	1
265/19/DR19/A1.1	Berriasian-basal Valanginian	0.54	3.3	75.2	21.6	75.8	4.5	4.5	0.0	15.2	0.0	1	1

Table 4.12 (Continued) *Vitrinite reflectance and maceral abundances for Survey 265 dredge samples.*

Dredge	Age	Rv[1]	Maceral Group			Liptinite Maceral						Weath[2]	Corr[3]
		%	% Vitrinite	% Inertinite	% Liptinite	% Sporinite	% Cutinite	% Resinite	% Suberinite	% Liptodetrinite	% Lamalginite		
265/19/DR19/C1.1	Berriasian-basal Valanginian	0.37	12.7	63.3	24.1	52.6	15.8	0.0	0.0	15.8	15.8	1	1
265/20/DR20/C1.1	Callovian-Kimmeridgian	0.41	0.7	45.1	54.2	12.5	0.0	0.0	0.0	4.2	83.3	2	1
265/21/DR21/C1.1	Berriasian-basal Valanginian	0.43	1.5	72.8	25.7	56.6	0.0	0.0	0.0	5.7	37.7	3	2
265/21/DR21/C2.2	Berriasian-basal Valanginian	0.40	2.6	52.4	45.0	58.1	3.5	0.0	0.0	3.5	34.9	3	2
265/21/DR21/C3.1	Berriasian-basal Valanginian	0.53	3.4	51.2	45.4	60.2	2.3	0.0	0.0	22.6	15.0	2	3
265/21/DR21/C4.1	Berriasian-basal Valanginian	0.64 (0.70)	5.9	94.1	0.0							2	1
265/21/DR21/D1.1	Berriasian-basal Valanginian	0.41	26.3	26.3	47.4	33.3	0.0	0.0	0.0	33.3	33.3	4	4
265/21/DR21/E1.1	indeterminate	4 (4)	0.0	100.0	0.0							2	1
265/22/DR22/C1.1	Berriasian-basal Valanginian	0.47 (0.41) 0.94 (0.79[4])	70.2	28.1	1.7	25.0	25.0	25.0	0.0	25.0	0.0	1	1
265/23/DR23/B1.1	Valanginian-?Early Aptian	0.40	31.3	31.3	37.5	0.0	0.0	0.0	0.0	50.0	50.0	2	3
265/23/DR23/C1.1	Late Aptian	0.51	10.3	69.0	20.7	0.0	0.0	0.0	0.0	50.0	50.0	2	2
265/23/DR23/F1.1	Berriasian-basal Valanginian	0.36 (0.37)	54.5	9.1	36.4	68.8	25.0	2.5	0.0	3.8	0.0	3	2
265/23/DR23/G1.1	Valanginian-?Early Aptian	0.45 (0.32)	1.5	15.4	83.1	18.5	3.7	0.0	0.0	3.7	74.1	2	2
265/23/DR23/G1.2	Late Aptian	0.46	16.1	64.5	19.4	0.0	0.0	0.0	0.0	50.0	50.0	3	2
265/24/DR24/C1.1	Cenomanian	0.45	6.4	51.3	42.3	9.1	0.0	0.0	0.0	30.3	60.6	1	1
265/24/DR24/D1.1	Late Aptian	0.45	23.8	47.6	28.6	0.0	0.0	0.0	0.0	50.0	50.0	4	3

Table 4.12 (Continued) *Vitrinite reflectance and maceral abundances for Survey 265 dredge samples.*

		Rv[1]	Maceral Group			Liptinite Maceral							
Dredge	Age	%	% Vitrinite	% Inertinite	% Liptinite	% Sporinite	% Cutinite	% Resinite	% Suberinite	% Liptodetrinite	% Lamalginite	Weath[2]	Corr[3]
265/25/DR25/A1.1	Latest Turonian-basal Santonian	0.46	31.3	31.3	37.5	0.0	0.0	0.0	0.0	50.0	50.0	1	2
265/25/DR25/B1.1	Latest Turonian-basal Santonian	0.45	12.2	73.2	14.6	0.0	0.0	0.0	0.0	50.0	50.0	1	1
265/25/DR25/C1.1	Latest Turonian-basal Santonian		0.0	45.5	54.5	0.0	0.0	0.0	0.0	50.0	50.0	1	1
265/27/DR27/A3.1	Valanginian-?Early Aptian	0.48	21.7	65.2	13.0	25.0	0.0	25.0	0.0	25.0	25.0	2	2
265/27/DR27/A4.1	Tithonian	0.35 (0.45)	77.2	14.5	8.4	3.8	7.7	19.2	38.5	30.8	0.0	1	1
265/27/DR27/B1.1	Late Hauterivian/ Early Barremian	0.35 (0.35)	76.3	0.8	22.9	26.7	0.0	0.0	0.0	6.7	66.7	1	1
265/27/DR27/C1.1	Berriasian-basal Valanginian	0.44	5.1	51.0	43.9	46.5	7.0	0.0	0.0	23.3	23.3	2	2
265/27/DR27/C2.2	Tithonian	0.45	29.4	58.8	11.8	25.0	25.0	0.0	0.0	25.0	25.0	1	2
265/28DR28B1.3	Callovian-Kimmeridgian	0.39	18.5	37.0	44.4	25.0	25.0	0.0	0.0	25.0	25.0	3	3
265/30/DR30/C1.1	indeterminate	0.42	50.0	50.0	0.0							2	3
265/32/DR32/B1.1	Berriasian-basal Valanginian	0.37	12.2	24.4	63.4	76.9	0.0	0.0	0.0	11.5	11.5	4	3
265/33/DR33/B1.1	indeterminate	0.54	5.3	85.1	9.6	33.3	0.0	0.0	0.0	33.3	33.3	3	3
265/33/DR33/B2.1	Berriasian-basal Valanginian	0.42	5.0	59.4	35.6	55.6	8.3	0.0	0.0	8.3	27.8	2	3
265/34/DR34/E1.1	Berriasian-basal Valanginian	0.45	18.5	37.0	44.4	25.0	25.0	0.0	0.0	25.0	25.0	4	4
265/34/DR34/F1.1	Valanginian-?Early Aptian	0.41 (0.34)	6.2	74.1	19.8	62.5	0.0	0.0	0.0	18.8	18.8	2	3
265/48/DR36/D1.2	Valanginian-?Early Aptian	0.43	14.7	58.8	26.5	33.3	0.0	0.0	0.0	33.3	33.3	3	3
265/48/DR36/D2.2	earliest Late Albian		0.0	45.5	54.5	0.0	0.0	0.0	0.0	50.0	50.0	2	3
265/49/DR37/B1.1	Berriasian-basal Valanginian	0.47 (0.41)	10.6	63.8	25.5	25.0	25.0	0.0	0.0	25.0	25.0	3	2

Table 4.12 (Continued) *Vitrinite reflectance and maceral abundances for Survey 265 dredge samples.*

Dredge	Age	Rv[1]	Maceral Group			Liptinite Maceral						Weath[2]	Corr[3]
		%	% Vitrinite	% Inertinite	% Liptinite	% Sporinite	% Cutinite	% Resinite	% Suberinite	% Liptodetrinite	% Lamalginite		
265/49/DR37/B2.1	Valanginian-?Early Aptian	0.47	10.4	62.5	27.1	11.5	0.0	0.0	0.0	11.5	76.9	2	3
265/51/DR39/A1.1	early Early Aptian	0.43	6.2	12.3	81.5	4.5	0.0	0.0	0.0	4.5	90.9	4	4
265/52/DR40/B1.2	Tithonian	0.49	2.3	82.6	15.1	60.6	0.0	0.0	0.0	9.1	30.3	1	1
265/52/DR40/C1.1	Indeterminate E. Jurassic	0.57	3.4	79.3	17.2	60.0	0.0	0.0	0.0	20.0	20.0	3	2
265/52/DR40/D1.2	Tithonian	0.58 (0.41)	2.7	53.2	44.1	60.2	3.6	0.0	0.0	12.0	24.1	3	2
265/54/DR42/B1.1	Berriasian-basal Valanginian	0.40	2.1	83.0	14.9	55.6	27.8	0.0	0.0	8.3	8.3	1	1
265/54/DR42/B2.1	Berriasian-basal Valanginian	0.43 (0.38)	5.5	54.9	39.6	8.3	0.0	0.0	0.0	8.3	83.3	2	2
265/54/DR42/C1.1	Callovian-Kimmeridgian	0.47 (0.41)	1.9	86.1	12.0	62.5	9.4	9.4	0.0	9.4	9.4	3	3
265/55/DR43/A1.2	Early Santonian		0.0	45.5	54.5	0.0	0.0	0.0	0.0	50.0	50.0	1	1
265/56/DR44/D1.1	Indeterminate		0.0	45.5	54.5	0.0	0.0	0.0	0.0	50.0	50.0	2	1
265/56/DR44/E1.1	Callovian-Kimmeridgian	0.54	2.2	78.9	18.9	69.8	0.0	0.0	0.0	7.0	23.3	3	1
265/56/DR44/F1.1	Valanginian-?Early Aptian	0.45	6.4	38.5	55.1	69.8	0.0	0.0	0.0	7.0	23.3	2	4

[1] VR data is from Appendix K.
[2] Weathering Index:
1 = Fresh, iron oxides absent, or sparse, fresh pyrite dominant
2 = Some weathering, iron oxides prominent, a high proportion of pyrite altered
3 = Strong weathering, iron oxides abundant, glauconite may be weathered.
4 = Very strong weathering, iron oxides abundant and may be replacing structures.
[3] Corrosion Index:
1 = No evidence of corrosion.
2 = Slight evidence of corrosion
3 = Strong evidence of corrosion
4 = Evidence of corrosion and presence of dark stains that probably represent oxidized phytoclasts.
[4] Two additional populations at 1.25 and 2.33%.

Table 4.13 *Rock Eval pyrolysis, total organic carbon and carbon isotopes for Survey 265 dredge samples.*

Dredge No.	Age	Depositional Environment	$\delta^{13}C$ kerogen ‰	% TOC	% TOC kerogen	Tmax °C	Tmax kerogen °C	S1 mg/ g rock	S2 mg/ g rock	S3 mg CO2/ g rock	PI	HI mg/ g TOC	HI kerogen mg/ g TOC	OI mg CO_2/ g TOC	OI kerogen mg CO_2/ g TOC
265/09/DR09/A1.3	Late Maastrichtian	Inner to middle shelf	-26.47	0.66	17.94	413	413	0.01	0.28	1.22	0.05	42	147	184	66
265/09DR/09/B1.3	Early Campanian	Inner shelf	-25.35	0.93	21.59	419	411	0.01	0.51	2.07	0.03	55	71	224	60
265/15/DR15/B1.2	Berriasian to basal Valanginian	Fresh to brackish lake	-23.14	4.85	48.08	426	422	0.07	8.94	6.19	0.01	185	278	128	38
265/15/DR15/C1.2	Berriasian to basal Valanginian	Fresh to brackish lake	-22.96	4.97	45.26	432	420	0.07	6.73	6.19	0.01	135	260	125	95
265/16/DR16/B1.1	Berriasian to basal Valanginian	Brackish lake	-22.55	1.26	57.18	435	415	0.01	0.26	1.14	0.05	21	51	91	73
265/16/DR16/C1.1	Berriasian to basal Valanginian	Brackish lake	-22.45	0.96	53.88	427	419	0.01	0.22	1.17	0.05	23	61	123	75
265/17/DR17/A1.2	Berriasian to basal Valanginian	Brackish lake	-23.60	1.47	60.44	427	421	0.01	0.75	1.90	0.01	51	147	129	76
265/17/DR17/B1.3	Valanginian to ?Early Aptian	Brackish lake	-22.70	0.75	56.46	434	417	0.00	0.31	1.34	0	41	60	178	88
265/17/DR17/C1.3	Valanginian to ?Early Aptian	Brackish lake	-22.70	0.79	58.93	428	416	0.01	0.31	1.29	0.02	39	54	164	81
265/18/DR18/B1.1	Berriasian to basal Valanginian	Brackish lake	-24.85	2.00	60.62	429	420	0.03	3.79	2.32	0.01	189	301	116	32
265/18/DR18/C1.1	Berriasian to basal Valanginian	Brackish lake	-24.80	2.05	63.95	433	419	0.03	4.04	2.43	0.01	197	298	119	42
265/18/DR18/D1.1	Valanginian to ?Early Aptian	Brackish lake	-24.10	2.11	67.33	432	421	0.02	3.15	3.11	0.01	149	228	148	40
265/19/DR19/A1.1	Berriasian to basal Valanginian	Indeterminate	-23.40	2.57	69.34	433	419	0.01	1.32	1.61	0.01	51	87	63	50
265/19/DR19/C1.1	Berriasian to basal Valanginian	Fresh to brackish lake	-23.38	3.04	45.33	435	423	0.02	1.70	1.77	0.01	56	99	58	52
265/20/DR20/C1.1	Callovian to Kimmeridgian	Fresh to brackish lake	-22.85	1.92	65.84	433	425	0.01	1.56	1.47	0.01	81	166	77	75
265/21/DR21/C1.1	Berriasian to basal Valanginian	Fresh to brackish lake	-21.50	1.98	60.15	427	422	0.01	0.34	3.00	0.03	17	15	152	98
265/21/DR21/C2.2	Berriasian to basal Valanginian	Fresh to brackish lake	-22.00	2.11	61.72	433	417	0.02	0.47	3.83	0.03	22	42	182	98
265/21/DR21/C3.1	Berriasian to basal Valanginian	Fresh to brackish lake	-21.95	3.36	65.66	429	414	0.03	1.12	4.55	0.02	33	50	135	94
265/21/DR21/C4.1	Berriasian to basal Valanginian	Fresh to brackish lake	-22.45	1.45	76.69	440	435	0.00	1.29	0.59	0	89	104	40	15
265/21/DR21/D1.1	Berriasian to basal Valanginian	Fresh to brackish lake	-22.30	0.66	53.37	506	422	0.00	0.19	1.19	0.02	29	16	179	86
265/21/DR21/E1.1	indeterminate	Indeterminate	-21.84	3.23	24.79	473*	396	0.02	0.36	0.98	0.05	11	9	30	32
265/22/DR22/C1.1	Berriasian to basal Valanginian	?Fluvial	-22.60	3.44	6.55	400	409	0.06	0.90	2.52	0.06	26	32	73	56
265/23/DR23/B1.1	Valanginian to ?Early Aptian	Brackish lake	-23.80	0.61	50.5	430	423	0.00	0.11	1.85	0	18	70	306	111

Table 4.13 (Continued) *Rock Eval pyrolysis, total organic carbon and carbon isotopes for Survey 265 dredge samples.*

Dredge No.	Age	Depositional Environment	$\delta^{13}C$ kerogen ‰	% TOC	% TOC kerogen	Tmax °C	Tmax kerogen °C	S1 mg/ g rock	S2 mg/ g rock	S3 mg CO2/ g rock	PI	HI mg/ g TOC	HI kerogen mg/ g TOC	OI mg CO_2/ g TOC	OI kerogen mg CO_2/ g TOC
265/23/DR23/C1.1	Late Aptian	Inner shelf	-24.15	0.36	57.55	427	422	0.00	0.10	1.01	0	27	24	282	56
265/23/DR23/F1.1	Berriasian to basal Valanginian	?Fluvial	-25.15	22.62	72.89	427	420	0.99	84.37	11.18	0.01	373	340	49	55
265/23/DR23/G1.1	Valanginian to ?EarlyAptian	?Marginal marine	-24.00	3.40	66.84	426	422	0.07	9.68	1.59	0.01	285	387	47	47
265/23/DR23/G1.2	Late Aptian	Inner shelf	-24.70	1.13	63.83	425	419	0.01	0.20	1.61	0.04	18	16	142	64
265/.24/DR24/C1.1	Cenomanian	Inner shelf	-24.75	0.83	59.35	406	419	0.00	0.21	0.68	0.01	26	20	81	63
265/24/DR24/D1.1	Late Aptian	Inner to ?middle shelf	-23.50	0.50	55.48	421	418	0.01	0.20	0.55	0.04	39	34	111	76
265/25/DR25/A1.1	Latest Turonian to basal Santonian	Inner shelf	-22.45	0.47	45.41	609	417	0.01	0.06	0.61	0.1	14	7	128	71
265/25/DR25/B1.1	Latest Turonian to basal Santonian	Inner shelf	-24.05	0.85	62.96	609	418	0.02	0.24	0.58	0.07	28	20	68	81
265/25/DR25/C1.1	Latest Turonian to basal Santonian	Inner shelf	-23.30	0.59	59.38	609	414	0.02	0.13	1.69	0.13	22	4	288	87
265/27/DR27/A3.1	Valanginian to ?Early Aptian	Fresh to brackish lake	-24.00	1.77	62.48	425	415	0.01	0.64	1.02	0.02	36	43	58	71
265/27/DR27/A4.1	Tithonian	?Freshwater lake	-23.93	12.50	50.1	425	417	0.07	5.41	6.03	0.01	43	61	48	37
265/27/DR27/B1.1	Late Hauterivian to Early Barremian	Marginal marine to inner shelf	-29.10	7.99	39.9	405	407	0.43	18.54	3.84	0.02	232	293	48	45
265/27/DR27/C1.1	Berriasian to basal Valanginian	Freshwater lake	-22.85	2.38	61.22	432	420	0.01	0.39	2.63	0.03	16	30	110	87
265/27/DR27/C2.2	Tithonian	?Freshwater lake	-23.90	1.85	52.59	427	415	0.01	0.68	1.06	0.02	37	45	57	53
265/28/DR28/B1.3	Callovian to Kimmeridgian	Fresh to brackish lake	-22.90	0.79	50.63	609	425	0.01	0.10	0.93	0.07	13	19	118	88
265/30/DR30/C1.1	Indeterminate	Indeterminate	-22.60	0.35	39.42	609	609	0.01	0.17	0.23	0.04	48	5	65	78
265/32/DR32/B1.1	Berriasian to basal Valanginian	Fresh to brackish lake	-22.20	1.12	59.77	609	419	0.01	0.30	2.35	0.03	27	20	210	80
265/33/DR33/B1.1	Indeterminate	Indeterminate	-22.47	0.50	4.6	490*	609	0.00	0.26	0.89	0.01	52	26	178	108
265/33/DR33/B2.1	Berriasian to basal Valanginian	Fresh to brackish lake	-22.55	1.45	56.39	494	423	0.02	0.23	1.41	0.07	16	13	97	88
265/34/DR34/E1.1	Berriasian to basal Valanginian	Fresh to brackish lake	-21.80	0.81	50.5	604	425	0.01	0.21	1.52	0.04	25	18	187	88
265/34/DR34/F1.1	Valanginian to ?Early Aptian	Fresh to brackish lake	-22.50	1.97	57.17	609	422	0.00	0.29	1.74	0.01	15	31	88	97
265/48/DR36/D1.2	Valanginian to ?Early Aptian	Fresh to brackish lake	-22.20	0.95	51.78	609	417	0.02	0.28	0.92	0.06	30	36	97	84
265/48/DR36/D2.2	earliest Late Albian	Inner shelf	-23.95	0.63	56.41	609	423	0.03	0.26	0.89	0.11	41	7	142	81
265/49/DR37/B1.1	Berriasian to basal Valanginian	Brackish lake	-22.40	0.51	14.26	488*	421	0.01	0.35	1.11	0.04	68	69	219	67

Table 4.13 *Rock Eval pyrolysis, total organic carbon and carbon isotopes for Survey 265 dredge samples.*

Dredge No.	Age	Depositional Environment	$\delta^{13}C$ kerogen ‰	% TOC	% TOC kerogen	Tmax °C	Tmax kerogen °C	S1 mg/ g rock	S2 mg/ g rock	S3 mg CO2/ g rock	PI	HI mg/ g TOC	HI kerogen mg/ g TOC	OI mg CO_2/ g TOC	OI kerogen mg CO_2/ g TOC
265/49/DR37/B2.1	Valanginian to ?Early Aptian	Fresh to brackish lake	-21.85	1.39	64.03	434	417	0.02	0.46	1.59	0.04	33	58	115	73
265/51/DR39/A1.1	early Early Aptian	Marginal marine to inner shelf	-21.45	0.60	52.35	517	417	0.01	0.15	2.61	0.03	25	43	435	105
265/52/DR40/B1.2	Tithonian	?Freshwater lake	-23.70	1.41	64.97	430	420	0.02	0.60	1.58	0.03	42	69	112	57
265/52/DR40/C1.1	Indeterminate ?Early Jurassic	?Fluvial	-24.75	3.92	75.46	432	426	0.02	3.54	2.59	0.01	90	151	66	25
265/52/DR40/D1.2	Tithonian	?Freshwater lake	-23.35	1.14	60.15	432	426	0.00	0.40	1.03	0.01	35	67	91	71
265/54/DR42/B1.1	Berriasian to basal Valanginian	Brackish lake	-22.94	2.30	34.04	435	424	0.02	0.70	2.43	0.02	30	43	106	85
265/54/DR42/B2.1	Berriasian to basal Valanginian	Fresh to brackish lake	-22.90	1.54	52.29	609	420	0.01	0.39	3.29	0.03	26	35	214	99
265/54/DR42/C1.1	Callovian to Kimmeridgian	Fresh to brackish lake	-22.75	3.25	66.56	437	417	0.01	0.81	4.12	0.01	25	58	127	79
265/55/DR43/A1.2	Early Santonian	Inner to ?middle shelf	-23.05	0.41	51.76	609	336	0.03	0.32	0.46	0.08	78	24	113	90
265/56/DR44/D1.1	Indeterminate	Indeterminate	-22.35	0.20	18.35	462	585	0.02	0.21	0.22	0.07	107	19	115	100
265/56/DR44/E1.1	Callovian to Kimmeridgian	?Fluvial	-23.50	3.43	71.37	436	421	0.02	1.65	2.34	0.01	48	97	68	45
265/56/DR44/F1.1	Valanginian to ?Early Aptian	Fresh to brackish lake	-22.35	1.27	55.86	609	423	0.00	0.23	1.60	0.01	18	15	126	91

Table 4.14 *Bulk and molecular composition of extractable organic matter from Survey 265 dredge samples.*

DREDGE NO.	AGE	DEPOSITIONAL ENVIRONMENT	SAMPLE LAB NO.	SAMPLE LAB ID	SOLVENT EXTRACTION AND COLUMN CHROMATOGRAPHY*				GAS CHROMATOGRAPHY				
					EOM (ppm)	SATS (%)	Arom (%)	NSOs (%)	Pr/Ph	Pr/C_{17}	Ph/C_{18}	CPI (22-32)	CPI (14-22)
265/15/DR15/B1.2	Berriasian-basal Valanginian	fresh to brackish lake	1394032	20040221	2041	9.1	11.1	79.2	1.00	0.08	0.11	3.56	2.35
265/15/DR15/C1.2	Berriasian-basal Valanginian	fresh to brackish lake	1394035	20040224	3079	4.4	2.3	44.3	2.00	0.11	0.05	3.63	2.08
265/18/DR18/B1.1	Berriasian-basal Valanginian	brackish lake	1394072	20040415	1311	8.7	6.2	42.2	1.63	0.30	0.24	3.36	1.93
265/18/DR18/C1.1	Berriasian-basal Valanginian	brackish lake	1394077	20040416	670	10.1	6.1	74.7	1.69	0.11	0.06	3.23	1.58
265/21/DR21/C4.1	Berriasian-basal Valanginian	?fresh to brackish lake	1394117	20040421	326	1.9	23.1	67.3	3.20	1.64	0.31	1.60	0.81
265/21/DR21/E1.1	indeterminate	-	1394120	20040220	317	13.3	40.0	33.3	1.33	0.32	0.17	nd	nd
265/22/DR22/C1.1	Berriasian-basal Valanginian	?fluvial	1408088	20040446	6053	2.0	4.7	24.4	4.50	1.70	0.23	2.34	0.99
265/23/DR23/F1.1	Berriasian-basal Valanginian	?fluvial	1408094	20040449	16613	23.1	8.0	67.2	nd	nd	nd	2.65	1.24
265/23/DR23/G1.1	Valanginian-?Early Aptian	?marginal marine	1394138	20040422	2179	9.2	5.7	57.3	nd	nd	nd	2.52	0.85
265/27/DR27/B1.1	Late Hauterivian/ Early Barremian	?marginal marine to inner shelf	1394178	20040425	6775	6.8	3.3	70.0	0.25	0.42	2.52	1.66	0.92
265/34/DR34/F1.1	Valanginian-?Early Aptian	fresh to brackish lake	1394243	20040431	130	17.6	41.2	35.3	nd	nd	nd	2.69	0.44
265/52/DR40/D1.2	Tithonian	?freshwater lake	1394331	20040436	61	33.3	33.3	22.2	4.75	0.31	0.04	1.61	0.91

*sum of SATS+AROM+NSOs is less than 100 due to losses on the silica gel column
CPI (22-32) = 0.5*((n-C23+nC25+n-C27+n-C29+n-C31)/(n-C22+n-C24+n-C26+n-C28+n-C30) + (n-C23+nC25+n-C27+n-C29+n-C31)/(n-C24+n-C26+n-C28+n-C30+n-C32
CPI (14-22) = 0.5*((n-C15+nC17+n-C19+n-C21)/(n-C14+n-C16+n-C18+n-C20) + (n-C15+nC17+n-C19+n-C21)/(n-C16+n-C18+n-C20+n-C22))
nd = peaks not detected.

Table 4.15 *GOI results for Bremer Sub-basin samples.*

Location	CSIRO Number	Geoscience Sample ID	Geoscience Sample No	Count Protocol	Grains with oil inclusion	Total grains scanned	GOI (%)
Bremer Sub-basin	130546	265/19/DR19/B1.3	1418353	C	1	11,967	<0.1
Bremer Sub-basin	130547	265/20/DR20/B1.2	1419829	C	0	15,773	<0.1
Bremer Sub-basin	130548	265/20/DR20/B2.1	1419830	C	0	6,156	<0.1
Bremer Sub-basin	130549	265/24/DR24/A1.1	1408096	C	0	23,380	<0.1
Bremer Sub-basin	130550	265/27/DR27/A1.2	1418356	C	1	7,616	<0.1
Bremer Sub-basin	130551	265/31/DR31/A3.1	1415949	C	1	13,920	<0.1
Bremer Sub-basin	130552	265/34/DR34/D1.2	1418357	C	0	23,954	<0.1
Bremer Sub-basin	130553	265/52/DR40/A1.3	1418358	C	1	2,339	<0.1
Bremer Sub-basin	130554	265/56/DR44/A1.1	1418360	C	0	7,344	<0.1
Bremer Sub-basin	130555	265/56/DR44/I1.2	1419831	C	1	20,370	<0.1

GOI: Grains containing Oil Inclusions.
R: Random scan of approximately 100 Fields of View (FOV).
C: Continuous scan of a proportion of the Area of Interest (AOI).

Table 4.16 *Colour and location of oil inclusions in Bremer Sub-basin samples.*

Well Name	CSIRO Number	Geoscience Sample ID	Aq. incs with small amount of oil	Oil Inclusion Fluorescence Colour			QOB
				Blue	White	Yellow	
Bremer Sub-basin	130546	265/19/DR19/B1.3	4	1	0	0	0
Bremer Sub-basin	130547	265/20/DR20/B1.2	3	0	0	0	0
Bremer Sub-basin	130548	265/20/DR20/B2.1	1	0	0	0	0
Bremer Sub-basin	130549	265/24/DR24/A1.1	0	0	0	0	0
Bremer Sub-basin	130550	265/27/DR27/A1.2	5	1	0	0	0
Bremer Sub-basin	130551	265/31/DR31/A3.1	4	1	0	0	0
Bremer Sub-basin	130552	265/34/DR34/D1.2	0	0	0	0	0
Bremer Sub-basin	130553	265/52/DR40/A1.3	1	1	0	0	0
Bremer Sub-basin	130554	265/56/DR44/A1.1	5	0	0	0	0
Bremer Sub-basin	130555	265/56/DR44/I1.2	0	1	0	0	0

QOB: Quartz overgrowth boundary

Table 4.17 *Summary of results for reservoir and seal analysis (MICP).*

SAMPLE NO.	LITHOLOGY	AGE OF SAMPLE	DEPOSITIONAL ENVIRONMENT	SEAL OR RESERVOIR POTENTIAL
265/15/DR15/C1.5	organic-rich claystone with mica and carbonaceous fragments	Berriasian toValanginian	fresh to brackish water lake	seal an oil column height of 42.4 to 70.7 m
265/19/DR19/A1.2	organic-rich mudstone with some mica, sandstone and coal	Tithonian to Berriasian	a fluvial to fresh–brackish water lake	seal an oil column height of 36.3 to 60 m
265/19/DR19/B1.3	medium to very coarse grained, quartzose sandstone to conglomerate with lithic and coal fragments and minor carbonate cement	Tithonian to Berriasian	fluvial	reservoir with a maximum porosity of 24% (note that traces of oil were identified during fluid inclusions analyses)
265/24/DR24/E1.4	fine grained calcarenite containing abundant sponge spicules	Santonian to earliest Eocene	marine	reservoir with a maximum porosity of 27.4%
265/25/DR25/B1.2	shale/mudstone	Coniacian	inner shelf	seal an oil column height of 87.6 to 146 m
265/27/DR27/A1.2	medium to coarse grained, sub-arkosic sandstone with biotite and lithic fragments, interbedded with organic rich claystones	Berriasian to Valanginian	fresh to brackish water lacustrine	reservoir with a maximum porosity of 29.9% (note that traces of oil were identified during fluid inclusions analyses)
265/34/DR34/D1.2	fine grained quartz arenite with abundant mica and pink feldspar	Early Cretaceous	fresh to brackish water lacustrine	reservoir with a maximum porosity of 34.2%
265/52/DR40/A1.3	silicified quartz arenite with some feldspar	possibly Early Jurassic	fluvial	limited reservoir with a maximum porosity of 10.2% (note that traces of oil were identified during fluid inclusions analyses)
265/55/DR43/B1.2	claystone with carbonaceous zones	Coniacian to Santonian	marine	seal an oil column height of 51.2 to 85.4m
265/56/DR44/A1.1	medium to coarse grained, red (oxidised) fluvial sandstone with mica and traces of feldspar			reservoir with a maximum porosity of 31.2%. Note that traces of oil inclusions were identified during fluid inclusions analysis

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5. Summary of Survey 265 Results

The Bremer Sub-basin on the rifted southwestern continental margin of Australia is a frontier basin in which no wells have been drilled. The petroleum potential of such frontier basins is generally limited to theoretical assessments from seismic data and analogue models. However, a series of submarine canyons have incised the Bremer Sub-basin, allowing geological sampling of the upper 2 km of the basin succession. Geochemical, petrographic and palaeontological analyses of rock samples recovered from 45 dredge sites, together with interpretations from regional seismic data, indicate that the Bremer Sub-basin contains a succession of Jurassic to Tertiary age sediments containing the essential petroleum system elements (source, reservoir and seal) to generate and trap hydrocarbons (Bradshaw 2005; Figure 5.1).

Fifty-nine dredge samples from the Bremer Sub-basin cruise were high-graded for petroleum potential assessment based on the organic matter content. The effect of prolonged exposure to the sea floor was shown not to be detrimental to source rock assessment. Extremely organic-rich coaly shales were found with up to 22.62% TOC, with twenty of the samples showing good organic richness, having TOC contents > 2%. Rock Eval pyrolysate yields (S2) maximise at 84.37 mg hydrocarbons/g rock with six samples showing good to excellent generative potential (S2 >5). TOC-normalised pyrolysis yields or Hydrogen Indices (HI) show a maximum value of 373 mg hydrocarbons/g TOC, including eight samples having moderate oil potential with HIs greater than 200 mg hydrocarbons/g TOC (Table 5.1). The majority of rock samples analysed are immature (VR < 0.65%), as only the upper 2 km of strata in the Bremer and Denmark sub-basins could be sampled by dredging sub-marine canyons. More mature successions will occur in the main half-graben depocentres where strata are buried up to 10 km sub-surface. This is supported by the presence of oil trapped in fluid inclusions in the sandstone dredge samples, which is an additional positive indicator of mobile hydrocarbons in the sub-surface.

Importantly, three diverse oil-prone potential source rock units have been recognised in the Bremer Sub-basin; an Early Cretaceous terrestrial land plant organic facies, Early Cretaceous–Jurassic lacustrine organic facies and, an Early Cretaceous marine organic facies. Each organic facies is characterised by a diagnostic molecular and carbon isotopic signature. Molecular and palaeontological assessment of the Valanginian to Early Jurassic non-marine sediments indicates a fluvio-lacustrine depositional environment with end-member lacustrine and coaly organic facies. The former is associated with sub-ordinate low molecular weight C_{14}-C_{22} *n*-alkanes (freshwater algal input) and abundant waxy (>C_{22}) *n*-alkanes with a *n*-C_{23} dominance (fern input), while the latter has a *n*-C_{31} dominance (gymnosperm input). Intermediate *n*-alkane dominances at *n*-C_{25}, *n*-C_{27} and *n*-C_{29} are associated with variable inputs from the end-member non-marine organic facies. Anoxic marine conditions in the Bremer Sub-basin were evident from the latest Hauterivian-earliest Barremian, leading to the deposition and preservation of oil-prone marine kerogen depleted in ^{13}C. However, significant dilution by allochthonous refractory terrestrial land plant inputs has lowered the overall hydrocarbon potential of the marine rocks. Source areas where the terrestrial input is reduced may provide oil-prone ‘sweet-spots’. Potential source kitchen areas with favourable geological conditions for the deposition of oil-prone source rocks and subsequent hydrocarbon generation are most likely to occur in the main half-graben depocentres of the Bremer Sub-basin.

Figure 5.1 Stratigraphy and petroleum system elements of the Bremer Sub-basin, based on dredge sample analyses and regional seismic interpretations (from Bradshaw, 2005).

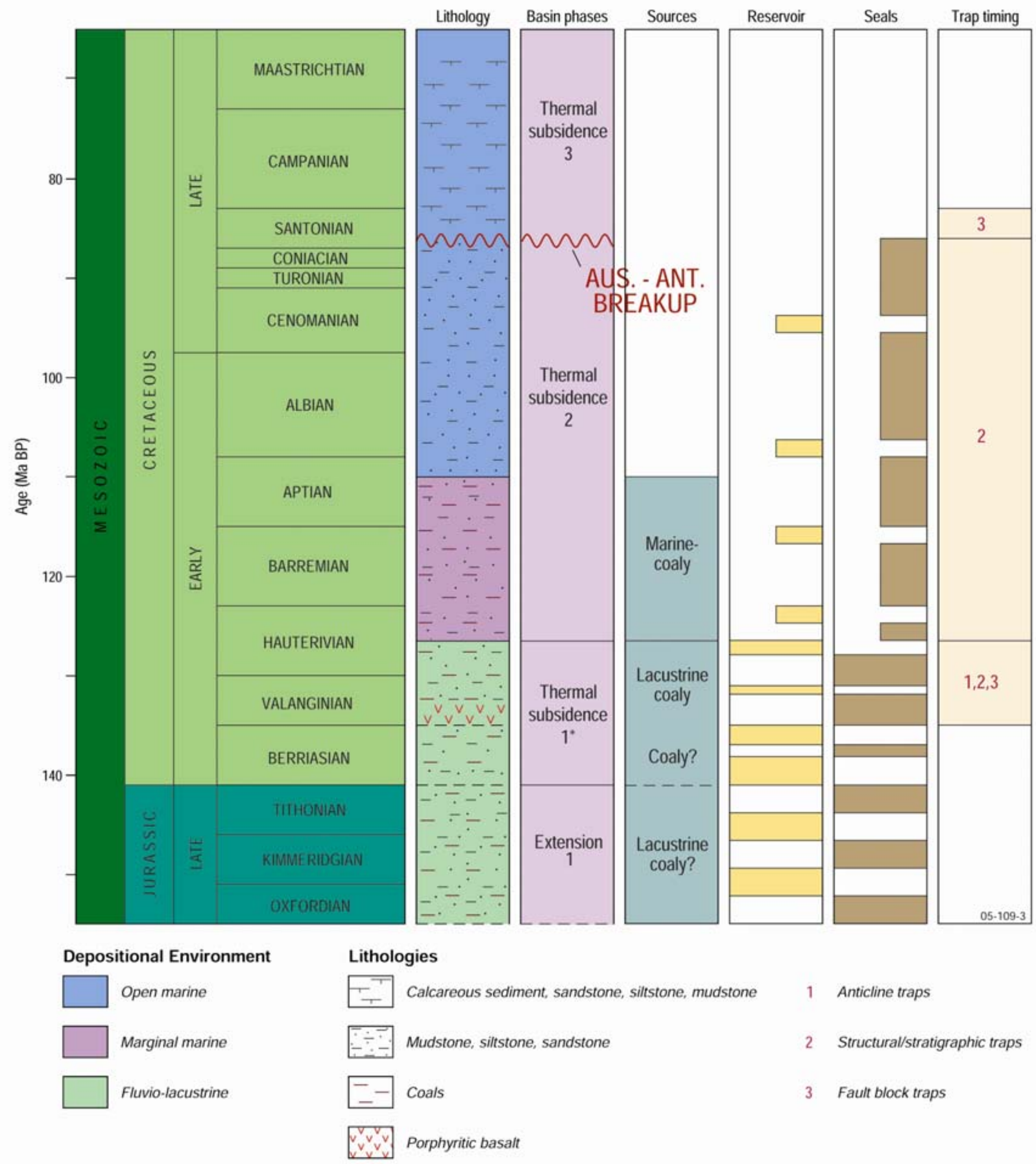

Table 5.1 *Summary of eight source rocks samples from the Bremer Sub-basin that show moderate oil potential.*

Dredge No.	Age	Environment	%TOC	Tmax ºC	S2 mg/g rock	HI mg/g TOC	HI kerogen mg/g TOC
265/23/DR23/F1	Berriasian-Valanginian	Fluvial (coaly)	22.6	427	84.4	373	340
265/27/DR27/B1	Hauterivian-Barremian	Marginal marine	8	405	18.5	232	293
265/23/DR23/G1	Valanginian-Aptian	Marginal marine	3.4	426	9.7	285	387
265/18/DR18/C1	Berriasian-Valanginian	Lacustrine	2.1	433	4	197	298
265/18/DR18/B1	Berriasian-Valanginian	Lacustrine	2	429	3.8	189	301
265/15/DR15/B1	Berriasian-Valanginian	Lacustrine	4.9	426	8.9	185	278
265/18/DR18/D1	Valanginian-Aptian	Lacustrine	2.1	432	3.1	149	228
265/15/DR15/C1	Berriasian-Valanginian	Lacustrine	5	432	6.7	135	260

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